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Edited by
George Drăghici

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TRIZ*Future* Conference 2009 – Innovative Product Design

Prof. George Drăghici
“Politehnica” University of Timisoara, Romania
Chair of the Local Organizing Committee

Dear conference participants,

As Chair of the Local Organizing Committee I have the honor to be your host for the TRIZ*Future* 2009 Conference. I am grateful to all the authors who have decided to share their experiences, bring new ideas, debate issues and introduce the latest developments during this event. You made the conference happen!

Romania is the first East Europe country that was chosen to organize a TRIZ*Future* conference. Timisoara is a city situated in the West part of Romania. Since 1920, here was built a technical university with a good reputation in the field of innovation. This is the reason why we have focused the 9th ETRIA World TRIZ*Future* conference on *Innovative Product Design*. Timisoara is well known for its innovating spirit and some important proofs are shown in the following:

1718 – The first brewery in Romania;

1728 – The first navigable channel in Romania;

1745 – The first town hospital in Romania (24 years before Vienna and 34 years before Budapest);

1760 – The first town in Habsburg Empire with kerosene lamps illuminated streets;

1771 – The first paper in Romania and the first German paper in South-Eastern Europe: "Temeswarer Nachrichten";

1815 – The first public library in Habsburg Empire and Romania;

1854 – The firs telegraph service in Romania;

1855 – The first town in Habsburg Empire with gas lamps illuminated streets;

1869 – The first horse traction tramway on the Romanian territory;

1869 – The first passenger cruise along Bega Channel, the first city in Romania that used this kind of public transportation;

1879 – The first phone network in Romania;

1884 – The first European city with electric lamps illuminated streets;

1895 – The first asphalt street in Romania;

1897 – The first cinema projections in Romania;

1899 – The first electric tramway in Romania;

1921 – The first factory in Romania in the field of illuminating devices manufacturing: "Dura";

1938 – The first railway welding machine in the world: Taurus;

1965 – The first electrical discharge machine in Romania;

1988 – The first industrial robot in Romania;

2000 – The first presentation about TRIZ in Romania, at Politehnica University of Timisoara.

So, it is not accidentally the organizing of the TRIZ*Future* Conference 2009 in Timisoara. The Politehnica University has now 10 faculties and 4 independent departments, 15,000 students in 84 specializations, 850 teaching staff and 900 administrative and auxiliary staff study. The education programs are organized in accord with the Bologna paradigm, in three cycles: Bachelor, Master and PhD programs.

The Mechanical Engineering Faculty is the core of the university. Since 2000, here was established the Integrated Engineering Research Centre, which coordinates the Master program in the field. The education and research activities are focused on Innovative Product Design, considering TRIZ as one of the adequate method.

In the name of the Local Organizing Committee, I would like to acknowledge the help, support and believe of all who made possible the creation of the TRIZ*Future* Conference 2009 in Timisoara, at Politehnica University. The benefits and the new experiences gain in the field of Innovative Product Design will have a positive impact upon all participants from the universities, research centers and, from the industrial environment, too. I hope that we meet your expectations and I wish you a pleasant and useful stay in our city.

Please enjoy your reading!

ETRIA TRIZ*Future* Conference 2009

Gaetano Cascini

Politecnico di Milano, Italy
President of the European TRIZ Association

Being at the end of my presidency of the European TRIZ Association, the introduction to the TRIZ Future Conference 2009 constitutes also the opportunity to thank all the ETRIA members for the chance I have had to contribute with this role to the evolution of TRIZ promotion and progress. Before to start any balance of what ETRIA has done since 2006 to now, it is necessary to mention the joined efforts of all the past and current Executive Board members who have actively contributed to ETRIA development.

During these years, ETRIA has introduced radical novelties in the way TRIZ is presented, discussed, developed: traditionally the TRIZ community has been mostly self-referential and rather closed to "foreign" contributions, requests and critiques. Such a dramatic limit of the TRIZ society has been approached by establishing regular relationships with other communities not necessarily related to TRIZ (e.g. the Flemish Quality Management society in 2006, the European TRIZ Centrum in 2007, the Virtual Reality Labs Network of Excellence in 2008), and most of all by obtaining the accreditation of a well acknowledged scientific organization, CIRP, the world leading organization in production engineering research.

As it often happens, radical changes are associated to temporary misalignments between the involved elements with consequent appearance of contradictions (after all, also the 5th Law of Technical Systems Evolution claims the irregular development of TS parts). Therefore, further important steps must be performed by the next ETRIA president in order to improve also the involvement of the industrial world to TRIZ progress and dissemination. From this point of view, the "biggest economic crisis since the Great Depression" we are living this year, might constitute the opportunity to start a novel approach to innovation in industry. It makes sense to remind some very meaningful thoughts by Albert Einstein about crisis: "Let's not pretend that things will change if we keep doing the same things. A crisis can be a real blessing to any person, to any nation. For all crises bring progress. [...] He, who overcomes crisis, overcomes himself, without getting overcome. He, who blames his failure to a crisis, neglects his own talent, and is more respectful to problems than to solutions. Incompetence is the true crisis. The greatest inconvenience of people and nations is the laziness with which they attempt to find the solutions to their problems. There's no challenge without a crisis. Without challenges, life becomes a routine, a slow agony".

Within this context, ETRIA continues its innovative approach to TRIZ promotion by organizing the first worldwide TRIZ conference in a country of the Eastern Europe, with the specific aim of attracting new participants and to create new opportunities of cooperation.

According to the recent tradition, the conference in Romania will be characterized by three different types of presentations, reported in the form of extended articles in these Proceedings:

- Educational papers will be focused on TRIZ training aspects, both according to industrial needs and school/academic requirements;
- Industrial papers will present real case studies and practical directions to apply TRIZ tools and leverage their problem solving potential;
- Scientific papers will discuss TRIZ methodological development and formalization with an academic approach.

All together they will keep the polymorphic structure of ETRIA conferences that constitutes the most valuable opportunity to establish connections and share experiences with the multi-faceted TRIZ worldwide community.

On behalf of ETRIA, I wish a pleasant and successful participation to the conference to all the speakers and attendees.

Milano, 10th October 2009

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TRIZ-Box – Improving Creativity by connecting TRIZ and Artifacts

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Abstract

The contribution proposes the application of artifacts for stimulation of analogy forming. These artifacts are related to the inventive principles of the TRIZ method. By formulating a contradiction based on Altshuller's parameters, a list of promising inventive principles is generated. The TRIZ-Box contains artifacts that represent these inventive principles physically. Access to the artifacts is provided by a web-based content management system (wiki), in which artifacts and related information can be searched and described.

Keywords

TRIZ, creativity, artifacts, triz-box, creative design, ideation, analogy, design-by-analogy

1 INTRODUCTION

Creativity is an essential part of innovative product development and the origin of successful products. There are several methods that support the activities in developing innovative products, e.g. TRIZ. One central principle is to depart from the identified problem by means of abstraction. In TRIZ the problem is formulated by an abstract contradiction. Using the matrix of contradictions, general solution principles promising to resolve the contradiction are represented within Altshuller's inventive principles (cp. [1]). Based on these principles, the inventor shall be inspired and create ideas for specific solutions addressing the original problem. This step very much depends on the creative ability and inspirational capacity of the method user. The process of concretizing the abstract principle to a problem-oriented solution can be supported by adequate methodological means. Known methods represent – based on a given inventive principle – explanations and descriptions of established exemplary solutions, patents or other evident concepts.

The method proposed by the authors is called TRIZ-Box and systematically supports the step of concretizing the abstract solution principle to a specific technical solution. Its main idea is to connect inventive principles and artifacts that represent those specific principles in a functional, technical or physical way. Integration of these objects into individual and group work, e.g. brainstorming, adds to the auditory and visual reception other sensory ways for giving impulses to the inventor resulting in more excited associations and analogies. Beside the theoretical and methodological framework of application, the method comprises a collection of chosen artifacts and a computer-supported list of inventive principles that directly links to corresponding artifacts.

The present contribution proposes on the one hand the use of artifacts for supporting ideation in TRIZ by analogy and cross-fertilization based on physical representation of inventive principles. On the other hand, central elements of TRIZ, i.e. contradiction matrix and inventive principles, are used as taxonomy for finding and selecting appropriate artifacts in order to support ideation activities. The following sections describe the background of creativity, analogy, cross-fertilization and artifacts as well as the TRIZ methodology. Against this background, the authors propose the TRIZ-Box method and its realization.

2 BACKGROUND AND STATE-OF-THE-ART

For the proposed means of support, three perspectives have to be considered: creativity, artifacts and cross-fertilization as well as the body of knowledge of classical TRIZ.

2.1 Creativity

In order to support creativity in engineering properly, sound understanding of creativity is necessary. Research addressed the topic of creativity from different points of view. Rhodes classified these points of view into four alliterative categories: product, person, process and press (i.e. environmental factors) [2]. The creative product is the result of the activities of one or several persons. The second factor focuses on personal traits while the third factor concentrates on the description of creative processes. The fourth view is on environmental factors and their influence on persons acting creatively. Recent research on creativity shifted its focus from pure personality psychology (e.g.[3]) to social and educational science (cp. [4], [5]).

Product, Person, Press and Process

An established definition of the creative product cannot be identified in literature. Creative products can be socially relevant or even intrinsically valuable without having any social relevance [3]. However, most commonly used definitions include two essential elements: originality and appropriateness. Creativity is also considered as an individual ability resulting in a creative product [6]. In literature, a common set of characteristics of creative persons can be identified (e.g. high aesthetic valuation, broad interests, attraction to complexity, independence of judgment intuition or self-confidence) [3]. Another frequently mentioned factor is intrinsic motivation [4]. A according to a system-based approach, creativity is a result of three interacting systems: a field constituted by social institutions that defines appropriateness of ideas, a cultural domain transmitting these ideas and the individual, who affects the domain creatively being considered by the field [7]. The research on creativity as a process considers models of sequential stages. A common model of the creative process is the four stage model according to Wallas [8], which consists of preparation, incubation, illumination and verification. During preparation, the problem is analyzed, knowledge is acquired and a "problem attitude" is defined. In the incubation stage, the creative mind works consciously and unconsciously, e.g. during mental relaxation, on the problem. Illumination is the sudden appearance of the idea. In verification the validity of the creative product is tested. These stages are gone through concurrently for different open problems. This results in a chance, that the preparation of one problem incubates another one's solution process.

Different psychological schools try to explain the process of creativity in terms of their own classical theories. In the theory of the associationist school the creative process forms new combinations of associative elements [9]. A creative solution is more likely to emerge if the situation the person is exposed to promotes the spatial and temporal proximity of associative elements (contiguity). Mednick derives three types of contiguity. Accidental contiguity (serendipity) leads unintentionally to idea activation. Similarity of stimuli or similar associative elements can also result in contiguity of structures or objects. Mediation activates associated elements by common elements e.g. by use of mathematical or chemical symbols. Cognitivism explains creativity not as a single associative process but as a result of several mental processes [10]. Generative processes, e.g. associations or analogy forming, develop mental representations. These pre-inventive structures are combined and interpreted in an explorative stage.

Analogy Forming, Similarity and Cross-Fertilization

In the design process, design-by-analogy is a common approach. Analogous products are used although not being recognized as origin of an idea by the designer [11].

Analogy is the mapping of two sets of propositions, in which corresponding relations are matched based on similarity [12]. The cognitive process for analogy forming to solve a given problem comprises four steps: source encoding, analogy retrieval (source), mapping of problem and source and inference based on mapping [11]. Forming of analogies and activation of associations are central elements of creativity [13]. Inspiration by analogy increases the number and variety of solutions [12],[14]. However, studies provide evidence that information being analogically related to a problem is hardly found and used [14]. Therefore, similarity has to be identified. In literature, surface and structural similarity are distinguished. Surface similarity refers to appearance or attributes, e.g. a product's purpose, while structural similarity describes similar relationships of objects, e.g. functional relations. Without surface similarity, recognition of analogies on structural, i.e. functional level is difficult [14]. From a functional perspective, similarity of different products can be quantified by a similarity metric [15]. Designers remembering analogies in a general representation are more likely influenced by these analogies than those remembering in domain-specific representations [11]. Analogies emerging from different domains provide the chance of arising ideas that would not be considered by a person of a single domain. This concept is called cross-fertilization. The explanation is that with more experience, the chance of having new combinations increases significantly [5].

In summary, the creative process includes a step, incubation, in which elements being distant to the original problem can lead to insight and illumination, e.g. by analogy forming. This is also emphasized by the creativity theories of associationism or cognitivism. The influence of analogies increases if the analogous representation is more general.

2.2 Methods for Analogy Forming

Methodological support is given for example by directed analogy forming (e.g. synectics [16]) or consideration of patterns or artifacts. Commonly known methods supporting the steps of encoding and retrieval in the process of analogy forming are functional models, synectics, biomimetics and TRIZ [11].

General Methodological Support of Analogy Forming

By compiling and analyzing functional models, analogous features can be identified and retrieved [15]. Other formal methods for design-by-analogy are for example synectics or biomimetics (bionics) [11]. Synectics is a group problem-solving method that basically tries to identify the problem, to make the familiar features strange and to related the strange ideas to the familiar problem [16]. It comprises a set of subjacent methods provoking analogies on different levels: personal, direct, symbolic and fantasy [11]. Bionics is the superordinate concept for incorporating natural solutions into man's technology [17]. The concept of TRIZ (see below in detail) allows forming of analogies on a general level by abstract inventive principles. Specific cases, e.g. examples and patents, make analogy forming on less abstract level feasible.

Analogy Forming by Design Patterns

In contrast to analogy forming by cross-fertilization design patterns allow analogy forming within a defined context, e.g. within a given domain.

Design patterns are a concept of providing problem-oriented knowledge about solutions in a defined context in an abstract and generic way. The pattern concept was introduced by the architecture theorist Alexander and was successfully transferred to software engineering (which is an example of cross-fertilization!) [18]. A design pattern represents the invariant elements of a multitude of similar solutions to a design problem in a specific context.

Analogy Forming by Artifacts

In the field of product design, collections of interesting things, e.g. material samples, or mechanical parts are used for inspiration. For example, Kelley [19] describes a such called tech box. The tech box contains inspiring artifacts, which seem to have had positive contribution to several design projects. Within a web-based database, the artifacts are listed and their features are specified in detail. The content of the tech box is subject to permanent change, i.e. new objects are added. It not only inspires, but also prevents reinvention of the wheel (cp. [20]). Within the tech box method the selection of adequate artifacts is intuitive and arbitrarily.

2.3 TRIZ

TRIZ was first invented by Altshuller in the 1950s. Since then the methodology has advanced through uncountable scientifical contribution and application experiences. Today the existing TRIZ-supporting tools as a whole try to cover the entirety of product development regardless of the area of application. Accordingly TRIZ consists of a vast method tool kit of heterogeneous nature. These range from problem formulation and clarification across generation of ideas to error detection covering the product development process. The subordinate principles TRIZ uses are the systematic approach, analogy, knowledge and visions. Because of the continuous advancement of TRIZ there are some methods that are well-known and others that are mostly unknown. [1],[21]

The best-known and most used tools are the technical contradiction and the list of inventive principles [1]. The technical contradiction is considered as the prerequisite and basis of any innovation [1]. According to Altshuller's research all solutions to every technical contradiction are based on the same principles. Based on a survey on 40000 patents 40 inventive principles are permitting the solution of any technical contradiction.

Using classical methods of product development, the space of all possible solutions is not confined. Within this space there is always a vector of inertia that points the

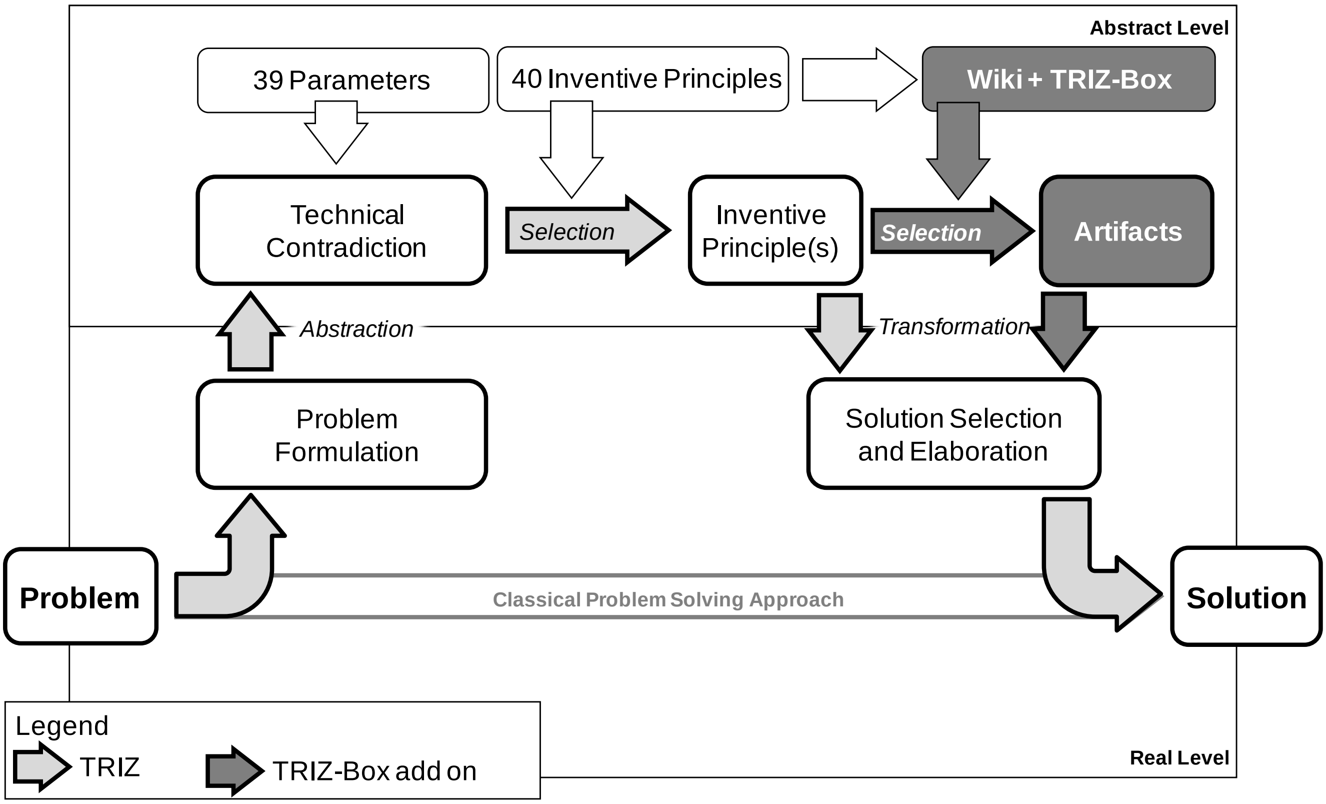

Figure 1: Comparison of TRIZ and the TRIZ-Box add on (cp. [13],[23]).

direction where most ideas are. Accordingly there are already a lot of solutions in this field. In order to create an innovation it is necessary to go past this vector of inertia and thus to avoid preconditioning. The systematic of TRIZ with the metaphor of the ideal final result, standing for the not existing ideal solution that consists of only the positiv functions, without any negative effects and with no additional effort.

For the practical application of TRIZ first the ideal final result is defined and the problem is formulated. The problem is transformed to the abstract level describing its main conflict as a technical contradiction. The description of the technical contradiction is carried out in a standard way. Any system behavior is modeled by parameter chosen from a standard list of 39 parameters. The technical contradiction is described by one improving and one worsening parameter. For this step it is helpful to use a systematic method such as the innovation checklist [22]. For the technical contradiction general solutions can be selected from the contradiction matrix in form of inventive principles [1]. These inventive principles describe promising solution principles, which, have to be retransformed to the reality level, to the given problem. Figure 1 visualizes the approach in contrast to the classical approach of problem solving.

There are several different software applications for TRIZ, ranging from the software representation of single tools to software systems that cover the whole TRIZ supported product development process. [22]

TRIZ provided tools, i.e. Altshuller's parameters, the contradiction matrix and the inventive principles give a taxonomy for storing, finding and administering design solution knowledge. However, all methods represent the solution principles in form of paper or software. The use of those usually is restricted to single users.

3 THE TRIZ-BOX METHOD

The discussion of the background and the state-of-the-art derives that there is a number of methods that support creativity by analogy forming, but not yet all use all ways of external stimulation of sensations. At the same time, external stimuli can be the missing piece completing the mental puzzle. Thus the TRIZ-Box method enables an additional access to inspiration.

A major difficulty of TRIZ lies in the retransformation of the general solution to the specific problem. This is the creative step. For example, software guides through the application of TRIZ and supports the implementation of general solutions by giving explanations and examples.

The tech box method originates in the design field. It is used as inspirational tool for single users or group brainstorming meetings. Its intuitive and non-systematic use is predestinated to support creative idea generation.

Combining the systematic approach of TRIZ on the one hand with the creativity support of the tech box on the other hand the TRIZ-Box method delivers a promising approach to support creative product development in the engineering design field.

3.1 Idea

In order to successfully transfer the idea of analogous reasoning by artifacts to the field of product development, the mostly intuitive and creative tech box method has to be adjusted. A method to restrict the multitude of possibly applicable artifacts is required. The system of TRIZ in contrast works with a systematic approach. The basic idea of the TRIZ-Box method is the combination of the two methods. The systematic approach of TRIZ assists the selection of artifacts while the analogy forming based on artifacts supports generation of solutions to the specific problem.

3.2 Method

The TRIZ-Box method picks up the basic idea of analogous reasoning based on artifacts (tech box) and improves its appliance with an effective selection system provided by the contradiction matrix. Applied in TRIZ only, at the same time it facilitates the transformation of the abstract inventive principle into the reality.

In the first step the problem is analyzed and formulated. With the help of the parameter list, it is transformed and reformulated to a technical contradiction. As soon as the contradiction is found, the contradiction matrix delivers a set of inventive principles, promising to solve the technical contradiction. Based on these principles artifacts are selected with the help of an arbitrary allocation system. This allocation system can be a simple spreadsheet, a database or a content management system. With this information the user is able to choose artifacts in a problem-oriented way and to use them for ideation, e.g. in methods like brainstorming.

The examination of a physical artifact stimulates all human senses. Not only visual but also acoustic, tactile and even olfactory and gustative effects capture the attention of the user. In this way the comprehension of the inventive principles is enhanced. The use of more specific artifacts stimulates different thoughts and ideas towards the direction of the ideal final result. The preoccupation with the selected artifacts offers the possibility for the creative person to gather information and supports the (unconscious) formulation of solution hypotheses. Other artifacts serve as distraction and thus support the incubation stage in the creative process. Therefore it is not necessary to choose different artifacts because many artifacts represent multiple aspects and inventive principles and thus suffice the distractive purpose.

With a successful application of inventive principles and corresponding artifacts the process results in a creative solution for the problem. Figure 1 shows the flow diagram of TRIZ with the method add on.

3.3 Realization

The realization of the TRIZ-Box follows a two-fold approach comprising a virtual and a physical collection of artifacts.

Virtual Artifact Collection

The virtual collection is used for the retrieval of appropriate artifacts. This is enabled by a web-based information system. Due to its advantageous features an open content management system, a wiki system, is chosen. This system allows users to easily share, store, retrieve and access information about available artifacts.

Wiki systems are web-based content management tools for computer supported collaborative work (CSCW) [24]. Basically, a wiki is a collection of interlinked pages based on hypertext that allow online publishing, editing and discussion. Pages can be edited by any user who is authorized to access the system. Due to simple syntax most wiki systems do not require profound programming skills [25]. The most advantageous features are various ways of finding information (tree-structured overview, table of contents, full text search or cross-referencing).

The TRIZ-Box wiki system (type: dokuwiki) is available via intranet. For reading only access is open to every user. Editing is restricted to the TRIZ-Box supervisor who is in charge of administering the content of the virtual and physical collection. Figure 2 depicts an extract from the wiki system and an exemplary artifact.

Physical Artifact Collection

Having chosen problem appropriate artifacts in the virtual TRIZ-Box, the user accesses the physical artifacts and deploys them as the method proposes, e.g. in brainstorming sessions. The physical TRIZ-Box contains artifacts, like metal foam, sandwich structures, shape-memory alloy, and technical toys.

When setting up a TRIZ-Box artifacts from different domains have to be considered. Here analogy forming is required in order to find artifacts that sufficiently physically represent an inventive principle. For deciding which artifact is supposed to be included, the authors use six criteria: safety, availability, costs, quality of principle representation, originality, size.

- Safety is a basic requirement. For example the use of strong oxidizers or very heavy artifacts could endanger users.
- Availability is necessary in order to use the artifact as physical representation of an inventive principle.
- Costs also affect the decision on purchasing an artifact.
- A minimum quality how good the inventive principle is represented is a relevant requirement.
- Originality is necessary in order to support analogy forming beyond the analogies that are very likely to occur initially.
- Size is a relevant criterion if the collection of artifacts should be manageable in an office environment.

Having found a solution by TRIZ, its physical realization can be included to the TRIZ-Box afterwards. Thus, the TRIZ-Box can also be used as storage for successful solutions and best practice cases. In this way the artifact collect is continuously broadened refreshed.

4 SUMMARY

A method called TRIZ-Box for supporting TRIZ and other methods requiring analogy forming is proposed. As theoretical background three perspectives have to be considered: creativity and analogy forming, methodological means of support and the body of knowledge of classical TRIZ. TRIZ-Box allows the directed application of artifacts that represent inventive principles in ideation processes by supporting analogy forming.

Current activities focus on enlarging the TRIZ-Box content to an extent of at least three artifacts per inventive principle. Further work is going to test in what way the application of the TRIZ-Box method affects ideation and its results.

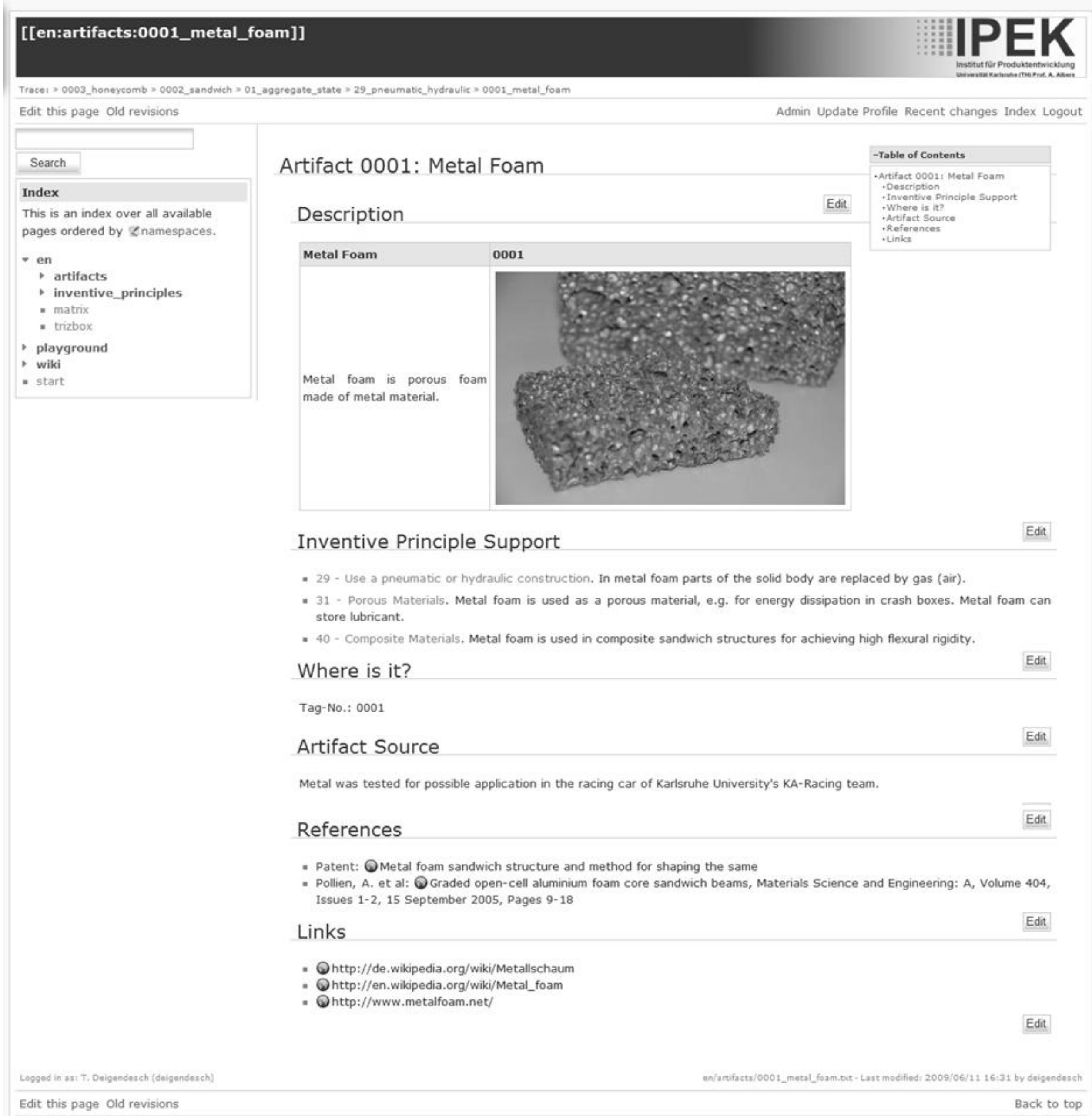

Figure 2: The TRIZ-Box wiki system: metal foam as exemplary artifact.

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Accessibility of the Innovative Principles to Further Levels of Abstraction in Product Development

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Abstract

The paper introduces the transformation of the 40 innovative principles of TRIZ into a description with the Contact and Channel Model (C&CM). Reason therefore is the attempt to make the principles better applicable for the generation of new ideas in product development at any stage of the product development process.

The paper in a first step introduces the C&CM. The core of the C&CM approach is an orderly assignment of the functions of a product to their shape, which enables designers to break up with rigid, pre-fixating representations of products. C&CM product models by means of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) force users to think about products in a more abstract way. Designing with the C&CM is conducted on a meta level through (i) adding WSP, (ii) removing WSP, (iii) changing the properties of WSP and (iiii) changing the properties of the CSS. The paper reflects the reasons for the transformation of the innovative principles of TRIZ into C&CM before the theoretical approach is explained. The paper closes with a case study where the coupling of the innovative principles to the C&CM meta-rules of designing is applied.

Keywords

Innovative Principles, Contact and Channel Model, C&CM

1 INTRODUCTION

The development of technical systems is a complex process, where designers have to think ahead many steps at the same time. They have to consider many interdependent factors in order to prevent decisions which lead to unsatisfying solutions.

The design process is determined by a permanent changing of steps of analyzing and synthesizing. Within this process the designer has to respect the abstract level of functions, which gives the objectives to the design process and the level of shape. The shape is the result of the design process, because only a real component can fulfill functions. Both levels have to be regarded parallel in order to find an optimal solution.

Good designers mostly have a long lasting professional experience on which he/she can rely. Out of many successful und unsuccessful attempts of designing products he/she has developed a “feeling” for decisions and workflows. This experience can hardly be couched, thus can hardly be handed on to other designers.

To put these things right many manuals and instructions have been developed for creating products. Beginning with very general procedures within e.g. the VDI guidelines in Germany 0, continuing with many partly very specific process and rule descriptions, there is an endless repertoire for designers to find. Yet, rules and descriptions are formulated on specific levels of abstraction, i.e. somewhere on the way between a pure functional description and a pure geometric description.

Figure 1 shows that within the spectrum of function and form many methods and tools are developed. For each of these departments, which all contribute to the development of the product, rules, guidelines and principles are developed. Many of them remain hard to access for designers.

In order to support the passage of the different levels of abstraction in several research approaches continuous process models have been developed to describe procedures in product development on a generally understandable way (e.g. 0, 0, 0).

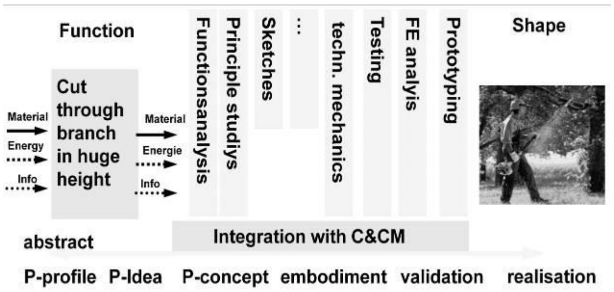

Figure 1: Different methods and models in the design process.

The combination of the process models with the rules, guidelines and principles, which are all placed at different steps in the process, is a rarely supported issue.

In order to integrate the different methods models that are developed in the different departments of a company, the Contact and Channel Model (C&CM) 0 has been developed. Within this paper the C&CM is applied to improve the integration of the innovative principles of the TRIZ methodology into the product development process.

On the basis of the C&CM it shall become possible to represent the Innovative principles in any step of the design process, at any level of abstraction.

2 BACKGROUND

During the development of products continuously new experience is generated. This experience that is not only suitable for the current project and can also be applied to other design activity in future projects. Specific experience may be applicable to only a small number of projects, whereas generally described procedures may be applicable to a huge amount of project. Yet, the general rules and principles must be adapted to the specific problem in order to benefit from their application.

In order to save the knowledge of experience and to make it also accessible for future projects out of the experience generally formulated rules, guidelines and principles are derived. Their allocation in knowledge-storages provides a useful support to inexperienced designers.

Numerous authors provide general but also topic- and technology based systems of rules. E.g. 0 represents a famous collection of many of these rules.

The concepts of the rules, guidelines and principles are not used consistently. Some authors use the term of guideline synonymously to principle or rule. Others applied these terms in an upside down hierarchy. There exist guidelines that are named principles whereas rules in other works. An elaborate description of this issue can be found in 0.

The terms basic rules, principles, guidelines and embodiment advices are shown in a coherent way (Figure 2).

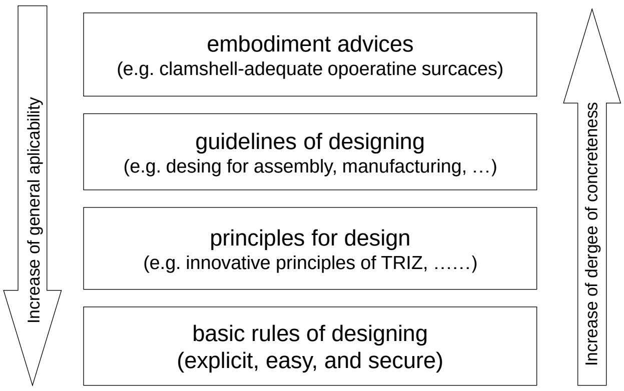

Figure 2: Hierarchy of basic rules principles guidelines and embodiment advices.

The hierarchy shows the categories of rules. Generally formulated approaches are located at the bottom. They can be applied to a wide range of design problems. On the top of the hierarchy concrete advices for specific embodiment problems are located. A specific embodiment advice is applicable to a smaller range of problems and requires a structured admission.

The "basic rules of designing" (explicit, easy, and secure) 0 are foundation for all other guidelines, principles and rules. The "principles for design" are more generally formulated (here the innovative principles of TRIZ are associated) than the "guidelines of designing". The "guidelines of designing" refer to specific topics like e.g. design for manufacturing or design for assembly. Embodiment advices already refer to very similar situations, low degree of abstraction and thus do not need to be interpreted in the depth of the principles.

2.1 Altschuller's Innovative Principles (TRIZ)

This paper focuses on the innovative principles of the TRIZ theory. In the section before the innovative principles were classified to the class of "principles of designing" on a rather high level of abstraction, thus applicable to a very wide range of design problems but on the other hand give huge area of interpretation to the designing engineer.

The innovative principles are an all covering collection of interdependent principles for finding new solutions in design processes.

Genrich Altschuller documented in the middle of the 20th century his experience of analyzing about 40000 Patents 0. His essential discovery at this was that on a certain level of abstraction the performance of innovation can be reduced onto 35 (later 40) basic principles. These principles are recurring in any innovation performed in any engineering design process 0.

For accessing these innovative basic principles Altshuller developed a theory which states that any problem that must be solved can be formulated as a contradiction. Any of these contradictions can be formulated as the combination of an improving and a worsening parameter. For any problem description there exist 39 technical parameters on whose basis the contradiction is formulated. The process is shown in Figure 3.

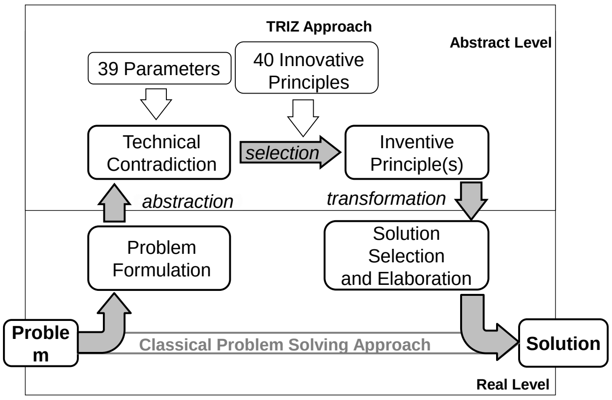

Figure 3: Course of applying the innovative principles.

Yet, TRIZ does not only comprise the application of the 40 innovative principles based on a contradiction formulated with 2 of 39 technical parameters. The TRIZ philosophy comprises several other approaches that cover a huge area of engineering design, which are all not part of the paper in hand.

3 PROBLEMATIC

The 40 innovative principles are a powerful tool. TRIZ claims that the principles can be applied to any kind of technical problem and find appropriate solutions.

Yet, the level of abstraction of the principles is very high. The designer has collect a lot of experience into the process, before the application of the principles leads to an optimal solution. The experience is needed to effectively interpret the principles according to the formulated problem. The abstraction of the problem and transformation of the principle solution (see Figure 3) into a concrete solution are process steps that need support.

This issue shall be exemplified by the application of the innovative principle number 12 (equipotentiality, remove stress). The principle states in the interpretation of 0: "Change the conditions in such a way that the object can work with a constant potential of energy". That means that the object should neither be lifted nor lowered. The principle makes clear, that a conventional piston combustion engine is not the ideal solution for transferring combustion energy into a mechanical movement. Indeed, for transferring this conclusion into e.g. a wankel engine with the aid of the principle number 12 a huge inventory performance in required. Therefore TRIZ does not provide support in any case.

The experience the designer has to collect to effectively transform the principal solution often concerns the knowledge about design decisions that limit the newly found concept. The concretization of the new innovative concept is limited by restrictions that stem from e.g. special knowhow in the electrical department of a company, whereas the new concept was discovered in the mechanical department. A key competence of the designer then is to transform the new concept into marketable solutions with respect to the limiting boundaries. As there is hardly any methodical support in integrating these conditions into the process of concretization the designer has to rely on his experience.

4 APROACH OF THIS WORK

The idea described in this paper is: through giving a more concrete reference to the abstractly formulated innovative principles, they become more easily applicable. A support especially in the abstraction and transformation steps is given through a concrete reference to the problem in hand. Although the finding of solutions can take place with very little description of a pre-fixating shape the transformation into the solution is supported by the location of the contradiction in a concrete Working Surface Pair (WSP) or Channel and Support Structure (CSS). The Contact and Channel Model is a means to relate abstractly formulated functions to the shape which is designed for the fulfillment of the function. As the finding of principle solution with TRIZ is based on rather abstract functional descriptions the C&CM seems suitable to also here integrate abstract and concrete real descriptions.

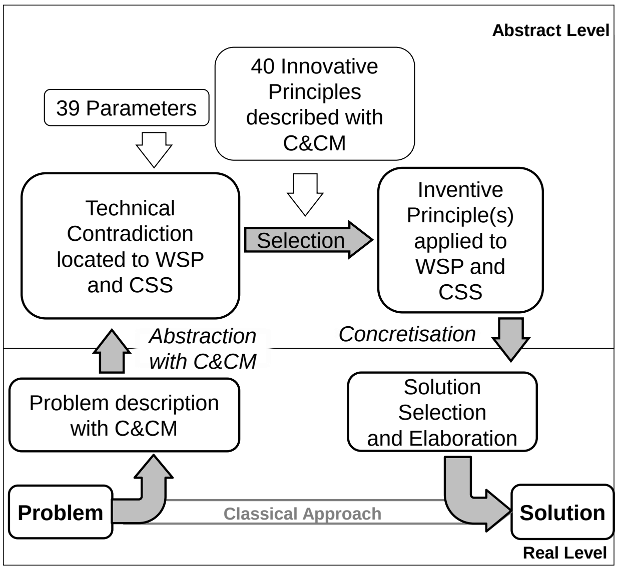

Figure 4: Proceeding of TRIZ with C&CM.

The approach has two aspects (fig. 4). First is a problem formulation on the basis of C&CM. A technical contradiction can then be formulated as the combination of two parameters in a WSP or CSS.

The second aspect is the formulation of the 40 innovative principles according to WSP and CSS. Thus, solutions that are found through the application of the Innovative principles can be transformed more easily as they receive to a concrete location on the object of the problem solving process.

In order to explain the approach more concretely the basics of Contact and Channel Model are briefly introduced in the next section. After that the formulation of the innovative principles with the C&CM is shown up by the example of only two of the 40 principles. The other principles have been formulated with the C&CM, but are left away in this paper due to space restrictions. Subsequently the description of a concrete application of the procedure at “the fixation of a carriage of a turning lathe” should finally make the approach clear.

4.1 The Contact and Channel model (C&CM)

The core of the C&CM approach is an orderly assignment of the functions of a product to their shape, which enables designers to break up with rigid, pre-fixating representations of products. C&CM product models by means of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) force users to think about products in a more abstract way 0.

How the C&CM works

By using C&CM it is possible to isolate an individual problem from the remaining technical system at any time of the design process and at any level of detail, to solve it and to integrate the solution into the entire system to check the effects of the changes on the entire system.

The Contact & Channel Model describes engineering products in terms of Working Surface Pairs and Channel and Support Structures 0. Every function of the product resides in a particular set of Working Surface Pairs (WSPs) and Channel and Support Structure (CSS), because a function cannot be applied other than through these interfaces. This enables designers to think about abstract functions in a concrete way, because they can picture them at a set of WSPs.

In terms of the C&CM approach, descriptions are generated for a particular problem through assigning a set of Working Surface Pairs and Channel and Support Structures to a specific function and searching for solutions on this clearly assigned level. The C&CM approach then picks and groups elements of the existing description in a new way, exploring the inherent ambiguity of how elements of a description are grouped.

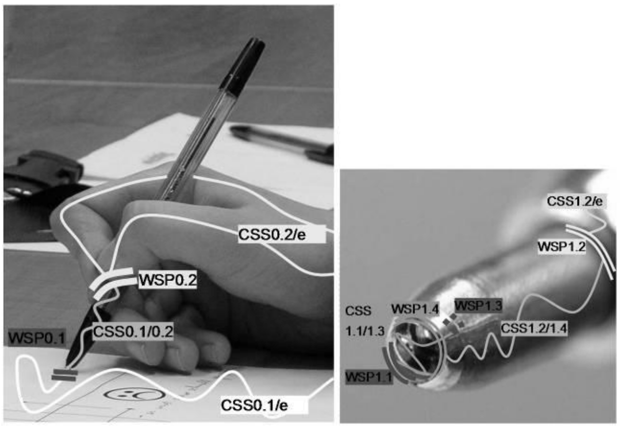

Figure 5: Functions of a ballpoint pen.

For example the function of a ballpoint pen (Figure 5) cannot be fulfilled unless WSP0.1 between paper and pen, WSP0.2 between pen and hand and the CSS0.1/0.2 represented by the body of the pen exist. If one of these elements is not build up correctly the function cannot be fulfilled. For example if somebody tries to write on glass, WSP0.1 does not work correctly. Reasoning on a lower level of detail it remains to clarify why the function cannot be obtained. What effect prevents writing on glass? Is there not enough friction in order to turn the ball, or do the properties of the liquid ink prevent a wetting of glass through ink? Are there other reasons? To clarify such a case remains then in the hands of the designing engineer who might be given the task of creating a ballpoint pen for labelling glass-surfaces.

Thus, C&CM models can be applied on different levels of detail always in the same way, so that the same type of mental model can be applied at different levels of hierarchy. The CSS0.1/0.2 of the ballpoint pen can be split up into further WSPs and CSSs, which represent the structure of parts in relation to the structure of functions contributing to the principal function. The model can be dynamically adjusted in its degree of detail, according to the problem posed by a product.

Frame work for designing with C&CM

The sections before indicated that C&CM provides support in describing abstract functional issues and shape in a combined way.

This point of view allows the designer to facilitate keeping the overview over the interdependencies during the product development process. The C&CM allows switching very quickly between representations that provide a highly detailed insight into a very special issue and representations that give an overview to the designer in order to evaluate the consequences of the work at the detailed point (e.g. see Figure 5).

Further the description of a system with C&CM opens up the possibility to integrate different functional and geometric descriptions that are required during the design process (see Figure 1). These descriptions can be referenced with the C&CM, so that in case of iteration the evaluation of the consequences can be conducted more easily because the designer has a support to integrate the different descriptions.

This also means that the different departments can fulfill their part of the design task more independent form their colleagues, because the can rely on a common language and do not have to interpret the descriptions from another departments.

Therefore designers have to organize their mental work differently. All kind Information is saved as properties about WSP and LSS without completely being assigned to one special shape. In the course of the design process this information is consolidated through the legwork of the different departments, and in the end leads to the concrete shape. Whereas today e.g. the different departments often have to face pre-fixated design decisions that limit their room for searching solutions.

The description with C&CM leaves the liberty to the designer to not stringently make decisions. The final shape can be defined when information of all departments come together. Thus, Iteration, rework and revision of stringently made decisions can be reduced.

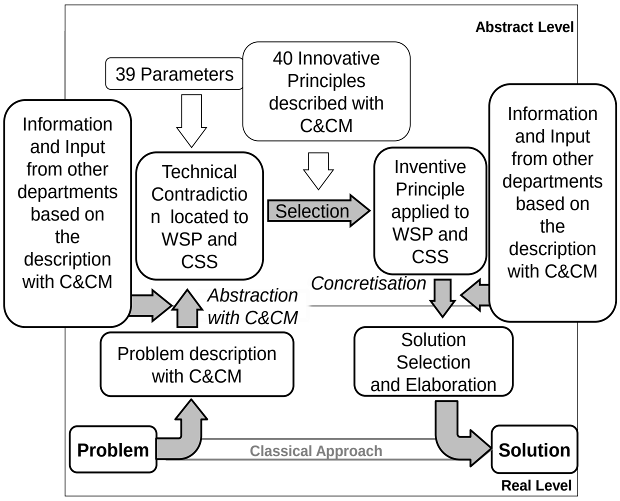

Figure 6: Support in the "transformation" steps

On the other hand the space of solution is not limited arbitrarily by one department based on their partial decision. The space of solution can be narrowed down with the respect to the information from the other departments. Thus, the chance of choosing a solution of higher quality can be improved.

Figure 6 shows in which cases the support to the application of the innovative principles of TRIZ is of greatest benefit. The abstractions with C&CM as well as the concretization step when a solution is found are the mainly supported steps. All the information about the problem description can be referred to the WSP and LSS. For the step of searching solutions this information can optionally be neglected in order to be "free" from limiting restrictions.

Yet, when the solution found has to be concretized all the information and input from other department has to be considered. Thus, an effective selection of solution according to the boundary conditions is supported.

Meta-rules of designing with C&CM

Principles and guidelines that are included into the C&CM can be divided into different groups, depending on which changes are made and how they are carried out in order to improve the result: One group only concerns the WSP of a technical system. This includes among others the principle of assembly-oriented design, wear-oriented design and corrosion-oriented design. A further group only influences the Channel & Support Structures of a technical system. It contains creeping and relaxation-oriented design, deformation-oriented design as well as some of the principles concerning energy and force transmission.

Apart from that there is a group which concerns the complete Working Structure of the technical system, i.e. the Working Surface Pairs essential for the function as well as the Channel and Support Structures. This group is relatively big and contains e.g. the principles of nearly flawless design, the principles of safety engineering, the principle of self-help and the risk-oriented design.

For the paper in hand the following generally described proceedings are relevant. An important organising criterion overlapping with the research work in this paper is the way the changes concerning the application of the principles and guidelines in the technical system are realised. In general, there are four possibilities for changing a technical system:

- Meta-Rule 1: Adding Working Surface Pairs or Channel and Support Structures,
- Meta-Rule 2: Removing Working Surface Pairs or Channel and Support Structures,
- Meta-Rule 3: Changing the properties of Working Surface Pairs, including their relation to other Working Surface Pairs or Channel and Support Structures and
- Meta-Rule 4: Changing the properties of Channel and Support.

From these rules all changes of any technical system can be derived. However, as the rules are so general a designer with some experience is required to guarantee a safe application in the design process and derive the correct measure from these very generally put rules. The combination of the meta rules with the innovative principle of TRIZ concretizes the application of the meta rules.

Innovative principles and the meta rules

Similar to the proposed procedure with C&CM the formulation of a contradiction is the description of the problem on a more abstract level.

The approach of this paper is: with formulating the problem contradiction on the basis of C&CM and through formulating the innovative principles with C&CM the integration of the found solution into the overall design process is improved.

Finding solutions with C&CM is conducted through applying one of the four meta rules, that were introduced in the section before. These meta rules give an abstract frame work for proceeding in the design process but lack to give innovative food for thought. In order to integrate the innovative principles into the process with C&CM the innovative principles have been reformulated on the basis of the four meta rules.

4.2 Applying the C&CM to the Innovative Principles of TRIZ

The problematic of applying the innovative principles is their absolute dissociation from the specific problem. Thus, the step of concretization becomes the core performance of the designer. Integrating the newly found innovative solution is a hardly supported step that is based on experience.

If the innovative principles are formulated in a way that these can be assigned to WSP and LSS a reference to the specific problem persists and the transformation of the innovative principles is facilitated, because the principles can be referred to a concrete location.

Further it is interesting to transform the innovative principles into C&CM for generating a basis to apply the principles to all kinds of changes of technical systems. In the following the conversion of the innovative principles is formulated as general as possible according to the introduced meta rules.

In this paper the formulation of the innovative principles is exemplified by only two of the 40 principles due to space restrictions. Yet, the goal of the paper is to principally explain the approach and lay a cornerstone for the immersion of the research work.

4.3 Exemplification of the innovative principle with C&CM

Principle Number 2: Extraction, Separation, Removal, Segregation

“Hiving the disruptive part of the object or in contrast hiving the only part essential“0. Explanation: the principle describes the possibility of separating a technical system in two or more parts if these fulfill different functions. The subsystem fulfilling the required function shall be retained whereas the subsystem fulfilling the unwanted function shall be removed.

Example for this is non-metal contaminations in metals. For removing those contaminations the metal material can be transferred into cast. Contaminations can then be removed, because they are still solid or are swimming upon the surface of the cast.

Description of principle no.2 with C&CM

A system should be broken down into its sub functions according to the subsystems fulfilling the wanted and unwanted functions. For each of these functions the WSP and LSS shall be determined as clearly as required. The clear determination of unwanted and wanted/required elements allows an easy separation.

Interdependencies between WSP and LSS of wanted and unwanted functions shall be uncovered.

If the WSP and LSS of wanted and unwanted functions are not depending on each other meta rule 2 can be applied: unwanted WSP and LSS shall be removed.

If the WSP and LSS of wanted and unwanted functions are depending from each other meta rule 1, 3 and 4 shall be applied in order to abolish the in interdependencies. Meta rule 4 “Changing the properties of the LSS” can be applied in order to transfer the metal into its cast (changing the property of aggregation state) by melting. Afterwards the unwanted function of the non-metal contamination can be removed.

Principle Number 4: asymmetry

„The symmetric form of an object shall be transferred into an asymmetric form”. If the object is already asymmetric, the degree of asymmetry shall be increased” 0.

Explanation: Symmetry can be understood with respect to symmetry of geometric features as well as in a figurative sense, e.g. the symmetric assignment of functions. The dim light of cars stronger illuminates the clipping of the drive lane than the middle of the street, in order to create a compromise between good illumination and blinding of oncoming traffic.

Description of principle no.4 with C&CM

“Change the alignment of WSP and LSS of a function in such a way, that they are arranged asymmetric“. There can be added WSP and LSS in order to realize asymmetry; there can be removed WSP and LSS in order to realize asymmetry. There can be changed the properties of the WSP and CSS in order to realize asymmetry.

In the case of the dim light of the car the two functions “illuminate drive lane” and “blinding the oncoming traffic” are fulfilled by the same WSP and CSS. Those are the WSP between headlamps and the light beam and the WSP between the light beam and the drive lane respectively the eyes of the driver in the oncoming car. The CSS is determined by the extension of the light beam in front of the car. Asymmetry is realized through focusing the beam on the WSP on the drive lane and minimizing the WSP on the eye of the oncoming driver as far as possible.

5 CASE STUDY

Figure 7 shows a device that was build for the objective of being able to quickly and easily adjust the tool carriage of the a turning lathe. The device consists of a lever and a screw (shown in fig. 8) that fixes the lever to the carriage.

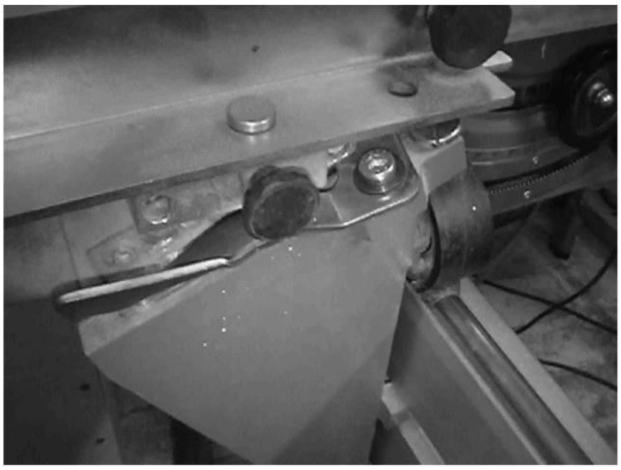

Figure 7: Lever for the guiding and fixation of the carriage.

Therefore the device fulfills several functions. In a functional state 1 (Figure 9) the “fixation of the carriage can be locked and unlocked”: the function is fulfilled through the WSP 1 between user and lever and WSP 2 between lever and screw. The “lever needs to be fixed and guided” through the WSP 2, 3 and 4.

A second functional state (Figure 10) is when the carriage is fixed (WSP 2 and WSP 5) and when the lever is not activated, when WSP 1 is not active. And also here the “lever needs to be fixed and guided” through the WSP 2, 3 and 4.

These two functional states allow the easy and quick adjustment of the carriage.

Figure 8: Fixation of the lever.

Problematic of this solution is that through the fulfilling of the function “lock and unlock the fixation (Figure 9, WSP1 and WSP 2) WSP 4 and WSP 3 are dissolving, so that the function “fix and guide lever” in both functional states lever is not fulfilled any more. Thus, the objective of the design process is not achieved any more.

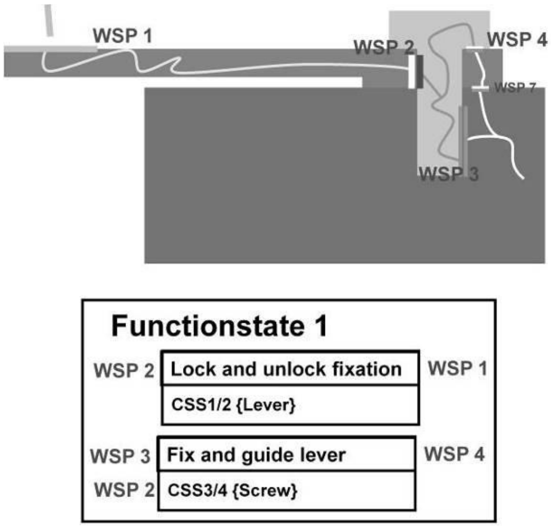

Figure 9: Functional State 1.

In order to make the system fulfill the functions again the screw has to be fixed all the time. In case of emergency the turning process is interrupted and the work piece can be destroyed.

Searching for solutions with the TRIZ C&CM approach

Searching for a solution with the approach introduced in the sections before the problem is formulated as a contradiction based on WSP and LSS that are responsible for the fulfilling of the functions, in order to find a suitable innovative principle.

The function that is dissolved „fix and guide the lever“ gives a first hint onto a contradiction. The WSPs 2, 3 and 4 have to make sure that on the one side the lever is fixed, but on the other side have to grant space for motion in order to be able to “guide the lever”.

The cropping up problem is that the “stability of the object’s composition” (technical parameter no. 13) decreases with the dissolving of the WSP 4 and WSP 3.

Thus, the parameter that needs to be improved is “stability of the objects composition”. WSPs 2,3,4,5 are not being obtained. The parameter can be referred to the mode of action in these WSPs. These parameters represent the stability of composition of the object.

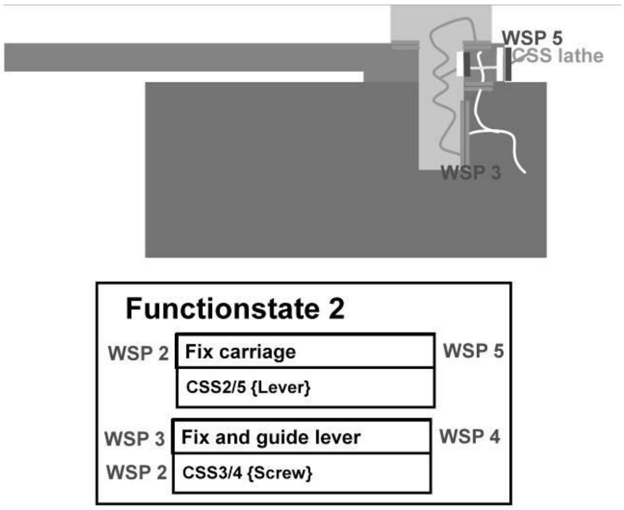

Figure 10: Functional State 2.

The loss of stability lies in the dissolving of the pressure in the WSP 4. Through WSP4 the movement of the lever is transfused into the screw and cause the breakup of WSP3 at the tread.

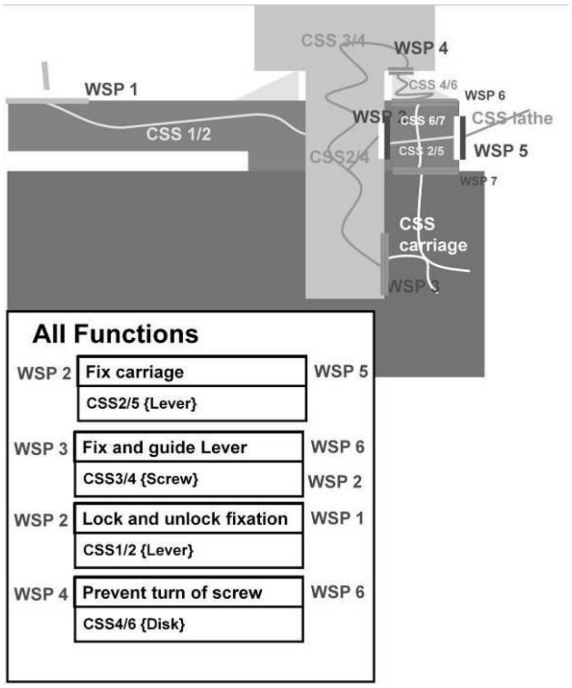

Figure 11: Applied principle of asymmetry.

Thus, the contradiction can be localized to the WSP 4 between the head of the screw and the upside of the lever. Here the unwanted movement is transferred.

Improving the parameter no.13

According to TRIZ the approach must then be to improve the parameter no 13 in order to reestablish the stability. Obvious solutions for re-increasing the stability of the composition of the WSPs could e.g. gluing the WSP4 or welding the WSP4 or strongly attaching the screw. Yet, these solutions would change the “shape” of the WSP 4 in such a way that WSP 4 cannot guide the lever any more. The technical parameter no 12 is decreased.

Accessing the table of contradictions

Taking the contradiction of technical parameter no 13 (improving) and technical parameter no 12 (worsening) to the table of contradictions, beneath others the innovative principle no 4 (asymmetry) can be chosen.

The principle formulated with C&CM ends in “Change the alignment of WSP and LSS of a function in such a way, that they are arranged asymmetric“. As the WSP 4 is mainly responsible for the problem, the contradiction is formulated for this WSP 4 in order to apply the principles here.

Finding solutions through the table of contradictions

Meta rule 1 of the C&CM proceeding states that “WSP and CSS” can be added in order to solve the problem. Thus, there should be WSP and CSS added in order to find an asymmetric solution.

This leads to the solution shown in Figure 11, where WSP 6 is introduced. WSP 4 and WSP 6 are asymmetric in their geometric extension. The increased contact pressure in WSP 4 in contrast to WSP 6 leads to ductile deformation and causes different friction coefficients in WSP 4 and WSP 6, thus the screw will probably not join the motion of the lever.

Further, applying meta rule 3,”Changing the properties of the WSP” can lead to another solutions with “asymmetric friction coefficients in WSP 4. WSP 4 could be a teflon-steel WSP that prevents the transmission of the motion into the screw.

6 SUMMARY AND FUTURE WORK

Designers in industry projects complaining the too abstract level of searching for solutions with the TRIZ innovative principles, difficulties of students applying the method to concrete design tasks has led the authors to think about a way to make the innovative principles more easily accessible for newcomers. Designers in industry produce fantastic new ideas with the method, yet the transfer of these ideas into concrete solutions that can really be implemented are very rare. Also students produce promising ideas but mainly fail to transfers the ideas to their problem. Unfortunately this leads to a “method shock” that convinces mechanical design students that they are better off with a conventional way.

Yet, the paper and the research work represent only the beginning of making the innovative principles better accessible. Another paper in this conference describes the improvement of the accessibility through creating real touchable artifacts (TRIZ-box) for the innovative principles. Thus, the problematic shall be abolished through the generation of analogies.

These both approaches will be evaluated systematically in real design projects in order to improve them.

The application of the C&CM in several industry projects e.g. described in 0 and 0 showed that relating abstract issues to the concrete objects of the design task through WSP and CSS is valuable way of improving product development. Thus, also the abstract issues of the innovative principles can be supported through the relation to a concrete WSP.

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Correlations between the Evolution of Contradictions and the Law of Ideality Increase

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Abstract

TRIZ literature largely claims the efficiency of Altshuller's Laws of Engineering System Evolution (LESE) as a means for producing technology forecasts. Besides, all the instruments and the procedures proposed so far suffer from poor repeatability, thus limiting the adoption of TRIZ instruments as reliable means for the analysis of emerging technologies and their potential impact. In a previous work [1, 2] the authors have presented their modelling approach based on a combination of well known TRIZ techniques and traditional engineering design reference models. The outcome is a Network of Evolutionary Trends which supports decision making by positioning alternative technologies and technical solutions according to the LESE. The choice of the favourite strategic direction is still assigned to the beneficiaries of the forecast, since decisions will be taken also based on their mission and values. Besides, it is necessary providing further means of judgement to the decision makers. According to this purpose, it is useful to assess the maturity level of the analyzed technologies. The present work is a study about the correlations existing between the evolution of contradictions and the Law of Ideality increase, as a means to estimate the stage of development of a Technical System. The paper details the method proposed to make a systematic comparison of the contradictions related to each technology. The approach is clarified by means of a case study related to the production of tablets in the pharmaceutical manufacturing sector.

Keywords

Technology Forecasting, Laws of Engineering Systems Evolution, Contradictions

1 INTRODUCTION

TRIZ is founded on three postulates: (i) the existence of objective laws (LESE) governing the evolution of Technical Systems (TS); (ii) the refusal of compromises and the advancement of TS through the resolution of contradictions, i.e. conflicts between a system and its environment or between the components of the system itself; (iii) the impact of the specific situation, i.e. the resources which determine the concrete means to develop more evolved solutions.

Nevertheless, a paradoxical dichotomy characterizes most of TRIZ works: those focused on problem solving tasks, take into account the concept of contradictions, but practically neglect any relationship with the LESE, despite an appropriate application of ARIZ hiddenly implies the respect of the LESE. Vice versa, evolutionary analyses and "technology forecasting" applications are just based on the directions inspired by the LESE and/or by a few trends (e.g. the Inventive Standards of Class 2 and 3), but the notion of contradiction is missing. Somehow the resources (third postulate) are usually taken into account in both the applications.

The necessity to integrate the analysis of contradictions with the LESE in any TRIZ-based study has been already highlighted in previous works (e.g. [3, 4]), but just preliminary directions are emerging about the way to harmonize them. The present paper provides a contribution in this context through a study about the correlations existing between the evolution of contradictions and the fourth Law of Evolution (Ideality increase).

Such a correlation is a valuable resource to assess the maturity of a certain technology and it is proposed as a decision aid when multiple directions emerge from an evolutionary analysis made through the TRIZ LESE.

The present paper first positions the present research in comparison with other publications related to contradiction analysis and TS evolution. Then the third section summarizes the modelling technique, already discussed in [2], which aims at improving the repeatability of TRIZ-based evolutionary analyses. Section 4 details the original approach here proposed to identify the contradictions characterizing the evolution of the technologies to be compared and the related correlation analysis. In section 5, these criteria are applied to the past and current technologies adopted in the pharmaceutical manufacturing sector for tablets production. The case study allows to discuss about the potentiality to adopt the proposed correlation analysis as a means for maturity assessment.

2 EVOLUTION OF TECHNICAL SYSTEMS AND RELATED CONTRADICTIONS

The evolution of Technical Systems follows objective laws and overcoming contradictions is the inherent mechanism which determines TS development. The first two postulates of TRIZ are clearly strictly related to each other; nevertheless, their coexistence is just "perceivable" into the classification of the Inventive Standards, while it is almost hidden in ARIZ, as well as in other items of the TRIZ body of knowledge.

As a matter of facts, in classical TRIZ there are no formalized tools to correlate the evolution of a TS with its contradictions: in [5] Altshuller, through the well known curves of system development, number of inventions, profitability, level of inventiveness (fig.1), implicitly highlighted the conceptual link existing between the maturity of a TS and its contradictions, since the latter index is measured through the degree of contradiction resolution. Besides, these curves are hardly usable for practical scopes, despite what has been claimed in several publications like [6-8], also due to the lack of information about the way Altshuller himself built them (therefore, with no references about their limits of validity). In facts, in these papers the technology maturity curves are usually fuzzily rebuilt, often with relevant details missing (e.g. x and y values in [6]), and with extremely doubtful determination of the inventiveness level [7, 8].

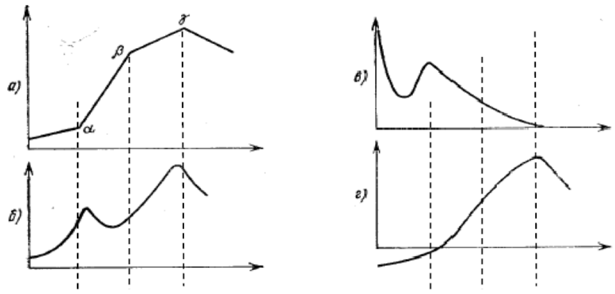

Figure 1: Correlation between the stages of the "life" S-curve of a technical system (top, left) with the number of inventions (bottom, left), the level of inventiveness (top, right) and the related benefit, i.e., profitability (bottom, right) [5].

Indeed, numerous attempts have been accomplished to systematize the count of inventions, but just time consuming manual analyses allow to filter out not relevant patents selected through standard computer search criteria. The determination of the Level of Inventiveness evolution is even more difficult, since it is supposed to be done through a careful identification of the contradictions behind the problem solved by the patented inventions and, most of all, by the assessment of the degree of elimination of the contradictions themselves, which is extremely time consuming. Besides, no practical means still exist to speed up the identification and assessment of the contradictions approached by a patented invention, despite preliminary studies have been published in [9].

According to these issues, it emerges the necessity to find out further correlations between the maturity stage of a technology in a certain field of application and other technical information, possibly manageable with computer means to improve the efficiency of the process.

Out of TRIZ literature, Technology Assessment (TA) has greatly evolved since the early experiences of the 1960s [10], but still there isn't a single, widely disseminated and applied methodology. Many different approaches to TA have been adopted in practice, depending on the specific aims and scope of the application and its context (institutional, private firms, private or public research centres, specific industries etc.) [11]. Due to the lack of an established TA approach, neither in the scientific literature, nor in the industrial practice, the authors have decided to investigate the possibility to correlate the maturity of a technology with the evolution of the contradictions underlying its application in a certain field. The existence of such a correlation is expected according to the fifth law of evolution (uneven development of TS parts) and addressed also by Cavallucci and Rousselot [3], where the purpose is indeed different: ordering the contradictions in accordance to the fact that they present an opposition to a specific law. In this paper the search for correlations between the evolution of TS contradictions and the LESE has been focused on the law of Ideality increase, due to some evidences arising from classical TRIZ literature. In facts, the growth of the degree of ideality can be compared with the consumption of resources according to the wave model by Salamatov [12], as depicted in fig. 2. By combining the S-curve of TS performance with such a bell shape resources consumption three main stages of evolution can be recognized. The specific objective of the present research is to check the possibility to correlate the nature of the contradictions acting on a TS with these stages of TS development.

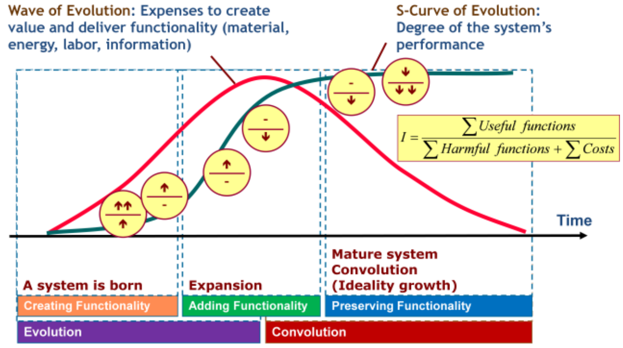

Figure: 2. Trend of Ideality increase (red line) compared with the consumption of resources (green line) which reflects the wave model by Salamatov [5].

3 FUNCTIONAL MODELING FOR TRIZ-BASED EVOLUTIONARY ANALYSES

With the aim of improving the repeatability of TRIZ-based evolutionary analyses, the authors have proposed in [1], then further detailed in [2], a functional modelling approach which integrates well known models and instruments for system description and function representation and allows a systematic application of the TRIZ LESE to classify existing technologies and to identify further opportunities of development through a Network of Evolutionary Trends (NET).

The modelling procedure is based on the following reference models:

- Function-Behaviour-Structure (FBS) model [13], to distinguish between the Function of a TS, i.e. the motivation of its existence, its Behaviour, i.e. the way the function is delivered according to the Laws of Nature, and the Structure, a combination of entities, attributes of these entities and relations among them, which determine the Behaviour of the TS.
- EMS (Energy, Material, Signal) model [14], to describe the Function of System and Subsystems.
- NIST Functional Basis for Engineering Design [15], to reduce ambiguity at the modelling level and to improve repeatability of the models through a taxonomy of actions and flows coherent with the EMS modelling approach.
- An extension of the classical TRIZ model of Minimal Technical System (MTS) [5], to represent the Behaviour of the TS also through Material and Signal flows (from the supply to the Tool through the Transmission).
- System Operator [5] to conduct the analysis at different detail levels (i.e. system, sub-systems etc.) with a proper hierarchical classification of system elements, by taking into account their Behaviour and modifications in time.

A detailed description of the modelling algorithm is out of the scopes of the present paper. Nevertheless, it is worth to mention its main steps:

1. The system is modelled through EMS boxes and decomposed into elementary functions until each functional unit can be described in terms of flows and actions belonging to the reference list proposed in [15] (fig. 3).
2. Then the Behaviour of each elementary function is represented by means of the TRIZ model of Minimal Technical System as follows (fig. 4):

a. identify the Product, i.e. the object of the function which determines a transformation of the input flow into the output;
b. identify the Tool, i.e. the element which acts directly on the Product;
c. determine which properties characterize the Tool's capability to deliver the function to the Product;
d. for each of the properties defined at step 2c, identify the "Engine" from where the properties derives;
e. complete the model of the minimal technical system, by adding the transmission from the Engine to the Tool, the control and its interactions with the other subsystems and the external supply of the engine.

3. Once that the available Behaviours have been modelled for each elementary function, a Su-Field model related to the interaction of each pair of interacting elements of the Minimal Technical System model is added (i.e. Tool-Product, Control-Tool etc.).
4. Identify the Evaluation Parameters defining the performance of each elementary function of the TS modelled at step 1.
5. Identify further Evaluation Parameters related to the harmful functions and the resources consumption of each Behavioural Models built at step 2.

The last two steps are part of the original contribution of the present paper and will be further detailed in the next section.

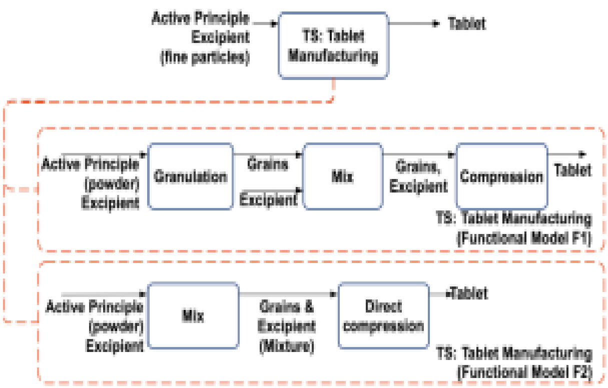

Figure 3: Functional model of a pharmaceutical tablet manufacturing process: EMS functional decomposition.

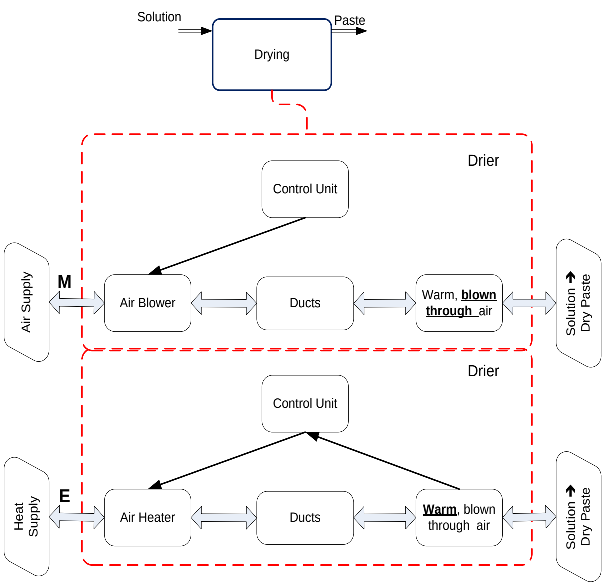

Figure 4: Exemplary Behaviour represented through the model of the Minimal Technical System associated to an elementary function described through the EMS model [2].

4 CORRELATING TS CONTRADICTIONS AND EVOLUTIONARY STAGES

In order to explain the proposed approach to study the existence of correlations between the evolution of the contradictions characterizing a certain TS and its stages of development, it is worth to recall the model of a TRIZ contradiction. The authors have adopted the OTSM formulation [16], which distinguishes between Evaluation and Control Parameters (fig. 5): <Control Parameter> of <Element X> should assume <Value 1> in order to improve <Evaluation Parameter 1> of <Element Y>, but then <Evaluation Parameter 2> of <Element Z> worsens; <Control Parameter> of <Element X> should assume <Value 2> (with <Value 2> ≠ <Value 1>) in order to improve <Evaluation Parameter 2> of <Element Z>, but then <Evaluation Parameter 1> of <Element Y> worsens.

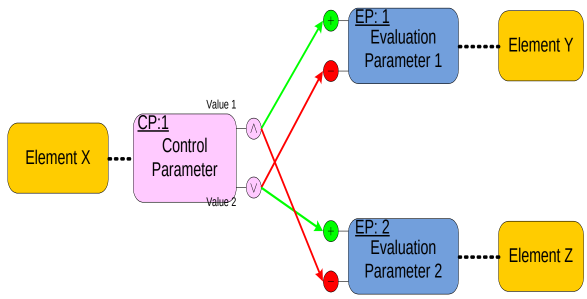

Figure 5: OTSM-TRIZ model of contradiction [16].

Aiming at the highest repeatability of the analysis, it is proposed to identify and classify the Evaluation Parameters (EP) of each Function/Behaviour according to a set of well defined rules; similarly, the Control Parameters (CP) of each Behavioural Model (BM) are clustered on the base of general rules as detailed below. Eventually, it is necessary to check the relationships between CPs and EPs in order to identify the contradictions characterizing each BM.

4.1 Clusters of Evaluation Parameters

The Evaluation Parameters represent the overall list of requirements to be satisfied by the TS and the means to assess its degree of Ideality.

According to such a definition, some Evaluation Parameters assess the Performance of the function delivered by TS. By definition, these parameters are just related to the function accomplished by the TS and not to its Behaviour and Structure, i.e. the way the function is delivered. Besides, other EPs represent a measure of the undesired side effects (harmful functions) and the consumption of resources to make the system work. It is clear that the latter two categories of EPs strongly depend on the nature of the Behavioural Model and the Structure of the TS.

Therefore, the authors have defined a standard classification of each class of EPs:

- Performance of the Main Useful Function and of other Useful Functions delivered by the TS;
- Harmful Functions;
- Resources consumption.

The cluster of Performance EPs can be divided into four sub-classes:

- threshold achievement: capability to impact the object of the function with the expected extent (in order to consider the function as "sufficient");
- versatility: parameters that characterize the capability to adapt the behaviour according to different operating conditions;

- robustness: parameters that take into account the capability to have the same desired outcome under varying inputs;
- controllability: parameters that consider the capability to set the function desired outcome according to the user will.

The Harmful Function cluster is divided into three different sub-classes, considering negative impacts on:

- object of the MUF (e.g. an undesired side effect caused by the same mechanism adopted to deliver the MUF);
- system and subsystems integrity (e.g. an undesired side effect on the TS or its parts, caused by the mechanism adopted to deliver the MUF);
- the external environment (e.g. an undesired side effect on the super-system caused by the mechanism adopted to deliver the MUF).

Finally, the EP related to Resources consumption are classified into five sub-clusters:

- Space;
- Time;
- Information;
- Material;
- Energy.

It is worth to notice that a comprehensive definition of the EPs related to HF and resources, should take into account also the auxiliary functions (AF) necessary to deliver the MUF, elicited during the modelling phase (from Function to Behaviour and Structure).

Figure 6 summarizes with a flow chart the EP classification process.

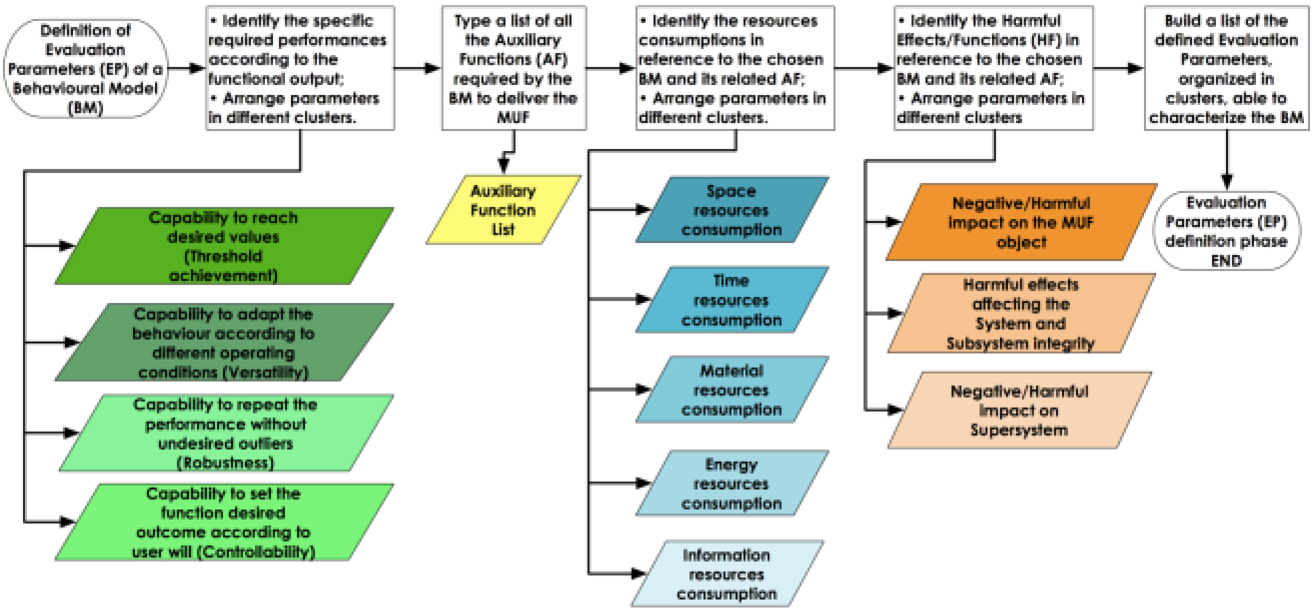

Figure 6: Algorithm for EP classification.

4.2 Clusters of Control Parameters

The Control Parameters, i.e. the design parameters that can be modified to impact on the EPs, clearly depend on the Behaviour and the Structure adopted to deliver a certain Function. Nevertheless, even in this case, the authors have proposed a reference categorization described here below.

More in details, two main classes of CPs are recognized:

- CP related to the EMS flows processed by the TS under study;
- CP related to the MTS model of the TS under study.

Both the above categories of CPs can be further distinguished according to the following classification criteria:

EMS flows

- The classification of EMS flows adopts the same schema proposed in [15] by NIST, i.e. a hierarchical three levels taxonomy including 6 secondary and 11 tertiary material flows, 12 secondary and 4 tertiary energy flows, 2 secondary and 7 tertiary signal flows.

MTS elements

- Nature of the Effect underlying the Behaviour of the TS. The CPs can be classified according to the type of effect they are associated with: Chemical Effects enable to obtain some substances from others by the absorption or isolation of energy; Physical Effects enable to transform one form of energy into another; Geometrical Effects organize and redistribute flows of energy and substances that are already available in the system.
- Role in the Behavioural Model according to the MTS schematization: the CPs are classified according to the element they are referred to, among Tool, Transmission, Engine, Control.
- Type of resources: the CPs modify the way the resources are used to improve the satisfaction of the EPs; therefore they can be classified according to the type of resource involved on, as described also for the EPs: Space, Time, Information, Material and Energy.

4.3 Contradictions characterizing a Behavioural Model

Before detailing the approach here proposed, it is worth highlighting that the goal of the present task is not solving contradictions, but modelling, counting and classifying them as a means to search for correlations with the maturity level of a TS.

As mentioned above, the reference model is the OTSM-TRIZ schema shown in fig. 5. Therefore, an elementary contradiction involves 1 CP and 2 EPs, such that opposite values are required to the CP itself in order to improve the two EPs alternatively.

Once that the lists of CPs and EPs have been built as described in the previous sections, it is necessary to assess the potential impact of each CP on each EP; then it is checked if a certain variation of a CP determines contradictory modifications on two or more EPs. More in details, the following steps must be accomplished:

1. Identify two opposite values for each CP and choose a reference orientation (e.g. from small to big, property Vs anti-property etc.).
2. Assess the impact IMP_{ij} of a CP_i variation on each EP_j (to be repeated for each CP_i):

- IMP_{ij} = +1 if a variation of CP_i towards the selected reference direction determines an improvement of EP_j;
- IMP_{ij} = -1 if a variation of CP_i towards the selected reference direction determines a worsening of EP_j;
- IMP_{ij} = 0 if a variation of CP_i doesn't impact on EP_j.

Figure 7 (above) clarifies the meaning of such a classification.

3. The overall number of elementary contradictions related to a certain CP_i can be evaluated as follows:

$$CNTD(CP_i) = (\#\text{ of } IMP_{ij} = +1) \times (\#\text{ of } IMP_{ij} = -1) \quad (1);$$

in other terms, a complex contradiction involving a CP and several EPs can be decomposed in $CNTD(CP_i)$ elementary contradictions (fig. 7, below). The overall number of contradictions related to the k-th behavioural model BM_k is evaluated as the sum of the contradictions related to each of its CPs:

$$CNTD(BM_k) = \sum_i CNTD(CP_i^k) \quad (2).$$

According to the goal of the present paper, it is interesting to analyze the evolution of $CNTD(BM_k)$ in the history of development of a certain TS. Similarly, it is worth to study the evolution of specific subsets of contradictions, defined according to the type of their EPs and/or CPs.

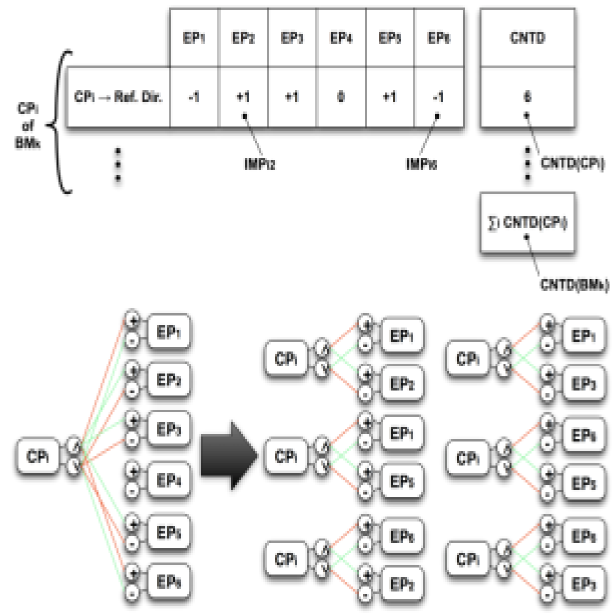

Figure 7: Decomposition of complex contradictions.

4.4 Clusters of Contradictions

In this paper the analysis of contradictions evolution is focused on the nature of their EPs, due to their closed connections with the Law of Ideality Increase. In facts, the three main clusters of EPs defined in section 4.1, i.e. performance of the main useful function, harmful functions, resources consumption, can be directly linked to the concept of Ideality (fig. 2). Function performances, intended as desired outcomes, can be related to the Ideality dividend; on the other hand "harmful function" and "costs" constitute its denominator.

Therefore, it is possible to organize the contradictions in clusters according to the type of their EPs conflicting pair, hence obtaining six different types of contradictions:

- Performance (*P*) vs. Performance (*P*);
- Performance (*P*) vs. Harmful Functions (*HF*);
- Performance (*P*) vs. Resources Consumptions (*RC*);
- Harmful Functions (*HF*) vs. Harmful Functions (*HF*);
- Resources Consumptions (*RC*) vs. Harmful Functions (*HF*);
- Resources Consumptions (*RC*) vs. Resources Consumptions (*RC*).

In analogy with the determination of the total number of contradictions associated to a certain BM (2), it is possible to calculate the contradictions separately for each of the 6 above listed classes, by taking into account the following recommendations:

- the count of IMP^m_{ij} should be limited to the EP_j of a specific class *m*, where *m* is alternatively P, HF, RC;
- therefore, (2) is updated as follows:

$$CNTD_{m,n}(BM_k) = \sum_i (\#\text{ of } IMP^m_{ij} = +1) \times (\#\text{ of } IMP^n_{ij} = -1) \quad (3)$$

where, $CNTD_{mn}(BM_k)$ is the number of contradictions involving an EP of class *m* and an EP of class *n* associated to the Behavioural Model *k*.

Similarly, since in section 4.1 twelve different classes of EPs have been defined, a total number of 78 permutations of EP pairs can be defined, thus producing 78 subsets of contradictions to be counted according to (3) for a more detailed analysis of contradiction evolution, as discussed below.

4.5 Evolution of Contradictions

In the study of the evolution of a TS, once that its functional analysis has been accomplished according to the criteria summarized in section 3, it is possible to evaluate the number of contradictions of each Behavioural Model as detailed in section 4.4.

The rationale of this analysis is the attempt of correlating the nature of the contradictions with the stage of development of the different BMs of a given TS. Indeed, different types of EPs are supposed to be involved in a different manner along the evolution from the infancy stage to the maturity. For example, according to the wave model by Salamatov [12] shown in fig. 2, the consumption of resources changes with a definite regularity.

However, due to the complexity of the possible situations, the authors don't intend to perform any assumption about possible regularities between contradictions and stages of development. Besides, it is proposed to apply the same classification to a number of case studies in order to check the existence of correlations between them.

Such an activity clearly implies an extensive work to be done for a proper validation; nevertheless, according to the limitations of the current approaches for maturity assessment mentioned in section 2, it is worth to dedicate adequate efforts to the initiative.

5 EXEMPLARY CORRELATION ANALYSIS BETWEEN EVOLUTION OF CONTRADICTIONS AND TS DEVELOPMENT

The authors have already experienced the NET modelling approach in four case studies related to disabled walkers, wood pellets production, aseptic filling of beverage containers and tablets production; in each of these case studies conducted from September 2007 to March 2009 the role of the authors was the definition of a structured set of scenarios to support company's management in the selection of the most appropriate directions for investment. The algorithm was carefully applied to collect and classify the implicit knowledge of company's experts, as well as to direct the search for further relevant information from patent databases and other scientific sources. Two further extended applications are in progress.

In this section the proposed classification and correlation analysis is applied to the case study in the field of production of tablets in the pharmaceutical manufacturing sector, since several technologies have been developed in the last decades and it is possible to appreciate the substitution process of emerging techniques over mature ones.

5.1 Functional and Behavioural Modelling

The tablet production process consists in agglomerating the Active Principle Ingredients (API) from a powder status into pills. All the existing technologies make use of excipients to improve the manufacturability and the conservation properties of the drug. Two main classes of processes can be distinguished: the largest majority of current production plants make use of an intermediary granulation phase to ease the moldability of the raw materials (fig. 8).

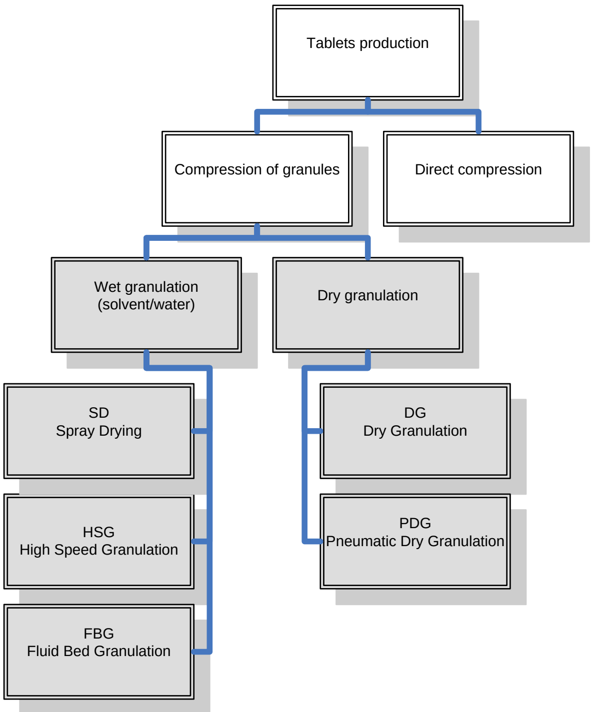

Figure 8: General classification of tablets production technologies, based on the compression (white boxes) and the granulation (gray boxes) phases.

Recently, direct compression has been applied to some APIs. Figure 3 shows the EMS model of the whole process and the functional decompositions characterizing these two major techniques. Due to the availability of detailed information from the industrial partner of the present study, a particular attention has been dedicated to the granulation phase. In the past, granulation was performed through the production of a solution to be homogenized, dried and eventually reduced to granules. After the introduction of severe limitations about solvents usage, wet granulation technologies have adopted water to substitute solutions with particle suspensions, but still keeping the same machinery. Recently, dry granulation processes have been proposed to reduce the harmful impact of water residuals into the tablets and to improve the efficiency of the overall production process. Therefore, the detailed analysis has been performed on the following technologies: High Speed Granulation (HSG), Fluid Bed Granulation (FBG), Spray Drying (SD), Dry Granulation (DG), and Pneumatic Dry Granulation (PDG) (fig. 8).

Each of the five granulation technologies has been decomposed into elementary functions according to the NIST classification, as described in section 3. Due to space limitations it is not possible to show all the functional and behavioural models built; however, it is worth to list the identified elementary functions, since they will constitute the main object of the evolutionary comparison between maturity level and contradictions types.

- HSG: Mixing (API, excipients, water), Fragmentation, Drying, Fragmentation, Sifting;
- FBG: Mixing (API, excipients), Fluidize, Agglomerate, Drying, Filtering;
- SD: Mixing (API, excipients, water), Atomizing, Drying, Sifting;
- DG: Mixing (API, excipients), Compacting, Pre-crushing, Flake Crushing, Sifting;
- PDG: Conveying (API, excipients), Compacting, Pre-crushing, Flake Crushing, Fraction.

Then, each of the elementary function has been analyzed in order to build its Behavioural Model through one or more Minimal Technical System models, as depicted in fig. 4. As a result, 14 different BMs have been recognized:

- BA1: agglomeration of fluidized powders by means of a liquid binder in a closed bin (Fluid Bed Agglomeration);
- BC1: powders compressed into a ribbon by means of two opposite counter rotating rollers (Roller Compaction);
- BD1: pneumatic conveying of particles/powders;
- BM1: mechanical mixing of powders and binders by means of moving surfaces ;
- BM2: pneumatic mixing of powders by fluidization (fluid bed mixing);
- BM3: mixing of powder by means of moving surfaces;
- BF1: mechanical fragmentation of wet mass by means of calibrated nets;
- BF2: mechanical fragmentation of dry compacts (slugs or flakes) by means of oscillating rollers: oscillating granulation;
- BF3: flakes spheronization;
- BS1: Vibro-sieving;
- BS2: PDG "smart" fractioning;
- BS3: cyclone separation;
- BE1= fluid bed drying;
- BE2= dehydration by means of a flow of warm air (oven drying).

Eventually, the EPs and CPs related to each BM have been identified: first, performance EPs are associated to each elementary function, according to the classification described in section 4.1. Then, the specific characteristics of each BM are analyzed to identify relevant resources and related harmful functions. Similarly, each MTS allows to extract the CPs impacting the behaviour of the related technology.

As a result, an elementary function characterizing different technologies (e.g. mixing, drying, sifting etc.) is evaluated through the same performance EPs, but possibly different resources and harmful functions EPs 8depending on the specific way the function is performed (behaviour). Fig. 9 depicts an exemplary analysis referred to the elementary function "mixing": above it is represented the EMS model, with details about the reference flows and actions according to the NIST classification. Six performance EPs are associated to the function, four aimed at evaluating the achievement of the useful result, three related to robustness, adaptability and controllability.

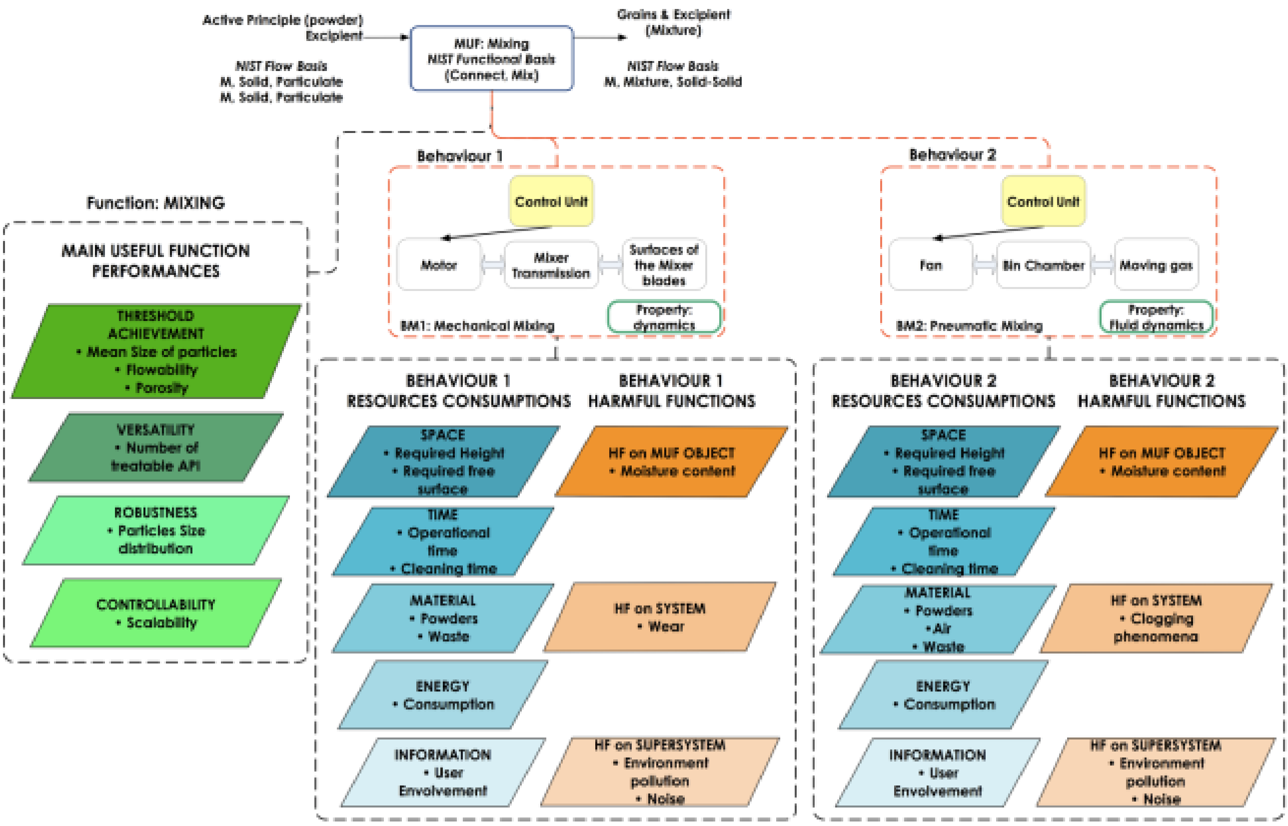

Figure9: Exemplary EP extraction and classification for two different Behavioural Models associated to the same elementary function.

Below, two different BMs are shown, related to mechanical and pneumatic mixing respectively. Each BM is characterized by a specific set of resources and harmful functions EPs. Similarly, each BM has a number of relevant CPs, classified according to the categories described in section 4.2.

5.2 Contradiction analysis

Once that EPs and CPs related to each BM have been identified, it is possible to analyze and count the related contradictions, as described in section 4.3.

BM	EPs	CPs	Contrad. count	Maturity Level
BA1	19	43	1127	G
BC1	22	16	633	E
BD1	20	16	553	E
BE1	19	23	445	G
BE2	19	22	456	D
BF1	19	18	319	D
BF2	21	18	537	G
BF3	18	14	274	E
BM1	18	29	464	D
BM2	19	29	518	G
BM3	20	19	521	G
BS1	21	11	239	D
BS2	21	26	869	E
BS3	21	21	566	E

Table 1: EPs, CPs, and contradictions identified for each BM and their maturity level estimated by the subject meta-experts: emerging (E); growing (G); declining (D)

Table 1 summarizes the overall number of EPs, CPs and resulting contradictions identified for each BM. The analysis has been further detailed, by classifying the contradictions into 6 subsets, according to the criteria described in section 4.4, thus distinguishing between contradictions characterized by EPs of different types (P vs. P, P vs. R, P vs. HF etc).

Moreover, the maturity level of each BM has been assessed on the basis of a joined evaluation of the subject meta-experts: each technology has been evaluated as "emerging", "growing" or "declining" (table 1, right), in accordance with the traditional evolutionary stages depicted in fig. 2.

Such a classification allows performing correlation analyses between the nature of the contradictions and the maturity level of a given technology, in order to check the existence of characteristic features (Table 2).

With the aim of identifying distribution peculiarities, it has been decided to focus the analysis only on the types of contradictions characterized by a higher non-uniformity, i.e. characterized by a bigger standard-deviation / average ratio (Table 2, below). Therefore, the contradictions involving mixed-types EPs, i.e. P vs. R, P vs. HF, R vs. HF, are assumed as not relevant for maturity assessment. The remaining contradictions types show a reducing number of P vs P contradictions, as well as an increase of conflicts between consumed resources R vs R (Table 3).

	P vs. P	P vs. R	P vs.	HF vs.	HF vs.	R vs. R
BA1	5,5%	39,8%	16,8%	3,9%	18,7%	15,4%
BC1	13,6	37,3%	24,2%	2,1%	12,0%	10,9%
BD1	8,0%	44,5%	24,6%	4,5%	11,6%	6,9%
BE1	2,5%	45,8%	15,7%	3,4%	18,0%	14,6%
BE2	2,4%	27,9%	14,9%	7,7%	27,2%	20,0%
BF1	5,6%	42,6%	13,8%	0,9%	10,7%	26,3%
BF2	3,7%	34,6%	26,8%	5,6%	18,2%	11,0%
BF3	15,0	44,2%	22,3%	0,4%	8,0%	10,2%
BM1	2,2%	42,7%	14,9%	0,4%	11,4%	28,4%
BM2	3,5%	38,8%	13,9%	4,2%	21,2%	18,3%
BM3	1,5%	43,4%	26,3%	1,3%	11,7%	15,7%
BS1	0,0%	26,8%	30,1%	5,0%	22,6%	15,5%
BS2	7,6%	30,5%	25,4%	7,2%	18,4%	10,8%
BS3	5,8%	41,0%	21,4%	6,2%	16,3%	9,4%
MAX	15,0	45,8%	30,1%	7,7%	27,2%	28,4%
AVG	5,5%	38,6%	20,8%	3,8%	16,1%	15,2%
MIN	0,0%	26,8%	13,8%	0,4%	8,0%	6,9%
StdDev	4,4%	6,3%	5,6%	2,5%	5,4%	6,3%
StdDev/Av	**79,7%**	16,4%	27,1%	**65,1%**	33,7%	**41,3%**

Table2: Distribution of contradictions among the BMs

Technology profile	Performance vs. Performance	Harmful functions vs. Harmful functions	Resources vs. Resources
Emerging	41,6%	17,9%	40,5%
Growing	14,8%	16,7%	68,5%
Declining	8,4%	17,6%	74,0%

Table 3: Average percentage of contradictions for BMs associated to the same stage of evolution

More detailed information can be extracted by analyzing the 78 sub-classes of contradictions defined in section 4.4, even if it is worth to perform the analysis by taking into account a wider range of technologies, in order to have a suitable statistical sample.

6 SUMMARY

The present paper has introduced a systematic approach for correlating the stage of evolution of a technical system and the contradictions characterizing its behaviour, with the aim of building a reliable index for maturity assessment. The proposed approach has been applied to the tablets manufacturing technologies in the pharmaceutical sector.

The promising results obtained so far suggest to extend the analysis to a higher number of case studies in order to check if the identified correlations can be assumed as invariant with respect to the field of applications.

It is worth to mention that the maturity level of a specific BM measures the evolutionary stage of a technology with respect to its way to deliver a certain elementary function. Nevertheless, each technology must be evaluated by taking into account the overall process, thus the whole sequence of elementary functions characterizing its process. This means that a technology overall classified as mature, can involve elementary actions accomplished with specific solutions still capable of further evolution and vice versa, emerging technologies sometimes include obsolete sub-steps. The correlation analysis proposed in this paper allows highlighting these non-uniformities, which can be leveraged to foster the development of innovative solutions and the hybridization of alternative technologies.

ACKNOWLEDGMENTS

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LIST OF ACRONYMS

AF: Auxiliary Function

BM: Behavioral Model

CP: Control Parameter

EMS: Energy-Material-Signal

EP: Evaluation Parameter

FBS: Function-Behavior-Structure

LESE: Laws of Engineering System Evolution

MTS: Minimal Technical System

MUF: Main useful Function

NET: Network of Evolutionary Trends

TA: Technology Assessment

TS: Technical System

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An ontology for TRIZ

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Abstract

This paper discusses the usefulness of an ontology for TRIZ and is an attempt to provide its readers (researchers, industrialists, educators, students) with answers regarding elementary questions they may have concerning TRIZ groundings and potential uses. These answers have the main objective to clarify how they may locate their perceptions of TRIZ and more easily find a way to contribute to its corpuses' evolution. An additional section will discuss about a software implementation of these elements through a software prototype built using this ontology. On a longer scale, we are aiming at sharing this ontology with a broader spectrum of research units in various disciplines, debate on its relevance through experiments with industry and further develop it in a collaborative way. A discussion section will then highlight the assets, the limits and the perspectives of having a shared ontology for TRIZ future developments.

Keywords

TRIZ, Ontology, Software Development, Knowledge Representation

1 INTRODUCTION

Since it arrives in highly industrialized countries, TRIZ has both fascinated and discouraged its observers. Several reasons are behind this paradox and have encouraged few tempetuous researchers in design to spend many years in finding roots to this problematic. After a decade and a half to study TRIZ and Engineering Design Science findings, we highlighted several incomplete elements in the corpus constituted by the theory [1]. We also noted that most of these elements were tacitly present in experts mind but have never been decomposed in order to be easily understood and taught to newcomers in an efficient manner as noted in [2].

Our postulate is that a first and important way to understand how TRIZ can be useful to engineering Design science is to understand at which point it differs from classical engineering way of understanding design and on which basis a relevant use of TRIZ can be organized.

These observations were both considered from an industrial, academical and educational perspective and have helped us to build a coherent corpus of elements described through an ontology which currently serve several research programs and plays a crucial role in moving towards acceptance of Inventive Design concept. Our work is a contribution in the direction of the building and the acceptance of an ontology for TRIZ and proposes a framework aiming at being shared and discussed in various scientific communities.

2 WHAT ARE ONTOLOGIES?

In recent years the development of ontologies has been moving from the realm of Artificial-Intelligence laboratories to the desktops of domain experts. Ontologies have become common on the World-Wide Web. The ontologies on the Web range from large taxonomies categorizing Web, to categorizations of products for sale and their features. The WWW Consortium (W3C) has developed RDF - the Resource Description Framework [3], a language for encoding knowledge on Web pages to make it understandable to electronic agents searching for information. The Defence Advanced Research Projects Agency (DARPA), in conjunction with the W3C, has developed the DARPA Agent Mark-up Language (DAML) by extending RDF with more expressive constructs aimed at facilitating agent interaction on the Web [4]. Many disciplines now develop standardized ontologies that domain experts can use to share and annotate information in their fields. Medicine, for example, has produced large, standardized, structured vocabularies.

An ontology defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them.

Although there is a lack of unanimity in the exact definition of the term *ontology,* it is generally regarded as a formalized representation of the knowledge in a domain taken from a particular perspective or conceptualization. The main use of ontology is to share and communicate knowledge, both between people and between computer systems. A number of generic ontologies have been constructed, each having application across a number of domains, which enables the reuse of knowledge. In this way, a project need not start with a blank sheet of paper, but with a number of skeletal frameworks that can act as predefined structures for the knowledge being acquired. Ontologies also provide guidance to the knowledge engineer regarding the types of knowledge to be investigated [5].

This formal explicit description of concepts in a domain of discourse includes classes called **concepts**, properties of each concept describing various features and attributes of the concept or **slots** (sometimes called **roles** or **properties**), and restrictions on slots , called **facets** (sometimes called **role restrictions**). An ontology together with a set of individual **instances** of concepts constitutes a **knowledge base**. In reality, there is a fine line where the ontology ends and the knowledge base begins [6].

[7] identifies three layers of knowledge, corresponding to three different types of ontologies, based on their levels of generality, namely:

- Generic or foundational ontologies, which capture general, domain independent knowledge (e.g. space, time, etc).
- Domain ontologies, which capture the knowledge in a specific domain (such as automobile industry).
- Application ontologies, which capture the knowledge necessary for a specific application.

3 WHY USE ONTOLOGIES?

Knowledge acquisition during the problem formulation phase will lead to the creation of a shared model and, therefore, the model concepts must then be clearly defined. The knowledge acquisition process is carried out without a precise ordering, a parameter will appear perhaps initially without belonging to a contradiction, a contradiction will perhaps appear without mentioning its dependence to a problem, and so on….

It is necessary to clearly define the concepts implemented and the relations that they present, it consists in providing assistance to the detection of possible inconsistencies and eventual missing items. To clarify relations between TRIZ associated concepts is a need; the elaborated model must be sharable, targeting a semantic integration of all useful sources of information. These pieces of information might be extracted either from the speech of an expert (interviews, working sessions…) or captured in texts (patents, list of requirements, norms).

In general, some of the reasons why it is advisable to develop an ontology are:

- to share common understanding of the structure of information among people or software agents,
- to enable reuse of domain knowledge,
- to make domain assumptions explicit,
- to separate domain knowledge from the operational knowledge,
- to analyze domain knowledge.

4 ONTOLOGICAL FRAMEWORK OF OUR WORKS

Application of “foundational” ontologies as a basis for this development has appeared a judicious choice to us, so as to take profit of the justification and formal organization characteristics of this type of ontology.

Only some foundational ontologies have been developed at a satisfactory level in the literature, in particular, DOLCE (the Descriptive Ontology for Linguistic and Cognitive Engineering) [8], GFO (the General Formal Ontology) [9], OCHRE (the Object-Centered High-level Reference Ontology) [8], SUMO (the Suggested Upper Merged Ontology) [10] and BFO (the Basic Formal Ontology) [8].

As foundational ontologies are complex systems, two crucial elements have to be taken into account to choose the right one to work on: the ontology has to provide a rich set of conceptual distinctions regarding the domain application, and all the needed characteristics have to be clearly characterized. We have decided to work with DOLCE, because this ontology provides a certain number of high level concepts that are useful for our application. DOLCE makes a distinction among objects (such as substances) and events, and also provides definitions concerning objects characteristics, such as attributes, values, qualities.

The entire development of our ontology along with its formal characterization can be found at [11].

5 THE ONTOLOGY WE HAVE DEVELOPED

The ontology we present aims to be a domain ontology of TRIZ in specifying its base notions. Current literature review indicates that these base notions are unevenly perceived by TRIZ world. Nevertheless it is unavoidable for a theory to evolve, to ensure that experts have a common and precise understanding of those notions and that the complementary ones are coherent. This ontology will therefore evolve, once we will add new elements of knowledge that appear, more or less explicitly, in acknowledged published sources.

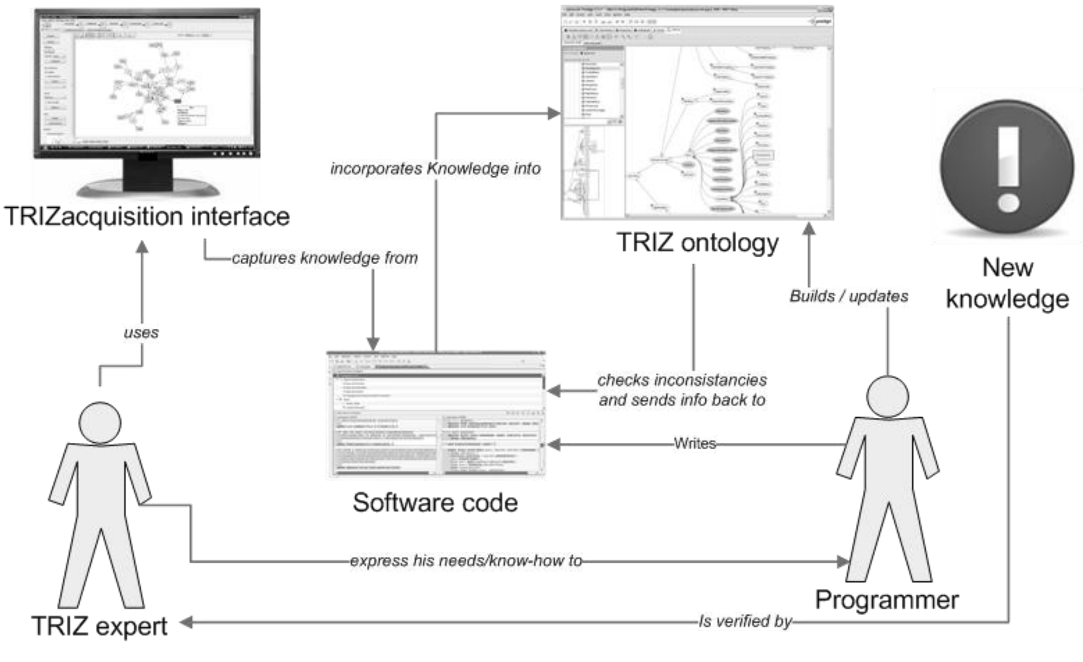


Figure 1: Graphical representation of interactors.

A Schematic illustration of the relation between our ontology and the software prototype is given figure 1.

Our ontology formalizes the main concepts of TRIZ for operating inventive design. Knowledge acquisition and problem formulation will then consist in populating this ontology. Ontology concepts are schematized as a set of objects, illustrated in “UML-like” diagrams [12]

The following notation will be used:

- Boxes represent concepts.
- Single links represent associations. Associations may be named and may include cardinality at the ends.

Bidirectional associations are represented by a single line while unidirectional associations are represented by a simple arrow.

- A clear diamond shaped arrow represents an aggregation, that is more specific that an association. It is an association that represents a part-whole relationship. As a type of association, an aggregation may be named and have a cardinality. Aggregation occurs when a concept is a container of other concepts. If the container is destroyed, its contents are not.
- A solid diamond shaped arrow represents a composition, a stronger variant of an association. It is a more specific part-whole relationship than an aggregation. In this case, if the container is destroyed, its contents are also destroyed.
- A hollow triangle shaped arrow indicates a generalization or is-a relationship. The arrow points to the super-concept.

With the goal of formalizing the theory's main concepts, we have compiled partially the vocabulary that is used by TRIZ experts. During knowledge acquisition, we have isolated the concepts, the predicates, the relationships and the class attributes; and have specified the meaning of every term that appears during the acquisition process.

Since TRIZ (observed from a classical viewpoint) was not featuring a complete and coherent set of concepts and relations, we completed this ontology both in reading available literature on further development of TRIZ like OTSM [13] and some existing publications on the subject.

An example of this ontology's role is the concept of Laws of engineering systems evolution. For many years, laws were used differently, sometimes forgotten or neglected. Not because people do not understand them or do not accept them, but just because it was unclear how to use them within a study case. This subject has already been discussed in [14]. As a result, the URL diagram (figure 1) of TRIZ ontology clearly shows that the reason was probably because nothing was linking them to other concepts. This situation was indeed a strong invitation to discuss about the creation of a new concept aiming at linking laws to the rest of the concepts.

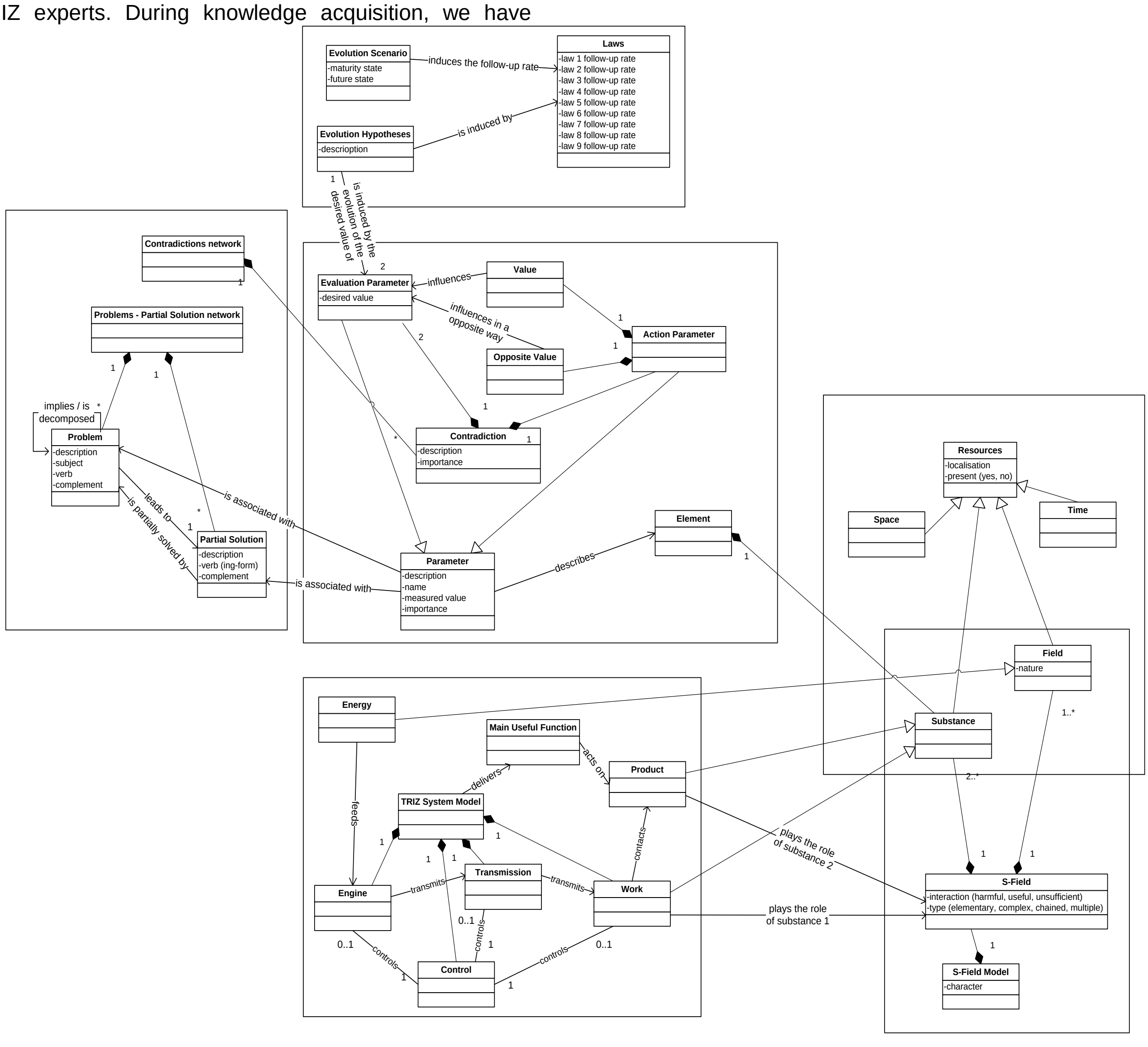


Figure 2: Domain ontology of TRIZ (UML representation).

6 A TRIZ RELATED SOFTWARE PROTOTYPE TO OPERATE AND USE THIS ONTOLOGY

As a logical implementation of this ontology, we have targeted the objective of framing TRIZ expert practices with the objective of being exhaustive and clear when using concepts. In that sense, it forced the process to follow a path which has some degree of freedom but also some obligation of completing and populating the ontology.

Our software prototype can be decomposed in the following form:

- Initial situation description (beyond classical TRIZ concepts).
- Contradiction disclosure (Within classical TRIZ concepts).
- Solution concept generation (Within Classical TRIZ Concepts).
- Decisions for R&D activities (beyond classical TRIZ concepts).

The navigation system follows the main steps of TRIZ and beyond; from Initial Situation analysis to Solution concepts evaluation.

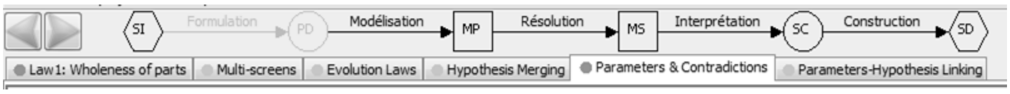


Figure 3: TRIZ acquisition navigation system – first level and formulation sub-level.

A screenshot of the software interface between the TRIZ expert and program is represented figure 4. The main idea of such interface is both to compile experts gathered data, but also to check their coherence and perform some functionalities useful for TRIZ study.

As an example, in the contradiction extraction step, we need to be respectful to the links between system's parameters. Parameters qualify elements while allocating them a specificity which, associated to elements, represent an explicit knowledge of the field observed. The forms of their expression are multiple; they are mainly names, complements of objects or adverbs and. They are divided in two categories:

- Action Parameters (AP): they represent parameters on which the designer has a capacity of state modifications (the designer can make a design choice, an anvil of large volume or a small one, in this case volume = AP).
- Evaluation Parameters (EP): Their nature lies in the capacity to evaluate the positive aspect resulting from a choice of the designer. The consequence to design an anvil with an important mass is that an ease of insertion is a logical consequence; (in this case Ease of driving = EP).

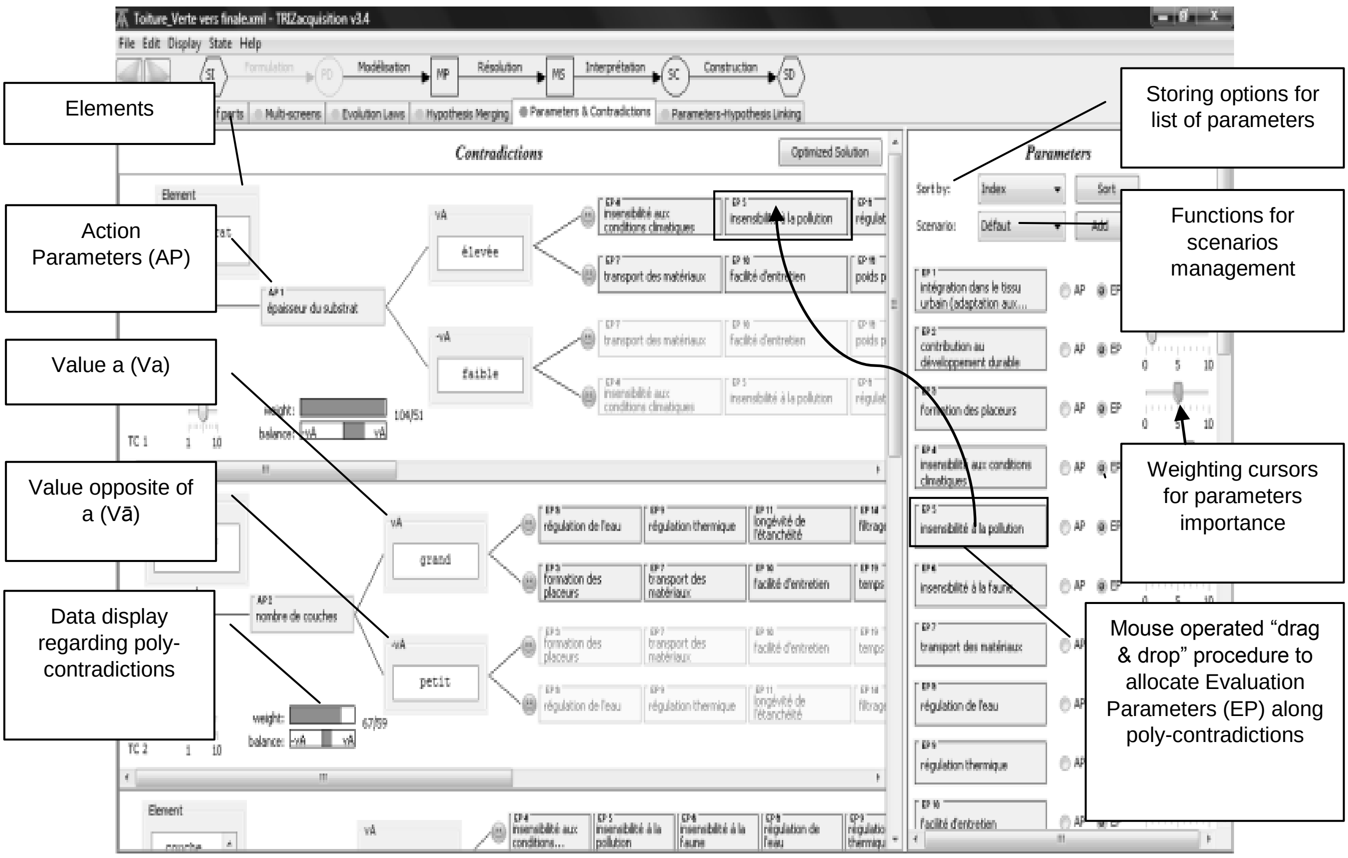
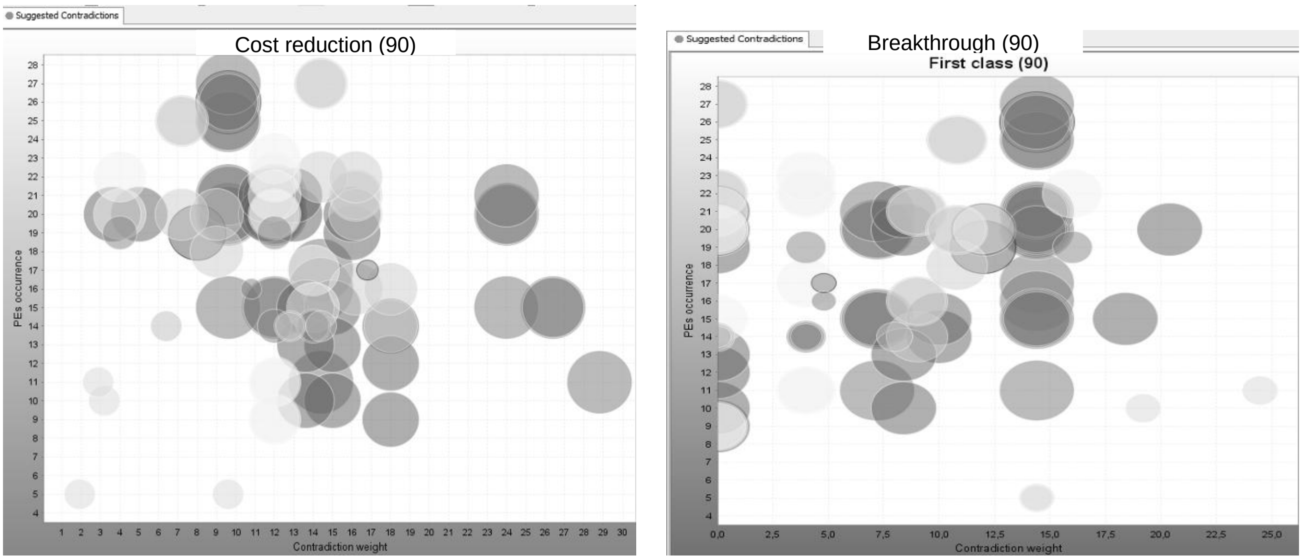


Figure 4: User interface of the poly-contradiction scenarios construction and weighting screen.



5a 5b

Figure 5: Weighted set of Contradictions based on cost reduction (a) and breakthrough (b) scenario.

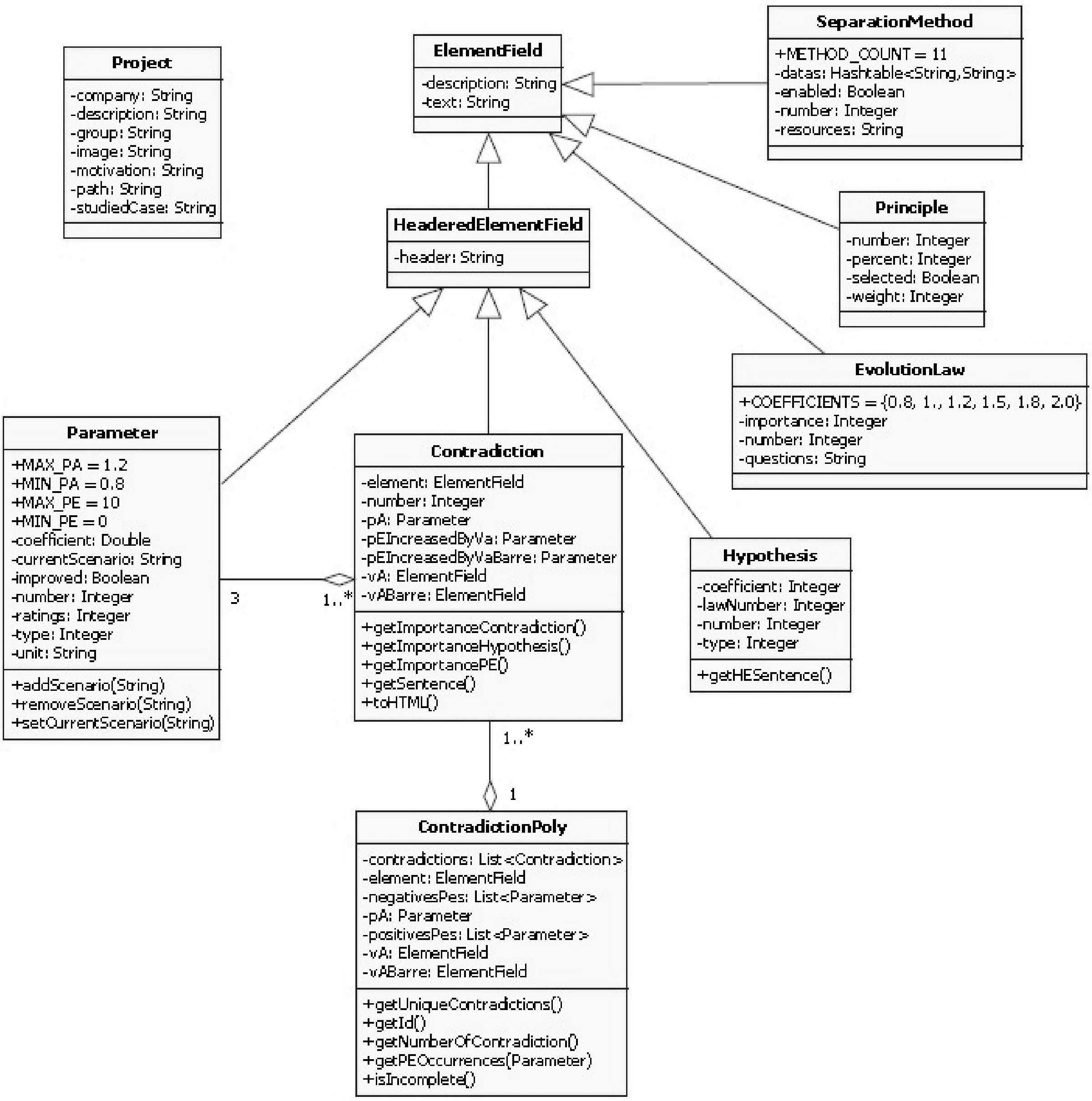


Figure 6: Concepts to be instantiated both in the code and in the ontology – formulation sub-level.

If we want to avoid any wrong construction of a contradiction, while the ontology is made, it will also check the coherence of the contradiction performed by the user and either accept the construction or refuse it. Rules for building relationships between EP and AP (and many other rules) are stored in the ontology.

Another example is related to a new notion we have observed during case studies and absent from classical TRIZ: the notion of viewpoints. The question is the following: "how to capture the fact that each value associated with the importance of an EP and an AP is tightly linked with the adopted viewpoint of the observers?"

An answer we provide to this question is the building of several ranking scenarios depending on the viewpoint the study team wants to adopt using tables. In coherence with the company's strategy, the study team might want to investigate both scenarios of cost reduction or breakthrough strategy in parallel. Of course we assume that depending on the strategy the company wants to adopt, the ranking of EP and AP will vary and provoke a different layout of contradictions to be solved in the rest of the studyIn the figures 5a & 5b, the layout of contradictions presented as a cloud, further details regarding this representation can be found in [15].

As case study data are discussed through the relation between domain experts and TRIZ expert, they are compiled in the ontology through the software interface.

The ontology is instantiated by the expert inputs through an established relationship between software code and protégé ontology model. To clarify the concepts attributes in detail, we compiled the elements using UML diagrams and we iterate them as new elements of knowledge appear out of our research findings. In figure 6, the example of UML is limited to the screenshot figure 4: problem formulation and contradiction synthesis sub-level.

7 DISCUSSIONS

Several analyses of our software prototype in operation have been conducted through case studies. They lead us to the following items of discussions:

An incomplete model tacitly creates confusion in engineers mind. As engineers are sometime intuitively acting when designing in projects, the fact that TRIZ way of conducting design differs from classical design, disturb the progress of the study. While engineers are expecting the model we build to be respectful to the model they have in mind, we face with a lot of questions as the TRIZ model seemed to be incomplete for them. The most predominant questions were oriented towards clarifying why customers needs were absent from the model. This is mostly due to lack of understanding of TRIZ thinking, which is law of evolution oriented. At this point, our ontology model allows us to highlight that customer's needs were present within evaluating parameters.

On the contrary, expressed completeness of the ontology positivizes people's attitude and confidence. We have observed that it was not traditional in their way of designing to automate the evaluation of solution concepts impact of the expressed problematic. This stage was mostly intuitive and based upon grid of evaluation (level of satisfaction to fulfilling criteria). Due to the completeness of our model, the feedback of the impact is thoroughly built all along the study and when solution concepts appear (based on contradiction's resolving) their impact of problem graph is rapidly made and displayed to the study group.

Sharing and co-working on a given ontology is essential for a domain to progress. If we assume that an ontology is an unavoidable step in the building of a theory it is even more crucial for the communication and understanding around its groundings. The findings are multiple, from easy building of a teaching curriculum to automating tasks in the process but moreover new research openings and findings for its evolution.

As an opening to other research communities and to assume what has been described through this paper, we have made available our ontology through web-protégé framework and hope to start a discussion around the concepts, their interrelations and that the result of such collaboration will be useful for all.

The software prototype we built (TRIZacquisition) is now in its third generation and has also opened its internal procedures to elements beyond the scope of classical TRIZ. We have implemented the notion of Problem Graph as a mean to build a multidisciplinary problematic model and tested the coherence of these new elements with the current TRIZ based ontology.

7 SUMMARY

As we clarify TRIZ major concepts and their interrelations, we observe a reduction of complains from its observers or newcomers relatively to its complexity. Indeed, if TRIZ remains mastered intuitively by a reduced amount of highly skilled experts, it will always appear fuzzy to outsiders or newcomers and complex to learn. What we are targeting through this article is to contribute to TRIZ progresses in using standard procedures in science: the building of an ontology.

Experiences of reduction of TRIZ's complexity through SIT, ASIT & others are valuable in certain sub-activity of classical design like "creative or ideation stage", but cannot support the complete driving of a design activity. Therefore, we shall distinguish reoriented uses of TRIZ for creative stage enhancement from exhaustive use of TRIZ for supporting inventive design practices. This ontology is not for SIT - derivate methods and tools but will certainly be helpful for positioning TRIZ and SIT as this question is recurrent in TRIZ societies.

In the coming future, what is known as TRIZ will certainly be less visible as tools for its implementation will represent its concepts on reliable basis. It will remain a theoretical grounding for methods and tool's construction, as any theory is logically proposing. This is nevertheless not avoiding industry to organize inventive practices from an organizational perspective: organizing innovation in the corporate structure. But again, since clearly defined, accepted and shared ontology will give a reliable rise of efficient computer supports, these tools will certainly assist the successful implementation and the soaring, not of TRIZ itself, but of its forthcoming derivate methods and tools.

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Innovative Design in Tensegrity Field

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Abstract
In nature, many systems function similarly to tensegrities, at all scale levels. The paper presents some applications of the method of creativity treated in [4], having the intention to reduce the types of structures of mechanical tensegrities to a finite number of models; so that we can simplify the design, in the same time maintaining a great variety of functions. The other purpose of this study is to obtain new tensegrity mechanisms that have the same structure and function in a similar way to natural systems.

Keywords
Innovative design, Tensegrity

1 INTRODUCTION

A tensegrity system is a prestressed (internal stress prior to application of external force) stable closed structural system, realised by compression struts within a network of tensile elements.

Initially, Snelson named this kind of structure "Floating Compression", but later Fuller changed its name into "tensegrity" which represents a contraction of the words "tension" and "integrity" [12, 27].

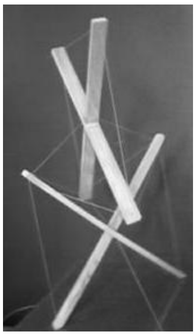


Figure 1: Snelson's "X" piece.

Tensegrities are structures (Fig. 2) or mobile systems (Fig. 3) depending on whether the flexible elements are cables or elastic elements respectively.

Figure 2: Tensegrity system built with cables, subjected to a perturbation; it doesn't change its shape.

Figure 3: Tensegrity system built with elastic elements, subjected to a force; it modifies its shape.

Tensegrity is the optimum way to organise mechanical systems' structure and use the energy and material, in order to obtain specific functions, as it is also the case in living forms.

There are many kinds of tensegrity models and different types of them have been designed using different methods, but so far there are no direct mathematical methods to determine the geometrical configuration of an arbitrary stable spatial tensegrity system.

More information about tensegrities can be found in specific literature such as [1, 12, 18, 27].

We intend to obtain new tensegrity models and reduce the diversity of the structures of tensegrities to a finite number of models in order to simplify the design but maintaining a great variety of functions. For this reasons we shall especially utilise the analogy between biological and tensegrity systems and also the TRIZ method.

2 THE STRATEGY [4]

The method of creativity is treated in detail in [4] and is based on a scheme similar to the one presented in [19].

Analogy is one of the powerful tools utilised in the process of creativity in bionics.

Both visual images and mathematical and causal relations play a very important role in the earlier phases of creativity.

3 FOR THAT REASON, FIRST OF ALL, WE IDENTIFY IN LIVING FORMS THE SYSTEMS AND SUBSYSTEMS THAT FUNCTION LIKE TENSEGRITIES AND ARGUE THE SIMILARITIES BETWEEN THEM.

The scheme of the initial source (the scheme-source) is realised by discarding irrelevant relations.

After the process of retrieval and elaboration of an analogical model (the enhanced source) follows the mapping and transfer between the enhanced source and the probable target. If the probable target does not agree with the wished target, the contradictions will be eliminated with the TRIZ method.

3.1 Tensegrity systems recognised in living forms

Scientists came to the conclusion that tensegrities are recognised in living forms, and this theory can be applied to modelling organic matter, at micro and macro levels [2-8, 11, 13-17, 20-22].

We especially analyse the observations of researchers in protein chemistry [29] and present some personal ones which sustain the introduction of tensegrity in this domain [8].

Each protein fold consists of a folded chain of between 80 and 200 amino acids**.** Some proteins are composed of a single fold, but many others are a combination of several folds.

Analysing the protein structure several levels of structural complexity are noted, this indicating the existence of four distinct structures [29].

The linear sequence of amino acids represents the primary structure of a protein. The peptide groups have higher order structures.

The local spatial arrangement of a polypeptide's backbone atoms represents the secondary structure.

The folding of the secondary structural elements of a protein (the three-dimensional structure of an entire polypeptide) represents the tertiary structure. This protein structure can be observed through X-ray crystallographic and nuclear magnetic resonance (NMR).

A large number of proteins are composed of subunits. The spatial arrangement of these subunits represents the protein's quaternary structure.

The α helix and the β sheet regular secondary structures are widespread. The α polypeptide helix, discovered by Linus Pauling in 1951, is right-handed, with its core tightly packed, so that its atoms are in van der Waals contact. In an α helix the hydrogen bonding occurs within one chain. In 1951 Pauling and Corey discovered the β sheet where the hydrogen bonding occurs between neighbouring polypeptide chains; there are two variants of β sheets: the antiparallel β sheet and the parallel β sheet.

β sheets in proteins contain more than 2 strands (an average of 6 strands) and present a right-handed twist.

Also proteins have been classified as fibrous or globular. The three well-known fibrous proteins are: keratins, silk fibroins and collagens.

Keratins could be α keratins or β keratins. Two keratin polypeptides form a dimer.

Certain groups, called motifs, occur in many globular proteins: $\beta\ \alpha\ \beta$ motifs, β hairpin motifs, $\alpha\ \alpha$ motifs, and β barrels. Polypeptide chains with more than 200 residues usually fold into more than two globular clusters named domains.

The conformation of the protein fold is stable; it can moves but is able to reach a state with minimum energy.

In 1957 Christian Anfinsen demonstrated through experimental ways that proteins can be denatured reversibly. He also demonstrated that proteins can fold spontaneously into their native three-dimensional structures which are dictated by the protein's primary form [29].

The previous observations support the introduction of the tensegrity concepts into the modelling of proteins.

3.2 **Applications**

Using bionics and the TRIZ method we try to realise some applications in the engineering field.

To reduce the types of structures of tensegrities to a finite number of models, we utilise the analogy with proteins and the inventive principles indicated by the Contradiction Matrix.

We present some observations that sustain this idea [29]. In nature, different symmetries can be observed at macro, micro and nanoscale levels. For example, approximately 7000 protein structures are known, which exhibit a remarkable degree of structural regularity, making it possible to be grouped into a finite number (a few hundred) of distinct structural families. Moreover, Denton sustained the hypothesis that they are made of Platonic forms [9, 10].

Cyrus Levinthal demonstrated that the forming process of the protein fold to its native conformation is not possible through the protein's random exploration of all the conformations available for this process until the stable correct one is obtained. He demonstrated that for a small protein of 100 residues the time required for the protein to explore all the conformations available to it is $t=10^{87}$s which is not possible; many proteins fold to their native conformations in less than a few seconds. Proteins fold to their native conformation via directed pathways so that the free energy decreases [29].

Scientists experimentally observed that protein folding is a hierarchical process which begins with the formation of the elements of the secondary structure (α helices and β sheets) and then the whole secondary structure forms and stabilises; next the tertiary structure forms and sometimes the quaternary structure is developed.

Martin Karplus realised some calculus and his conclusion is that a protein's native structure probably consists of a lot of conformations with equal stabilities, which rapidly interconvert [29].

On the other hand, we exemplify the strategy of creativity for three kinds of living systems: the dimer, the collagen triple helix and the Cowpea Chlorotic Mottle Virus hexamer.

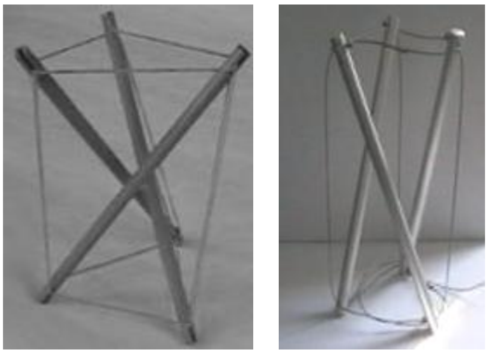
The polypeptide α helix is *right-handed* but two α keratin polypeptides, each of them being an α helix, form a *left-handed* coil by twisting around each other (the dimer) [29].

Unlike the dimer, the collagen triple helix has three l*eft-handed* polypeptide helices, twisted together to form a *right-handed* superhelical structure. The triple helix structure of collagen is rigid, well-packed, because the polypeptide chains are twisted together in the opposite direction to the conformation of the polypeptide chains, similarly to dimers [29].

We put ourselves the question [8] whether we can create by analogy a tensegrity system that is able to diminish its rotation around the proper axis, like the dimer (α keratin) and the collagen triple helix, and which has cylindrical shape and the same structure like the Cowpea Chlorotic Mottle Virus hexamer (containing six bars, parallel two by two) [30]. These constitute the visual images and the relations that create the initial source (the scheme-source), without considering other irrelevant relations to our purpose.

For the first aim the reducing of the tensegrity structures to a finite number of models, the TRIZ method will be utilised in order to eliminate the contradiction: improving the function of the systems ('*adaptability or versatility*' (35)), concomitantly with the worsening of the characteristic '*device complexity*' (*36*); but we want to use the simplest possible structures and design of the structures. The contradiction which must be eliminated in this case is 35/36. We utilise the inventive principles recommended by the Contradiction Matrix [28]: 15 (dynamics), 29 (pneumatics and hydraulics), 37 (thermal expansion), 28 (mechanical substitution), to eliminate the contradiction 35/36, which appears in this case. We present a new method [5] where tensegrity systems are obtained by modifying Plato's primary bodies which have triangles per faces [26], with the help of flexible elements of adjustable lengths by means of gas, liquid or thermal expansion.

Further, a triangular tensegrity prism (T3 prism), composed of three bars and nine cables (Fig. 4) [1], will be obtained from a tetrahedron model [5].



a) b)

Figure 4: T3 prisms; a) right-handed; b) left-handed.

Fig. 5 depicts the tetrahedron with triangles per faces such as in [5]. This system has three bars which do not touch one another: DE, BF, CA and the other segments are cables: AE, EB, CB, CE, CF, FD, AD and AF.

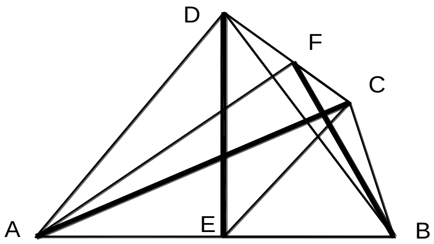


Figure 5: Regular tetrahedron.

Modifying the lengths of the cables, according to the inventive principles 29, 37 or 28, we can transform the regular tetrahedron into a T3 prism. Each base is a scalene triangle, EBC and ADF respectively, both formed of cables (Fig. 6).

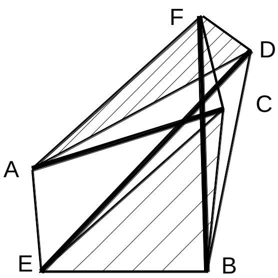


Figure 6: T3 prism.

Diminishing the length of the cables EB and DF and adjusting the length of the cables AE and FC we obtain a tensegrity structure which resembles the letter X [5].

With this "X" tensegrity system we can model the human forearm, and its movements; so, if we realise torsion of the model, it modifies its shape and when this action ceases, the tensegrity comes back to its stable configuration, like the human forearm [5, 7].

In conclusion, two types of tensegrity systems can be obtained from a single one.

Also by analogy and using the inventive principle 29 (pneumatic and hydraulic) we can model the movement of the T3 prism with the help of parallel mechanisms composed only of rigid links (Figs. 7, 8, 9) and by acting on their driving joints [8].

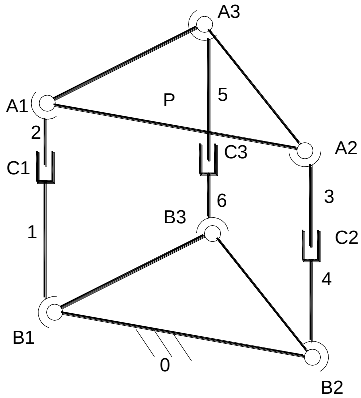


Figure 7: Parallel mechanism.

Figure 8: Parallel mechanisms.

Figure 9: Parallel mechanism.

Using two T3 prisms, one *right-handed* and the other *left-handed*, on two layers, we can obtain another known model, the tensegrity icosahedron (Fig. 10), which scientists have successfully utilised to simulate the behaviour of systems at micro [13-15] and macro [16,17] levels.

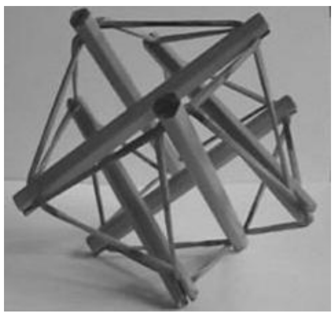


Figure 10: Tensegrity icosahedron.

We used the same model, the T3 prism, to compose new systems which reproduce the movement of different systems of living creatures, like dimers or Cowpea Chlorotic Mottle Virus hexamers [8].

For this purpose, not only visual analogy, but also the relation between the polypeptide chains (which are twisted together in the opposite direction to the conformation of the polypeptide chains) and the inventive principles dynamics and "Nested doll" help us to create a new tensegrity system (Fig. 11) [8].

We utilise two T3 prisms, one *left-handed* and the other *right-handed* (T3l, T3r prisms), one inside the other, but we unify them into one single tensegrity system, on a single layer (Fig. 11).

Figure 11: T3l, T3r prisms [8].

The system functions similarly to a dimer and to a collagen triple helix: it can not rotate around its axis, because one T3 prism is *left-handed* and the other is *right-handed*. But this system can be flattened very easily (Fig. 12) into three planes, each of them initially containing two parallel bars.

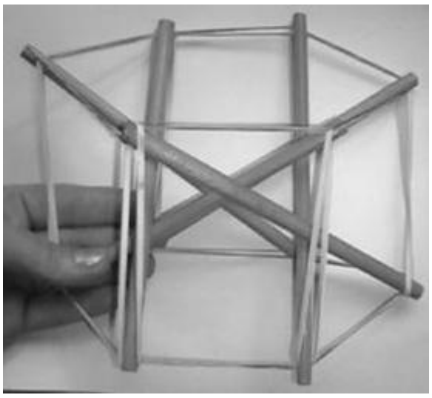


Figure 12: The new flattened model.

The other question is whether this new system can be created from two T3 prisms, using one of the inventive principles presented by the TRIZ theory. For example, by using the principle 15 (dynamics), we can divide the tensegrity icosahedron into two parts, two T3 prisms capable of translation movement relative to each other. We obtain one left-handed T3-prism inside another right-handed T3 prism (or vice-versa), at the same time demonstrating the principle 7, "Nested doll".

4 SUMMARY

In the last years tensegrity systems have been used to model living forms, to simulate and design locomotor robots [23, 24, 25] and most probably their importance will increase, because tensegrities present numerous advantages and behave in a very similar manner to biological systems with capability for movement.

Our contribution refers to:

- some personal observations, based on innovative design, that sustain the modelling of living forms' structures by tensegrities;
- we propose to reduce the tensegrity structures to a finite number of models;
- we utilise inventive principles indicated by the Contradiction Matrix to act on the driving joints;
- we create a new tensegrity model, especially using the analogy between proteins and tensegrities, which functions similarly to a dimer and to a collagen triple helix, and we also propose it to model the Cowpea Chlorotic Mottle Virus hexamer.

We conclude that it is important to pay attention to the introduction of innovative design into the tensegrity field.

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A Functional Analysis Approach for Product Reengineering

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Abstract

Product reengineering is a very common practice in industry to improve and optimize product properties for new and individualized customer requirements and to meet internal requirements for less design and production costs. Products are thereby reengineered by applying new technologies and redesigning a number of product parts. The functional analysis applied by product reengineering is less abstract than by New Product Development and thus problems and weak points in a product structure can be easier identified. Disadvantage thereby is that the solution space for problem solving can be tremendously constrained through the detailed problem statements. In order to avoid this effect and to enhance innovative problem solving by product reengineering we introduce a functional analysis approach for problem modelling of existing product structures. We define a number of hierarchical levels for a product function structure in order to enable problem modelling on different abstraction levels. Thereby a large number of technologies and solution principles are included in the solution space. We use a pneumatic valve for rail systems as a case study in order to demonstrate the functional analysis and the problem modelling on different abstraction levels. Furthermore we clearly define terms such as technology, constructive layout, requirements, product properties and functions as well as their relations to each other, in order to enhance the use of this approach in the industry.

Keywords

Functional Analysis, Functional Modelling, Product Reengineering, Problem Modelling, Hierarchical Levels

1 INTRODUCTION

By problem solving during product reengineering and optimization most of the engineers focus on an identified problem core. In this way possible solutions can be overlooked that would appear if the problem statements were derived from a higher functional abstraction level.

In order to identify problems or weak points in a product, functional analysis and graphical functional models are widely used in the context of TRIZ as problem definition tools. A very common function modelling method is the relational function model, as it was introduced by Pahl and Beitz [1], and which contain both useful and harmful functions. The setting up of a relational function model is a basic part of the problem formulation process in TRIZ, as it is used to derive problem statements [2]. Another widely applied function modelling method that was also introduced by Pahl and Beitz [1], is the hierarchical function model, which orders product functions in different hierarchical and abstraction levels.

After applying the relational functional analysis method to a large range of existing technical products, it became apparent that all relational function models feature a hierarchical structure of their functions. This hierarchical structure cannot be identified when viewing the models. Moreover, it is not possible to define the boundaries of the hierarchical levels in a consistent way.

In this paper we suggest a new functional analysis methodology, which integrates the hierarchical levels of the hierarchical function model to the relational function model. Through considering both the hierarchical and the relational view of a product's structure more entry points to the problem solution can be identified as well as the derived problem statements can be hierarchically classified. The problem statements are set up using the standard problem formulator used by TRIZ [2]. These are suggestions for new entry points to problem solving procedure provided by the problem formulator. Furthermore, because in this way the relations between the problem statements become obvious, one can choose between solving one hierarchically higher problem or several rudimental problems.

This approach supports lateral thinking, as introduced by de Bono [3], as it emphasizes at the identification of different possible solutions and not at the identification of the most obvious problem solution. It generates not just an amount of problem statements but a chain of problem statements, which can be of great support by product reengineering.

2 OUTLINE AND STRUCTURE OF THIS PAPER

In order to outline this contribution we use the inventive approach introduced by Terninko [2]. Figure 1 shows the outline of this research's purpose according to Terninko's [2] four basic steps for inventive problem solving.

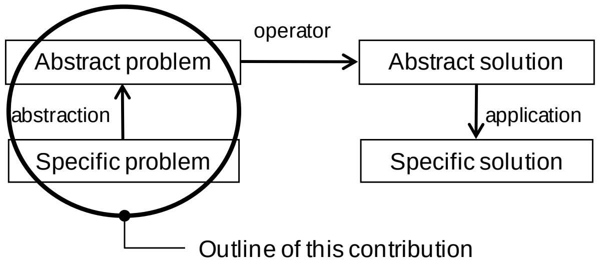

Figure 1: Scope of this research according to Terninko's [2] approach.

Similar approaches can also be found in the works of Orloff [4] and Marconi [5]. Whereby, Orloff does not entitle these four steps as Terninko but describes the problem solving process as a process containing four basic steps, which are Diagnostic, Reduction, Transformation and Verification.

During the first step of the approach – specific problem or diagnostic – a functional analysis of the examined artefact has to be carried out and a function model has to be set up. Using this function model as input for the next process step, abstract problem statements are formulated in order to identify entry points to problem solution. As in the previous section described, this paper introduces a methodology for the problem specification and for the structuring of the solution space derived by the function models.

In the following chapter 3 we outline and clearly define the terms used in the context of this research. In chapter 4 we introduce the functional analysis of this approach using a pneumatic valve as a case study. According to this case study we demonstrate in chapter 5 the resulted problem statements and the benefits of this approach.

3 DEFINITIONS

In this section we define and outline terms that are often used in product development; that is requirement, function, constructive layout and technology. Our effort is to facilitate and to systematize the determination of abstraction levels in a functional model and to avoid obscurities when distinguishing e.g. between constructive layout and technology.

Lindemann [6] defines requirement as a design objective, which has to be achieved and as prerequisite, which has to be fulfilled. Requirements can be derived from design constraints, customer requests and boundary conditions such as specification of the maximum allowable weight, which determine the values of the design technical characteristics. In the context of this contribution the source of the requirements will not be further examined.

In order to meet the defined requirements, functions have to be set that satisfy them. As Ehrlenspiel [7] points out, a function is the solution independent description of a system activity. Furthermore, Pahl and Beitz [1] define function as the relation between input and output of a system with the goal to complete an activity or task and thus a function can be used in order to describe a system’s activity on an abstract and solution independent level.

Nevertheless, in the next section it will become apparent that not all the functions of a product feature the same solution independency. The extent of the solution independency of a function depends on which hierarchical level the function is arranged. Accordingly, the extent of the solution independency of a function constitutes an accurate criterion in order to define hierarchical levels in a function model.

By constructive layout we mean the form and the design solution that has been chosen in order to realize a function. A constructive layout mostly consists of a set of interacting physical components that are composed in an adequate manner. In order to compose the components adequately and to assure their interactions technology know-how is required. Thus technologies determine the kind of the components composition and beyond that the functional feasibility of the constructive layout.

The figure below outlines the relations between these terms. Beginning from the defined product requirements functions are set in order to fulfil the requirements. As pointed out, these functions are abstract solution definitions but do not give any technical and technological information about how to realize a solution. They are used in order to structure and subdivide the problem in smaller and easier to solve sub-problems. Furthermore, they feature a hierarchical structure and can be analyzed and broken down to elemental functions. These elemental functions can then be linked to physical components that realize them. The components’ composition and interactions are defined in constructive layouts, which in turn require technology know-how in order to be carried into effect.

In figure 2 the defined requirement is that a leak between the valve piston and piston guidance has to be prevented. In order to satisfy this requirement the function “seal guidance” is set, which is realized by a “sealing ring”. The constructive layout specifies further the solution through the definition of the “sealing ring” and the components that interact with the “sealing ring”. In order to implement this solution and to assure the required component interactions, technology know-how is needed about the ring material, the tribological behaviour of this material with the guidance material and beyond that know-how is required about surface treatments in order to achieve the required tribological conditions between ring and guidance material [8].

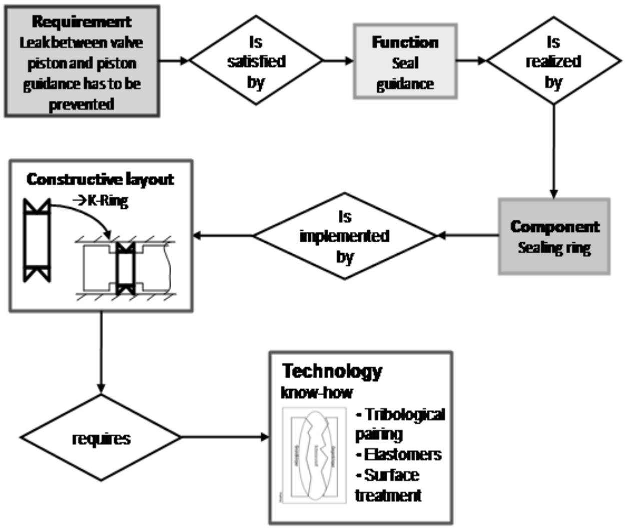

Figure 2: Schematical presentation of the terms relations.

4 FUNCTIONAL MODELLING

This section presents the functional modelling methodology for the problem formulation process using a pneumatic valve as a case study. Components of the introduced methodology are the hierarchical and the relational function model. The relational function model, which is mainly used by the TRIZ methodology, contains useful and harmful functions of a system. The functions are – as described in the previous chapter – abstract solution descriptions. The more abstract the functions are the merrier abstract are the derived problem statements and the merrier are the entry points that are included in the solution space. By product reengineering the constructed function models become detailed because of the known implemented solutions. Thus, the derived problem statements are less abstract as well, which constrains the solution space and prevents innovative solutions. In order to avoid this effect and structure the solution space we integrated hierarchical levels to the relational function model. The hierarchical levels and their boundaries were defined by applying the hierarchical function model. In figure 3 is the introduced approach shown. The derived problem statements are arranged hierarchically as well and the relations between them are made apparent. By this means, is the solution space structured in abstraction levels and an engineer can decide between solving a hierarchically higher problem or several elementary problems according to his available resources.

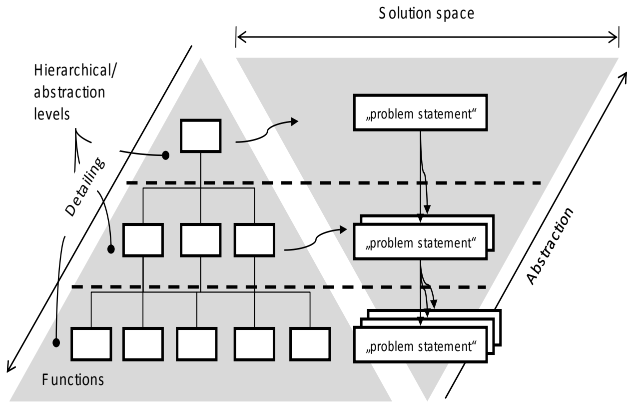

Figure 3: Schematical view of the introduced approach.

4.1 Hierarchical modelling

The hierarchical function model – as it was introduced by Pahl and Beitz [1] – is used in the context of this research in order to set hierarchical levels and to define their boundaries. The hierarchical function model of a technical product constitutes a hierarchical breakdown of the main product function. The main function is broken down to less abstract and thus elemental functions, which contain more information about how to achieve the product functionality and are required in order to realize the main function. The product functions are thereby arranged hierarchically according to their level of abstraction.

In order to define hierarchical or abstraction levels and their boundaries within a product function hierarchy an adequate criterion is needed. Prerequisite is that all product function must be able to be classified according to this criterion. As the functions give more information about a solution as we move downwards in the function model it becomes apparent that the information extent about a solution is an adequate criterion to classify functions. Thereby, we need to distinguish between two kinds of information. Information about the technical solution and thus the constructive layout and information about the applied technology. In chapter 3 we defined that technology know-how is required in order to implement a constructive layout. Furthermore, a technical solution can be implemented using different technologies according to the available know-how. Thus, functions containing technology information are more elemental and are arranged lower in the function hierarchy than functions containing information about the constructive layout. In example, the defined housing of a pneumatic valve can be produced by casting or alternatively by milling. Thereby, the definition of the housing form is the constructive layout and casting and milling are regarded as technologies.

According to the two kinds of information that can be contained in a function, we defined three hierarchy levels in a product function structure.

- Solution independent functions
- Solution dependent functions and
- Technology and solution dependent functions.

Figure 4 shows a segment of a hierarchical function model of a pressure reducing valve. Thereby, it is obvious that solution independent and dependent functions don't give any technology information, as it was defined in the previous sections.

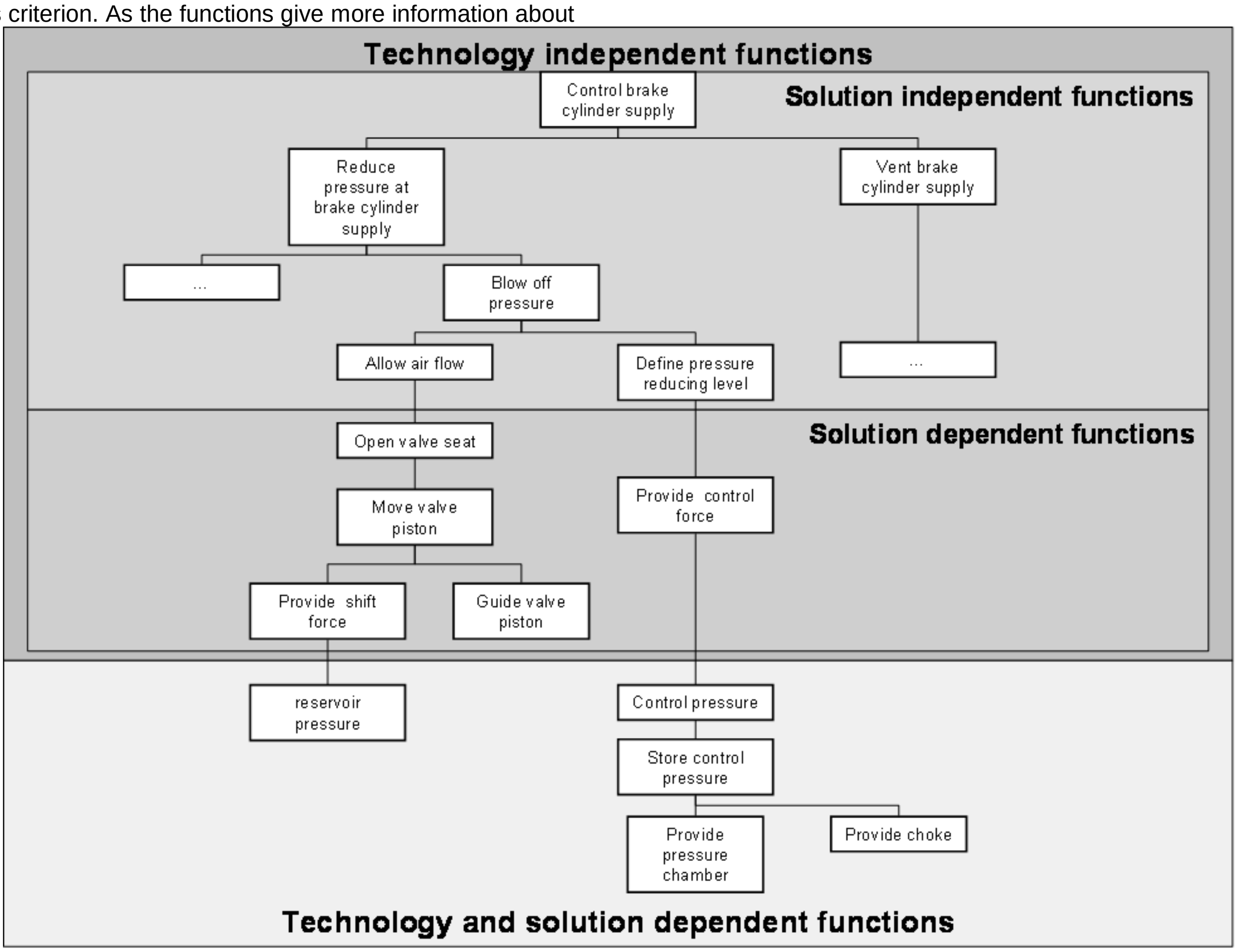

Figure 4: Hierarchical function structure of a pressure reducing valve.

The main function of a pressure reducing valve is defined by the application situation of the valve. Thereby, the main function is (control brake cylinder supply pressure). In order to control the supply pressure the valve has to be able on the one hand to (reduce pressure at brake cylinder supply) and on the other hand to (vent brake cylinder supply) with pressurized air. These functions can be further broken down to less abstract and more detailed functions. In example, in order to (reduce pressure at brake cylinder supply) the valve has to be able to (blow off pressure) from the supply reservoir and thus to (allow air flow). Furthermore, the function (define pressure reducing level) has to be realized for a controlled brake cylinder supply pressure. In the context of this publication only the branch of (blow off pressure) will be further elaborated on. The functions described above contain no information about any technical solution and how they could be realized. In general, these functions match exactly the definitions of Ehrlenspiel [7] and Pahl and Beitz [1].

The further breakdown of these functions derives functions, which are less abstract and contain technical information, such as (open valve seat) by (moving valve piston) and (provide control force) to (define pressure reducing level). The technical information thereby is e.g. the existence of a valve piston and not of a valve head. Nevertheless, no information is contained about how the valve piston movement is realized, which is a technological issue. Thus, these functions are defined as technology independent and solution dependent functions.

The functions (reservoir pressure) and (control pressure) refer to the question, how the functionality of the defined constructive layout can be assured. Besides from providing pressurized air in order to realize the needed movements, compression springs could be used. Thereby, the employment of springs instead of pressurized air requires the availability of totally different technology know-how and thus functions such as (provide spring force), (reservoir pressure) and (control pressure) are considered as technology and solution dependent functions.

It is important to notice that the issues considered to be technological, which practically define the boundary between technology independent and technology dependent functions, are company and industrial sector specific and therefore have to be adjusted according to the application situation.

4.2 Relational modelling

The relational function model consists of two types of functions, useful and harmful ones. Furthermore, as shown in figure 5, the relational function model distinguishes between the kinds of functions relations. The syntax as well as the kinds of relations are shown in figure 5 [2]. The relations can be used to state whether a useful function is needed to enable another one, a useful function has been introduced to avoid a harmful function or whether a useful or harmful function causes another harmful function. In contrast to the hierarchical function model, the relational function model allows also the cross linking of functions, which are arranged in the same hierarchical level and thus allows a more accurate modelling of the reality.

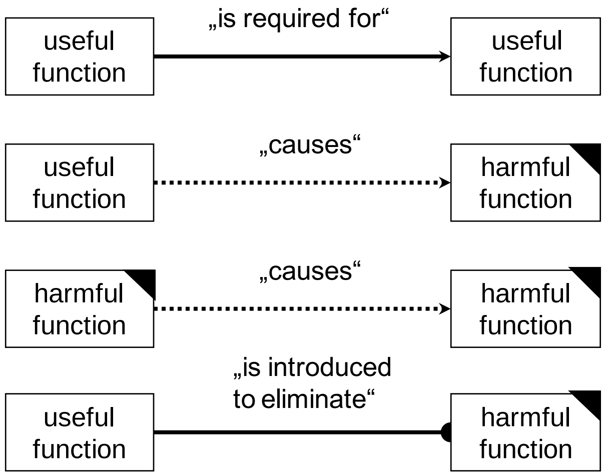

Figure 5: Basic relations between functions.

The setting up of a function structure with the relational function model is described by Eben [9]. In the context of this research, the relational function model will be set up using another approach as information from the hierarchical model is to be incorporated. This approach will be further described in the next section. After setting up a function structure with the relational function model problem formulations can be derived using the contradictions, which are formed through the relation of useful with harmful functions. A structured approach of wording problem statements is the problem formulator, which can be found in the work of Terninko [2].

Figure 6 shows the relational function model of the pressure reducing valve presented in the previous section. Thereby, the useful functions were adopted from the hierarchical function model and the procedure described by Eben [9] was applied in order to identify harmful functions and their relations to the useful functions.

A very common harmful function that was identified is the (leak) of pressurized air. In order to prevent this harmful function extensive sealing mechanisms have to be applied. Furthermore, a possible (leak) would affect seriously the functionality of the valve and of the brake system. Other harmful functions that were identified are e.g. the (fully discharge) of the pressure caused by (blowing off pressure). The function (define pressure reducing level) was introduced in order to avoid this effect and is realized by using pressurized air as (control force). Nevertheless, this solution causes a number of further harmful functions, such as (leak) of pressurized air and (rapid discharge of the control pressure). Furthermore, a solution has to be found in order to avoid (single-level control) of the pressure reduction. Figure 6 shows further harmful functions, which were identified and the resulted function structure of the valve.

The incorporation of harmful functions provides a more accurate understanding of a system and entry points to the system's optimization as well [2]. On the other hand, the hierarchical function model provides a more structured system image, which facilitates the system's understanding to less practiced eyes.

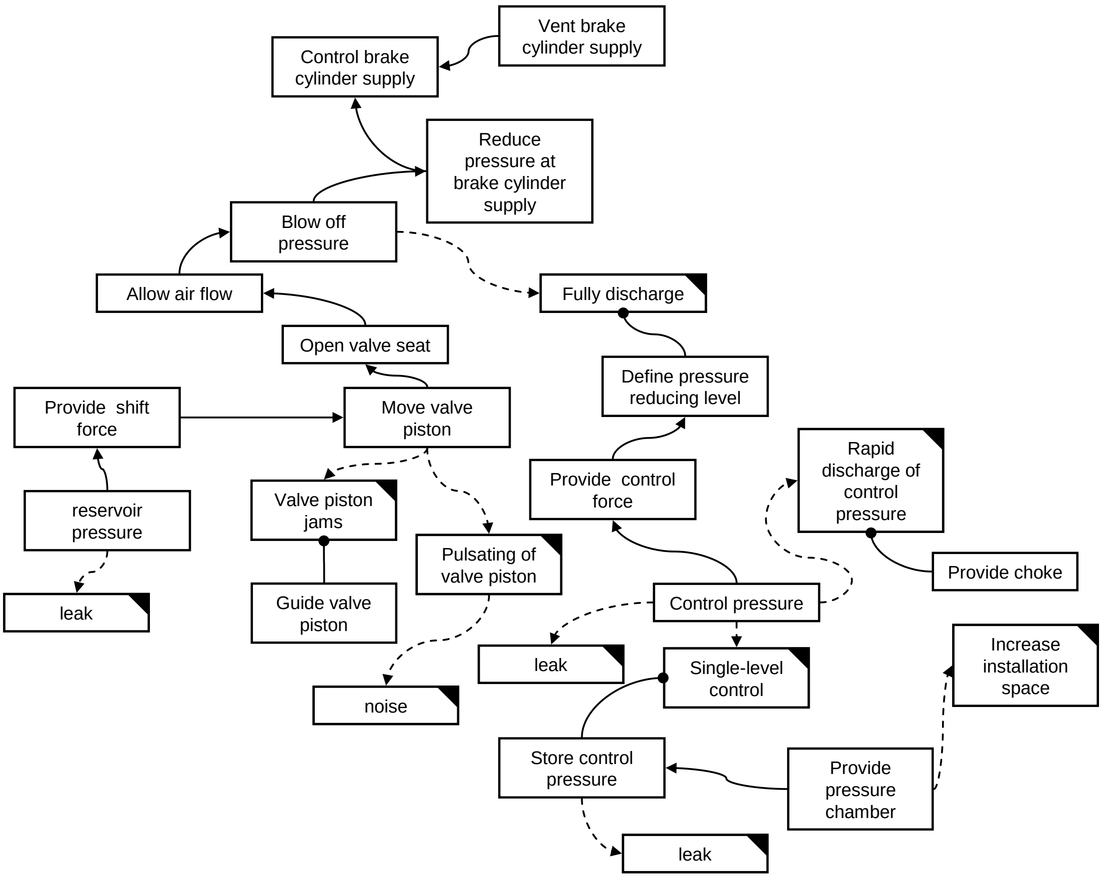

Figure 6: Relational function model of a pressure reducing valve.

4.3 Integrated hierarchical and relational function model

As already described in the introduction, by product reengineering a more structured solution space is required in order to enable innovative problem solving and not focus on a priori identified problem cores.

The integration of the two previously presented functional modelling approaches can provide a function model, which incorporates the benefits of the hierarchical and the relational function model as well. These are, the accurate modelling of the reality and the identification of entry points to the problem solving process through the formulation of problem statements as well as the hierarchically structured system's image.

Figure 7 presents schematically the process steps for the introduced functional modelling approach. Thereby, a hierarchical function model is firstly set up, whereby the defined product's main function is broken down to less abstract and more information containing functions. The functions are then classified to hierarchical levels according to the information they contain, as shown in chapter 4.1. The information has either to do with the constructive layout or with technological issues, which are considered to be more rudimental in the function hierarchy as defined in chapter 3 or with both of them.

The defined functions in the hierarchical model are afterwards used in order to set up a relational function model. Nevertheless, the hierarchical function model contains only useful functions, so the standard procedure of setting up a relational model is then applied in order to complement the function model with harmful functions. Furthermore, in this way function relations across a hierarchical level and different branches of the hierarchical model can recognized.

In the next step the defined hierarchical levels are integrated into the relational function model. Figure 8 shows a potential alternative for structuring the relational model. Thereby, the hierarchical levels are modelled as rings. The more central a function is located, the merrier abstract is the function. Furthermore, the quadrants of the middle ring stand for the branches of the hierarchical model.

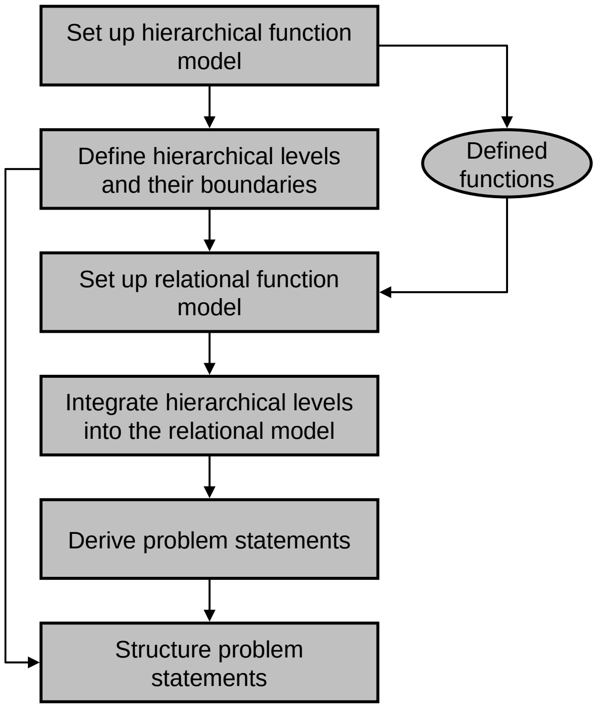

Figure 7: Steps of the introduced functional modelling approach.

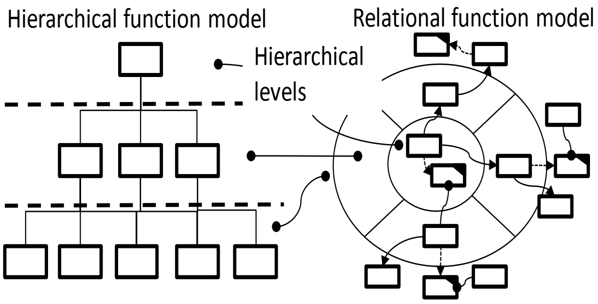

Figure 8: Integrated hierarchical and relational function model.

Figure 9 shows the integrated function model of the pressure reducing valve presented in the previous sections. Thereby, we practically have a hierarchical function model containing harmful functions and different types of function relations in order to formulate problem statements. As a result, the derived problem statements can also be hierarchically arranged, as it will be shown in the next chapter.

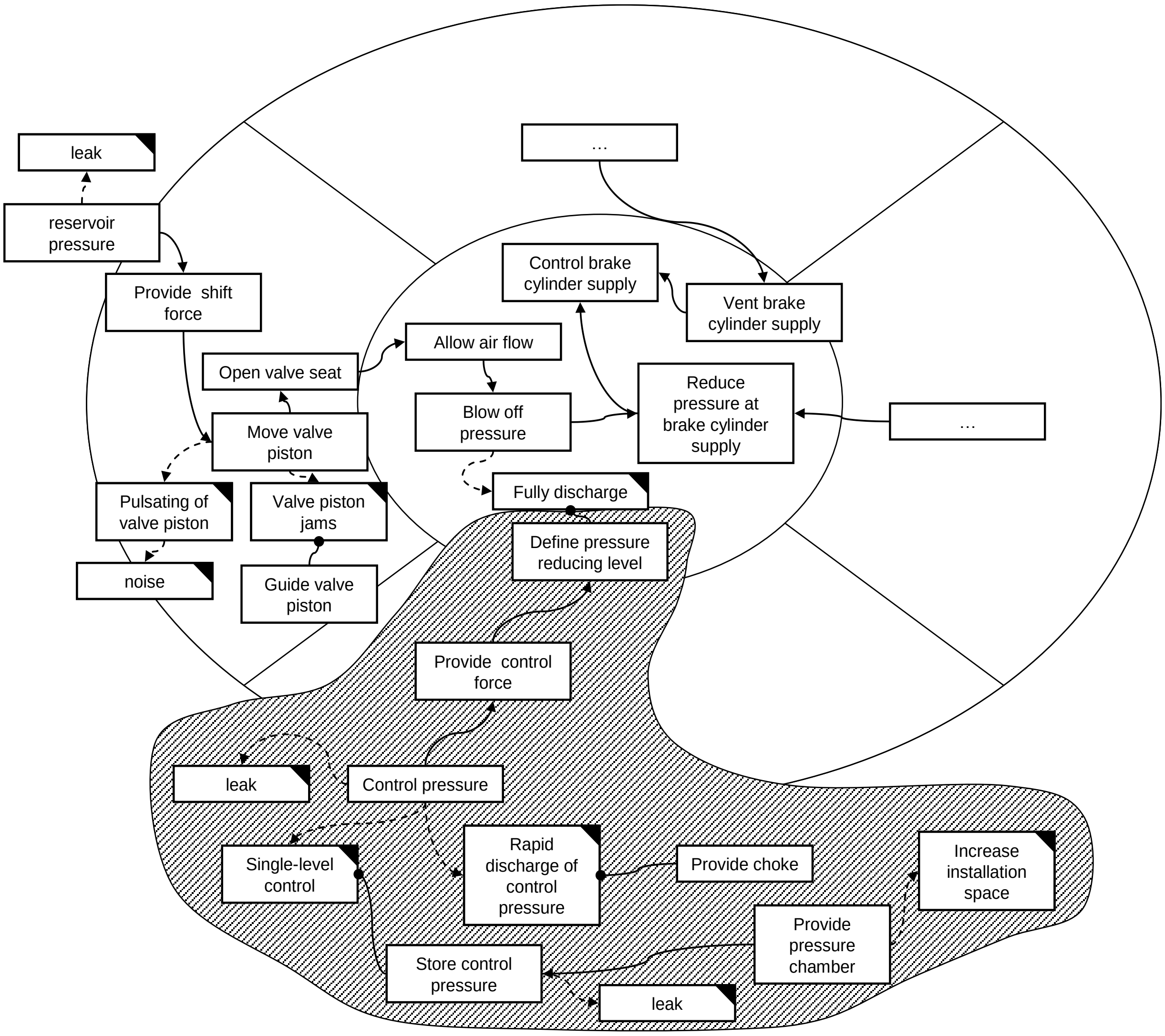

Figure 9: Integrated function model of a pressure reducing valve.

5 PROBLEM STATEMENTS AND DISCUSSION

In order to formulate problem statements from the function structure of the pneumatic valve the standard problem formulator was used, as described by Terninko [2].

In the following example only the hatched area of the integrated function model will be examined. From the functions of this area more than 30 problem statements could be derived [2]. For the sake of clarity we use 6 problem statements to demonstrate the relations between them and how this can be used as decision support by product reengineering.

1. Find an alternative way of (define pressure reducing level) that (provides control force) and does not cause (leak), (single-level control) and (rapid discharge of control pressure).
2. Find a way to resolve CONTRADICTION: (control pressure) provides (control force) and does not cause (leak), (single-level control) and (rapid discharge of control pressure).
3. Find a way to eliminate, reduce or prevent (rapid discharge of control pressure) under the condition of (control pressure).
4. Find a way to eliminate, reduce or prevent (leak) under the condition of (control pressure).

5. Find a way to eliminate, reduce or prevent (single-level control) under the condition of (control pressure).
6. Find a way to eliminate, reduce or prevent (increase installation space) under the condition of (provide pressure chamber).

Figure 10 shows the hierarchical structure of the derived problem statements, which is corresponds to the hierarchical function structure. A problem statement derived from a function exhibits the same hierarchical level and solution dependency. The problem statements are therefore arranged and interrelated according to their abstraction level and to the solution dependency they feature.

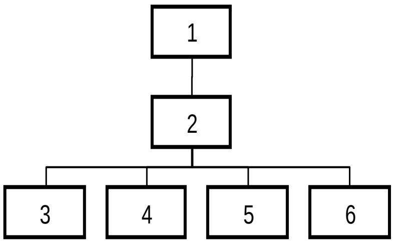

Figure 10: Hierarchical structure of the derived problem statements.

In this way by product reengineering one can chose solving a problem of a higher hierarchical level, which is related to further rudimental problems or solving a number of rudimental problems without optimizing the general concept of the constructive layout. In example, by realizing (define pressure reducing level) or (provide control force) in another way than using pressurized air all the following harmful functions would not apply. The reason for that, is that the harmful functions (leak), (single-level control) and (rapid discharge of control pressure) are caused by (control pressure). Furthermore, the following harmful functions (increase installation space) and (leak) are also caused by functions that are required in order to realize (control pressure). Such a solution could e.g. be the use of a spring mechanism in order to (provide control force) that can eliminate (single-level control). In this way, the harmful functions stated above would be eliminated through the introduction of a new concept to realize (provide control force).

Concluding, by this means an engineer trying to optimize the structure of the pressure reducing valve has an overview about which are the available entry points to the problem solution and how are they related to each other. According to the available resources and purpose of the optimization the engineer can chose, which problem statement solution is more adequate.

6 SUMMARY AND OUTLOOK

In this paper a functional analysis approach is introduced, which structures the solution space and facilitates the decision making by product reengineering. The approach introduces an integrated function model, which combines the hierarchical and the relational function model. In this way hierarchical levels are incorporated to the relational function model, which is used to derive problem statements. Correlating the derived problem statements with the functions and the function hierarchy, the problem statements are structured hierarchically as well.

Prerequisite for structuring the problem statements and identifying relations between them is a clear definition of hierarchical levels and their boundaries by setting up the hierarchical function model. In order to facilitate this task, the functions are classified according to extent and kind of information they contain. The more information a function contains the merrier rudimental is the function and is arranged to the lower levels of the function hierarchy. Furthermore, in order to facilitate the use of this approach we clearly define terms used in the context of the approach, that is requirement, function, constructive layout and technology. The difference between constructive layout and technology is thereby used to classify functions by specifying the extent and kind of information they contain. As pointed out in chapter 4.1, the definition of technological issues, which practically define the boundary between technology independent and technology dependent functions, and issues concerning the constructive layout are company and industrial sector specific and therefore have to be adjusted according to the application situation. Concluding, this approach provides an engineer a methodology for analysing an existing product and for structuring the derived problem statements in hierarchical levels and relating them to each other. By this means, an engineer has an overview about which are the available entry points to the problem solving process and can chose solving a problem of a higher hierarchical level or solving a number of rudimental problems according to the available resources and purpose of the product reengineering.

In the context of this research future work has to be done in order to systematically select relevant problem statements as the amount of the derived problem statements can increase rapidly (see chapter 5). Furthermore, the introduction of an approach to define relevant technological issues and draw the outline between them and issues concerning the constructive layout would be of great value.

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Problem Solving for Multiple Product Variants

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Abstract

Pneumatic control systems are built using various types of valves of which each single one is to meet specific constraints given by the environment a brake system is operated in. In the perspective of a manufacturer of pneumatic appliances this results in a high number of product variants, while each variant requires several product versions.

Complexity of product range inflicted by e.g. functional requirements might increase with the growth of a company, if the products of absorbed enterprises are retained and employed as a basis for new developments as well as the firm's original products. Thus the aim of the approach presented in this paper is the identification of highly similar or even redundant products and the design of standardized components in order to facilitate the development process and to reduce current manufacturing costs. Thereby the approach should give the means to determine what has to be standardized and optimized in product architectures and how external and internal constraints should be taken into consideration.

By the use of functional modelling the products embodying physical solutions of identical function structures are recognized. Further the function structures of all product types are compared with the objective of discovering identical substructures. By the analysis of substructures, contradictory as well as consistent ones, standardized patterns and problem statements can be derived. Finally standardized designs can be defined for each problem statement to form a construction kit to be used over all product variants.

Keywords

Product Variety, Functional Modelling, Product Architecture, Problem Statements

1 INTRODUCTION

The design of a company's product program is crucial for its success in the market. One the one hand a maximum of customer orientation is to be achieved. On the other hand this endeavour may have an impact on development and production costs, since not only the expenses in development increase through a high number of product adaptations but also production costs are raised by a high number of different components used in product assemblies.

The product range may comprise a large number of products using the same technologies but embodying different functionalities, as it is the case in the use case presented in this paper. In order to ensure the company's competitiveness the necessity might arise to maintain the current product portfolio fulfilling the customers wishes to the outside, while internally the current design has to be rethought. This may have an even higher importance if with the growth of a company the products of absorbed enterprises are retained and employed as a basis for new developments as well as the firm's original products.

In the next section it is described how variant management currently is employed to meet the situation described above appropriately.

1.1 Variant management – state of the art

Variant management can be achieved via the use of different strategies. The simple elimination rarely sold products from the product program may lead to benefits [1], as their production costs likely are higher than those of frequently sold products.

According to Renner [2] variant management strives for reaching an optimal degree of complexity either by elimination, reduction or control of complexity. Both Renner [2] and Maurer [3] state that potentially successful applications of complexity reduction can be the implementation of building blocks, platforms, or standardized interfaces. This can be accomplished by the modularisation of product architectures. Thereby design lead time and costs can be reduced as well as design quality improved. Redesign and change processes are influenced positively as well. Moreover, the standardisation of components is supported by modularisation [4, 5, 6].

According to Ulrich and Eppinger [7] a product's architecture is formed by the physical representation of its functional elements, and the specific relations between the physical components. Further the specification of the interfaces among interacting physical components has to be taken into account [4].

In the course of modularisation product architectures are decomposed into modules. These modules are units each providing a unique basic function necessary for the product to operate as desired [8]. The decomposition is often conducted using functional structures. For example a functional structure can be set up to define modules with the purpose of identifying and building distinct brand platforms across a product family [9].

Product function structures are also employed to identify modules which can be diversified to deliver product variety according to customer needs and functional constraints [10]. Additionally lifecycle and serviceability aspects into consideration are taken into consideration in analysis of architectures [11].

Functional structures can be derived by hierarchically decomposing a product's main function to detailed functions [12]. In the field of TRIZ functional analysis starts with stating the primary useful or primary harmful function [13]. Beginning from that point the complete structure is gained by considering each function whether other functions influence or are influenced by the former one.

1.2 TRIZ – abstraction and standard solutions

TRIZ – the theory of inventive problem solving – comprises a collection of different tools, which can be summarised and described by the four pillars of TRIZ: Systematic, knowledge, analogy and vision [14].

The initial problem, the design task, is analysed systematically. To solve the problem existing design knowledge is for example used in the form of databases and analogies, i.e. standard solutions, are drawn. Moreover evolution principles or the s-curve of a product or technology serve to predict the necessity or possible direction of innovation [14].

One link between variant management and TRIZ lies within the application of functional analyses. This way of abstracting the initial task in development serves as a basis for further steps.

Dewulf [15] introduces the so called directed variation. Therefore the genetic code of a product, i.e. the product DNA, is analysed. By abstractly describing a product's functions and properties using standardized functions with defined links to properties, alternative designs can be derived. The formulation of the abstract DNA enables designers to rethink the functionalities and physical representation without being stuck to the current design.

Miecznik and Glaser [16] developed an approach for reverse market research. By analysing key products of a company and the abstract formulation using the innovative principles [17] catchwords are derived. These catchwords are applied to search of patent databases. The aim of this procedure is the identification of market fields in which the core competencies and strengths of a company could be of additional value. Thus the identification of new market segments is achieved.

Schuh et al. [18] use a database of generic mechanisms to be employed against product piracy by applying the analogy approach. Promising principles are selected and elaborated to specific solutions for a company or methods in additional TRIZ-workshops.

1.3 Multiple product variants and standardization

The approach presented in this contribution aims at restructuring a company's product program. Redundant products providing identical functionalities and fulfilling the same requirements are identified.

In a next step the functionalities of different product types are compared with the purpose of standardising the currently used components in such a way that the development process is facilitated and manufacturing costs are reduced.

The original product range is observed integrally with the purpose of modularisation. Functional modelling serves as means to abstract the analyzed functionalities. From the gained structures a set of general functional sub structures is derived, which serves as a basis for the design of a standardized construction kit. The kit consists of standardized modules, which can be combined to products comprising all original functionalities.

The solutions forming the single building blocks are derived partly from a database created during the analysis of products and comprising current design elements. Therefore the existing design knowledge and the core competencies can be preserved in a company specific database. Additionally TRIZ tools like the s-curve or the 40 innovative principles serve as means to evolve the current product portfolio technically [14, 17].

In contrast to Gietka and Vermin [19], the aim of the database linking functional structures to existing solutions is not only to reuse design elements in order to generate as many design alternatives as possible, but to select designs appropriate to achieve standardization of the complete product range. Moreover in the application of the approach presented in this paper strengths and weaknesses of current design are documented by the use of functional substructures.

Dewulf [15] describes the task design to be solved by a combination of functions and properties. Both the functions and properties and the linkage between the two domains is defined in a way that a set of functions and product properties from the genetic code of a product. This abstract formulation is used to generate creatively new solutions comprising the original functions. Design knowledge embodied in the current products is not used for the development of new products. Further the task of standardization is not addressed.

Miecznik and Glaser [16] use abstract product functions and properties in order to identify new markets. Schuh et al. [18] aim at eliminating the danger of product piracy. Both do not cover standardization of the current product program.

The scope of the presented approach differs therein from the state of the art that an existing product range is completely restructured and modularised. A minimum of elements or modules form a construction kit which can be used to generate products fulfilling at least all original functionalities. This is achieved by the application of functional analysis, the derivation of a knowledge database and the generation of new solutions using other TRIZ tools supporting innovative new designs. It is to be examined whether the advantages of modularisation and TRIZ can be brought together in this context.

In the following section of this contribution the approach aiming at the restructuring a company's product portfolio regarding multiple product variants is presented. Regarding the case study covered in section 3 in a first step the current technology is to be maintained by the single use of the derived database. In future a second step might be the application of creative inventing tools. As it is still work in progress the scope of this paper lies mainly on the analysis of the current product types and versions. Finally the content of this contribution is summarised in section 4 and an outlook on future work is given.

2 APPROACH

This section shows how multiple product variants can be examined in order to identify redundant products as well as functional similarities. Further the approach covers the procedure for the synthesis of a construction kit which enables maintaining the original product range and the creative development of entirely new products while a maximum of economies of scale can be achieved.

The presented approach follows the procedure described by Terniko et al. [13]. As depicted in figure 1 the application of TRIZ follows the path from stating a specific problem which is abstracted to a standard problem. Subsequently this problem is transformed to a standard solution and finally transferred to the initial situation to form a specific solution.

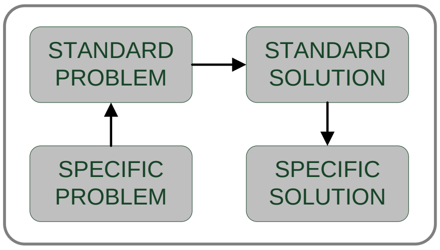

Figure 1: TRIZ – Procedure according to Terniko et al. [13].

The procedure of the approach presented in this paper shows a similar structure. As depicted in figure 2 the approach the approach consists of two major steps or phases, which are the analysis phase – resulting in a conceptual construction kit – and the synthesis phase.

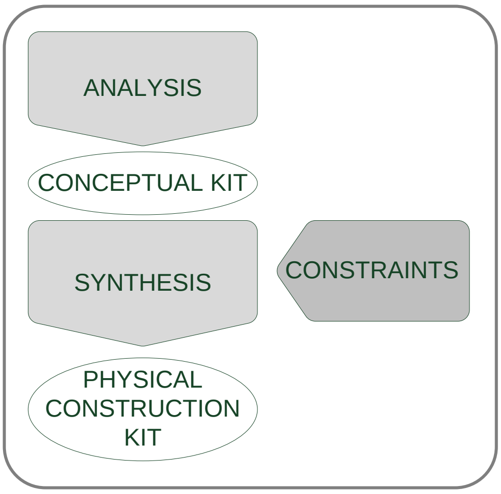

Figure 2: Structure of the presented approach.

The conceptual construction kit serves as a basis for the generation of standardized physical solutions in order to provide a sufficient number of building blocks to assemble a range of products bearing all functionalities of the original program, i.e. the physical construction kit.

Compared to the procedure in figure 1 the analysis phase covers the first two steps from the specific problem to the standard problem, while the conceptual construction kit stands for the standard solution of the whole product range. Thus the synthesis phase can be considered as the last step from the standard solution to the specific one, as the final result is the physical construction kit.

The third phase shown in figure 2, labelled constraints, is conducted in parallel to the other phases, as it conveys the information necessary to evaluate and select existing and new solutions.

The following subsections describe the single steps in detail.

2.1 Analysis phase

By the use of functional modelling the products are analysed. The structures gained from all product types are compared with the objective of discovering identical substructures.

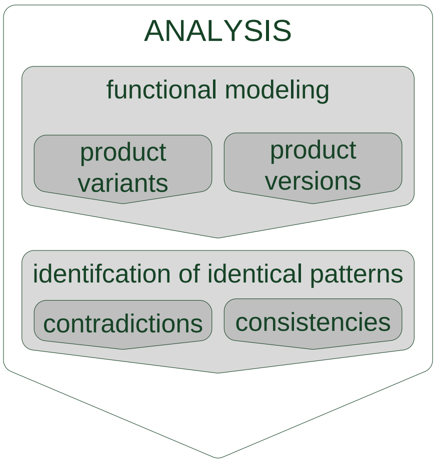

Figure 3: Analysis phase.

Analysis of Product Structures – Functional modelling

Figure 4 shows the syntax of the functional modelling approach which is used in this contribution. There are two types of functions useful (UF) and harmful (HF) ones and the resulting function structures contain the relations between these functions [13]. The three relations can be used to state whether a useful function is needed to enable another one, a useful function has been introduced to avoid a harmful function or whether a useful or harmful function cause another harmful function.

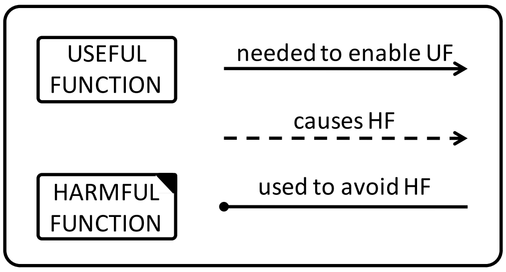

Figure 4: Syntax of functional model according to Terniko et al. [13].

When setting up the function structure the first step is to point out the primary useful or the harmful function. This primary function serves as the starting point for modelling, as it is considered whether and which other functions it influences or is influenced by. Each newly formulated function is regarded in the same way [13]. The result is a complete function structure as it is depicted exemplarily in figure 5.

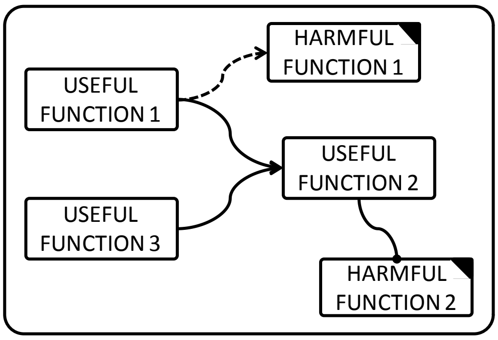

Figure 5: Exemplary functional structure.

From the gained function structure problem formulations can be derived, if functional constellations form contradictions [13]. For example in figure 5 causes useful function 1 the harmful function 1 but is at the same time required to enable useful function 2. This could lead to the following problem formulation: “Find an alternative way to enable useful function 2 without causing harmful function1”.

Such problem formulations can be used as a basis for the application of the contradiction matrix, i.e. the 40 innovative principles [17]. This is not the only advantage of this modelling method; strengths and weaknesses of the modelled product become evident as contradictions are be documented.

Thus regarding the goal of standardization by modularisation – which affords an optimal design in order to enable the broad use of each module – this method is appropriate for the decomposition of products.

The functional modelling is used to analyse a company’s product range, different versions of a single product type as well as different product types, in order to compare their functionalities.

Identification of identical patterns

After the analysis and modelling of the current product range is completed it is to be determined to which extent the different structures comprise identical constellations.

The gained structures are examined whether they contain the similar patterns. To attain this every model has to be analysed and substructures, e.g. contradictions, have to be documented.

To facilitate the comparison of the different structures the functional structures can be depicted by the means of matrix based approaches like for example the Design Structure Matrix (DSM) [20, 21].

Here it is important that the type of a function is made clear by its formulation as the graphical difference gets lost in the matrix. Consequently it is important to label the three kinds of relations explicitly. Figure 6 shows the example, which is depicted in figure 5, using a DSM.

n: neded to enable
c: causes
a: used to avoid

	useful function 1	useful function 2	useful function 3	harmful function 1	harmful function 2
useful function 1		n		c	
useful function 2					a
useful function 3		n			
harmful function 1					
harmful function 2					

Figure 6: Using the DSM to depict functional models.

In order to identify significant functional constellations the relations depicted in such a matrix can be clustered. The aim of clustering is to situate all relations between the single functions as near as possible to the matrix's diagonal by rearranging the matrix's rows and columns. Much research has been conducted on clustering algorithms in order to cluster the matrices automatically [22, 23], but it is also possible to cluster them by hand [22]. The identified clusters of different functional structures, i.e. different product versions or types, then can be checked on matching functional constellations.

The analysis of functional structures provides a large amount of constellations. Thereby the two following cases are of interest.

First there are substructures just consisting of useful functions. One the one hand it is important to capture identical groups of functions in different products or product variants. On the other hand differences in the models have to be assessed. For example the structure might be quite simple in one product, as only one function is necessary to enable another function which is essential for the product, but in another structure several functions are required to fulfil this essential one. Thus it would be to examine whether the simple structure would be sufficient to be used in both products.

Second there are substructures containing useful and harmful functions and thus contradictions. It has to be investigated whether these contradictory substructures have been solved in other products or the contradictions still have to be overcome.

The resulting collection of substructures and functions has to be structured in order to derive the conceptual construction kit. Based on the analysis described above similar patterns are merged in a way that the merged structures can be used in a maximum of products. Identical patterns, consistent ones as well as contradictions, are documented. A product's unique patterns are retained as they are required to constitute the products complete functionality.

2.2 Conceptual construction kit

The subsection above covers the decomposition of a product into functions and the subsequent analysis of the derived functional substructures.

In a next step a conceptual construction kit is derived. Preferably this kit should form the ideal final result [17] to the task of building the complete product range from a minimised number of building blocks, while at this stage the building blocks are represented by the functional constellations identified in subsection 2.1.

In reality the kit will comprise of contradictions as they are found in the functional structures examined before. These remaining contradictions serve as an indicator for inevitability of optimisation of the current design. Identical patterns in different products are a sign for a possible standardisation of components. As well as the identified unique sub structures they are included in the conceptual kit. Consequently the conceptual construction kit contains all functional constellations being necessary to describe all original functionalities embodied by the different product types and versions.

These groups of functions are defined as modules, as they each provide a different sub-function essentially to the overall function of a product [8].

In order to handle the remaining contradictions problem formulations are derived, serving as a basis for the generation of solutions in the synthesis phase.

In the following subsection solutions can be gained for all products of a product range at the same time by developing physical components for each of the modules defined in the conceptual construction kit, as illustrated in figure 7.

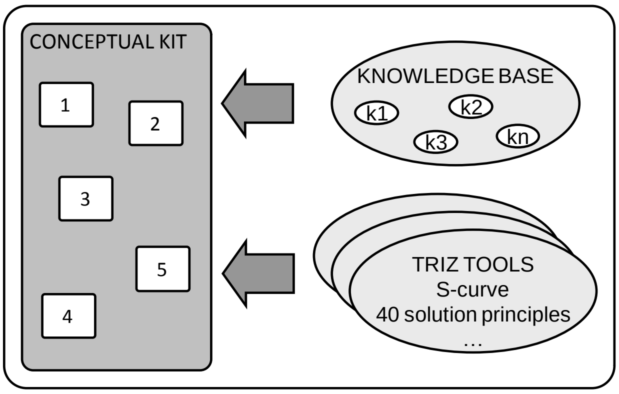

Figure 7: Conceptual construction kit – modules (No. 1 to 5) used as a basis for generating physical solutions.

2.3 Synthesis phase

Based on the conceptual construction kit physical modules are generated in the synthesis phase. As shown in figure 8 solutions are gained from a knowledge database conveying physical solutions and by the application of other TRIZ tools:

Conducting an analysis using the s-curve can lead to insights at which point of evolution the current design is to be located [14]. Thus on the one hand it might be reasonable to stick to the current technology or on the other hand the introduction of a new technology might be inevitable in order to maintain the company's position in the market.

The 40 principles [17] provide access to innovative new solutions by completely disengaging the developer from the specific problem by solving the task on an abstract basis.

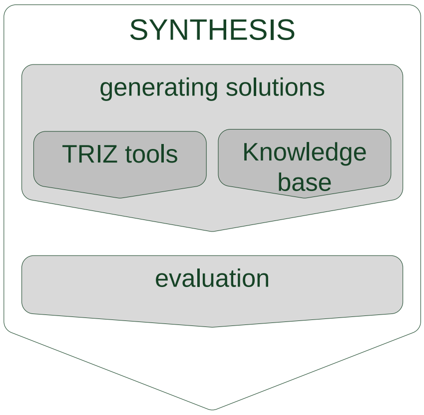

Figure 8: Synthesis phase.

Existing solutions – the knowledge base

The knowledge base comprises of information about the original design of the regarded products. While products and product versions are analysed and the functional modelling is conducted as well the components embodying the products' functionalities are regarded.

These are documented using the corresponding functional substructures identified during modelling of the products, i.e. the knowledge base contains functional modules.

In the synthesis phase solutions for the modules from the conceptual construction kit are extracted from the knowledge base by comparison to the functional modules in the database.

The knowledge base not only serves the purpose of providing design solutions for reuse but also of preserving and documenting the design wisdom available in the company. For example no loss of design knowledge is caused by employees leaving the company.

New solutions – S-curve and 40 principles

As described above the s-curve can be used to determine whether immediate innovation of products is essential. This approach can be used to conclude to which extent it would beneficial to use the knowledge base.

Alternatively the 40 principles can serve to generate innovative new solutions if on the one hand the conceptual construction kit still contains contradictions or on the other hand a leap of technology is inevitable.

Constraints, evaluation of solutions and final result

During the analysis and modelling of products information – additionally to functional and design aspects – is gathered concerning the specific conditions in the use of a product and the resulting required product properties. Moreover knowledge about manufacturing requirements, for example required quality of surfaces for sealing the device, used materials and their properties is documented in the database.

These pieces of information comprise all relevant product requirements which can be categorised into internal requirements, considering constraints resulting from the current manufacturing process, and external requirements regarding customer requirements, product use, available space etc.

The so gathered requirements serve as criteria to assess the solutions generated in the synthesis phase. Only those solutions meeting those requests being relevant to the respective module or regarded functionality are selected.

Thus the modules being sufficient to be employed in the final products finally are combined to form the physical construction kit. Hence the kit can be used to rebuild the original product range, as all requirements are fulfilled. Additionally new products can be derived by combining the defined modules without raising the variety of components. The construction kit is to be used whenever a new development project is launched. New designs are created solely if the requirements stated in this project cannot be fulfilled by any existing building blocks. By the means of standardisation, i.e. the construction kit, economies of scale can be attained and thus production costs and the lower number of single components reduced.

3 CASE STUDY

The approach presented above is currently applied to the product range of a manufacturer of pneumatic brake control systems. As the development of the final construction kit has not been completed yet, the case study can serve as demonstration of possible achievements and benefits attained by conducting the procedure of the analysis phase and the use of the knowledge base in order to derive the necessary building blocks.

Pneumatic brake control systems differ widely in their configuration. They consist of various types of valves, each of which is contained in different quantities.

The valves themselves are to meet specific constraints given by the environment a brake system is operated in.

Thus on the one hand there is a large number of different valve types and on the other hand there are large numbers of these valve types' versions meeting varying requirements.

Currently each valve is developed on its own. Hence every time a new specification is required a valve is designed on the basis of the knowledge of one designer. As the knowledge of one developer cannot capture the whole amount of products in the portfolio, frequently valves partly redundant to existing ones are generated. Concerning the complete product range this results in a high complexity regarding the amount of different manufactured components and pneumatic devices.

In order to reduce the complexity by eliminating redundant products and minimising the number of manufactured components the approach of combining modularisation and TRIZ is used.

3.1 Exemplary application of the approach

Describing the analysis of all kinds of different valve types would exceeds the room given by this contribution, only the implementation of the approach to check valves and pressure control valves is shown.

Check valves are to fulfil the task of allowing air flow in only one defined direction. Pressure control valves control the pressure of the air flow. They allow a defined maximum of pressure, while controlling the operating pressure. This is for example necessary if a brake system contains devices with lower tolerable pressure than the highest possible pressure in the brake system [24].

When setting up the functional models the same labels for the functions are to be used for each valve type so far as possible. This is of help as soon as the resulting structures are compared, which is conducted by hand as the gained models consist of a relatively low number of elements.

The analysis of the gained functional models shows differences regarding single product types. For example with some check valves there can be found the function of damping moved components, while in other check valves the forces resulting from the air flow and its pressure is balanced at valve seat. Both mechanisms are due to differently tight requirements concerning accuracy and reaction time of the valves. These are documented in the knowledge base as well as the differences in the corresponding design elements.

Pressure control valves can be distinguished by their way of adjusting pressure. On the one hand the pressure can be reduced by releasing compressed air to the surroundings and on the other hand it may be sufficient to simply not allow any air flow as long as the pressure is intolerably high.

Alongside to the identified differences it becomes apparent that many valves, which are part of the product range, fulfil the same functional and technical requirements. The comparison of the functional models belonging to one kind of pneumatic devices results in a collection of all functional substructures available for this type.

By comparing of both types identical substructures can be identified. In the following two contradictions, which can be found in all functional models, are described.

Figure 9 depicts the contradiction, that the movement of the valve seat, which is needed in order to open it, causes the oscillation of the involved components. This by itself causes noise and additional wear on the surfaces. The contradiction is transformed into a problem formulation: “Find a way to avoid the oscillation of components or eliminate its outcome.”

As mentioned before some check valves provide a solution to this task by damping the moved components. This is realised by encasing air in a chamber between the valve’s housing and the moved component, i.e. the valve seat. Thus if the valve seat gets opened it is slowed down by compressing the enclosed air. When moving in the opposite direction negative pressure is built up and again the movement is slowed down. Hence the damping serves as well as means to compensate any occurring pressure fluctuation.

This mechanism can only work if a defined gap width is maintained between valve seat and bearing surface. All this information is gathered during the analysis and modelling of products and documented in the knowledge database.

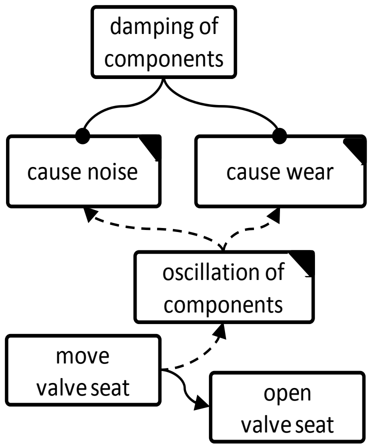

Figure 9: Damping as solution for some check valves.

Another example for a contradiction is that the movement of the valve seat, in order to open it, causes that the valve seat – the moved component – gets jammed. The resulting problem formulation is: “Find a way to open the valve seat while avoiding the locking of components caused by the valve seats movement.”

This problem can be avoided by the design of the valve seat and the corresponding components. For example the valve seat may consist of elastomeric material and have a conical shape corresponding to the conical shape of the bearing. Alternatively the bearing surface can be designed that broad and with a defined surface quality that a locking is not possible.

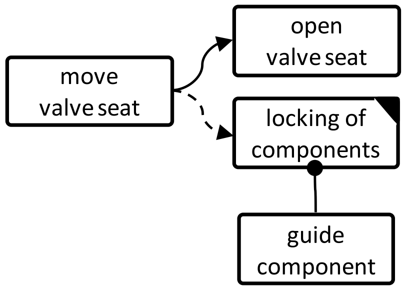

Figure 10: Contradiction solved by means of guiding the moved component.

Along with the identified contradictions, several functional substructures are found to be necessary to represent all functionalities of the original valves. These standardised patterns each are defined as modules forming the conceptual construction kit. In figure 11 the modules are depicted, which represent the contradictions shown above. The module “avoid oscillation” stands for the contradiction of figure 9, as the module “guide component” does for the contradiction pictured in figure 10.

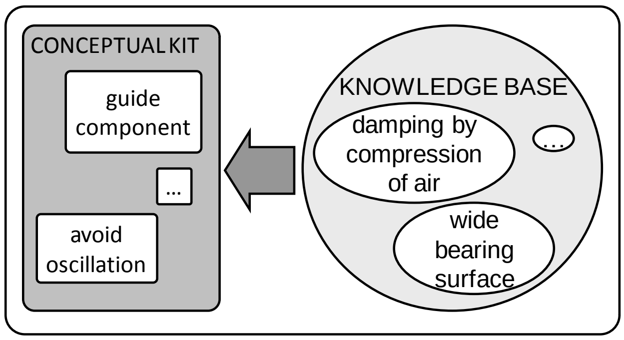

Figure 11: Conceptual construction kit and knowledge base of pneumatic valves.

When describing the contradictions and possible solutions embodied by the different valves, some requirements resulting from these solutions have been named. Further external constraints as accuracy and reaction time of the valves as well as operating temperature or the required flow rate are taken into account to assess the design alternatives contained in the knowledge base.

Finally standardized designs can be derived from the database in order to form the physical construction kit to be used over all product variants. Figure 12 shows two exemplary details corresponding to the modules defined above. The building block “damping using compressed air” is the solution for the module “avoid oscillation”, as the building block “broad bearing surface” is selected to solve the problem stated by the module “guide component”.

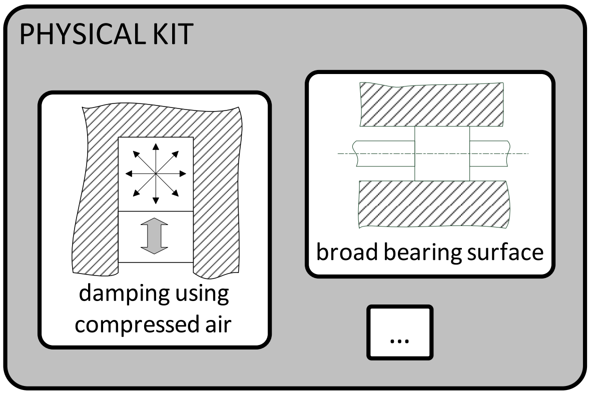

Figure 12: Standardized construction kit.

So far in the case study only activities towards the standardised physical constructions kit which have been carried out are based on the knowledge database. However, the derived problem formulations – together with the conceptual kit – form a well-founded background to the application of the 40 principles.

3.2 Discussion of results

The application of the presented approach to the case study results in the identification of redundant products. Further standardized patterns can be derived to form a conceptual construction kit for pneumatic valves.

By setting up a knowledge database the large number of existing design alternatives and knowledge can be documented. Up to this point the different product types and corresponding product versions had not been captured in similar systematic way of documentation. Thus the database provides an extensive range of possible solutions which are used to derive the solutions of the valve construction kit.

An advantage of using solely the knowledge database is that existing manufacturing tools, e.g. casting moulds, still can be employed. No additional costs arise for the development and production of new tools.

As the case study still is conducted, only the database has been used to derive physical solutions. Although this leads to a reduction of manufacturing costs by achieving economies of scale, no prediction can be made whether the creation of completely new and innovative solutions would lead to more success. For example a leap in technology, the use of new materials etc. could lead to a better performance of the valves than possible using the elements form the database.

Thus in a next step an analysis using the s-curve is to be conducted in order to investigate the potential of an application of the 40 principles.

4 SUMMARY AND OUTLOOK

In this paper an approach combining variant management in the form of modularisation with TRIZ is presented. The aim of the introduced procedure is to restructure a company's complete product range in order to reduce manufacturing costs and facilitate the design process. This goal is reached by the development of a construction kit containing all standardised modules necessary to rebuild all products from the original portfolio. Thus the generation of solutions is conducted for the complete product range at the same time.

By the use of functional modelling the products and product versions embodying physical solutions to identical functional substructures structures are recognized. The identified patterns form a conceptual construction kit which serves as a basis for the creation of standardised solutions to be employed in the final construction kit.

Existing Design knowledge is preserved and reused by setting up a knowledge database comprising the original design elements. New innovative solutions are created using the 40 principles [17].

This systematic and integral procedure is rather time consuming but provides solutions for current and future tasks as the derived constriction kit also serves to create new products. Nevertheless future work should concentrate on the facilitation of the analysis process as the amount of data to be compared may become confusing easily.

Further research also has to be conducted regarding the creation of new solutions. The case study provides promising results for the analysis phase but as it still is work in progress only few conclusions can be drawn on the creation of the final construction kit. One open task in particular is to investigate whether a leap in technology would lead to results bearing additional advantages.

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Principles of Technology Evolutions for Manufacturing Process Design

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Abstract

Current research activities in the field of manufacturing technology development increasingly focus on integrated approaches for process performance enhancements. As in many process development activities, systematic design methodologies such as TRIZ are either not applied or even unknown in such instances. The main problem in such research efforts of finding integrated solutions is getting the relevant information or knowledge. This paper shows some important trends in the development of production systems in high wage countries and highlights important directions for manufacturing process improvements that are necessary for future innovations. The research reported herein is based on the systematic approach of a design methodology for the development of hybrid processes that was presented at the 2008 ETRIA TRIZ Future Conference. This general methodology still requires the knowledge of other technology domains in terms of standard solutions according to TRIZ.

Keywords

TRIZ, Manufacturing Process Design, Manufacturing Technology, Manufacturing Technology Knowledge

1 INTRODUCTION

The current state of the world economy has strongly emphasised the role of manufacturing in sustainable wealth creation, with due regard for the limited natural resources and stewardship of the environment. In this light manufacturing technology, which is defined as the *science of using manufacturing techniques,* assumes considerable importance. The above definition is central to the work described in this paper, according to which the technology of manufacturing refers to the knowledge of causes and effects that pertain to the design and application of manufacturing processes.

This paper examines commonalities in the evolution of manufacturing process technology in the recent past to chart plausible future courses and identify technology gaps. A review of several manufacturing process technologies is accomplished with particular emphasis on general modelling approaches adopted. The literature on novel machining processes is analyzed to recognize general principles that underlie the process of evolutionary technology enhancements. These principles of specific improvements are traced back to physical mechanisms associated with the respective technologies.

With a view to realizing a holistic treatment, several manufacturing processes corresponding to different technology domains are evaluated. The research considers different types of innovations such as improvements referring to the evolution of single processes as well as the combination of several processes or energy forms that constitute hybrid processes. Aspects of technology evolution thus identified from the viewpoint of manufacturing processes are aligned with TRIZ solution principles as appropriate.

2 MOTIVATION FOR INNOVATIVE MANUFACTURING TECHNOLOGY DEVELEOPMENT

The current difficult business situation for the production industry sector in Western Europe is often explained by a strongly increasing number of global competitors. New competitors from low-wage countries benefit from the low labour costs and improving technology capabilities at the same time. This trend is clearly recognisable considering the development of worldwide production distribution over the last centuries, see Figure 1.

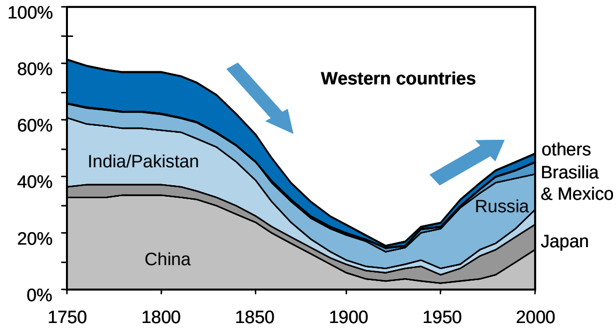

Figure 1: Distribution of world-wide production between 1750 and 2000 [1].

Highly qualified personnel is a significant factor within the globalised market. Thus workers in a West European company for instance have to compete with Chinese colleagues concerning productivity and quality aspects. Hence, the goal of today's research activities is to offset the difference in the labour costs by higher manufacturing process efficiency in addition to the optimal use of human resources. Thus synergy effects should be reached by an improved integration of production systems and valuable human capital.

Here the high level of human qualification and technology knowledge in high wage countries have to be utilised better, which can be a significant advantage in the context of increasing market dynamics and shorter product or technology life cycles. By effectively using knowledge, a highly agile production system can be realised and innovations can become an important factor in ensuring competitiveness. This implies that besides innovative products, it should also be focussed on the development of innovative production processes. New developments in manufacturing technologies can contribute substantially towards this end.

3 TRENDS IN MANUFACTURING TECHNOLOGIES

According to the laws of technical system evolution technological and engineering systems tend towards increasing ideality over time [2] [3] [4] [5] [6]. In the case of manufacturing technologies, an enhancement in quality and accuracy is a general trend; however, ideality is evaluated in terms of multiple criteria. Some important technology requirements are hence depicted in Figure 2.

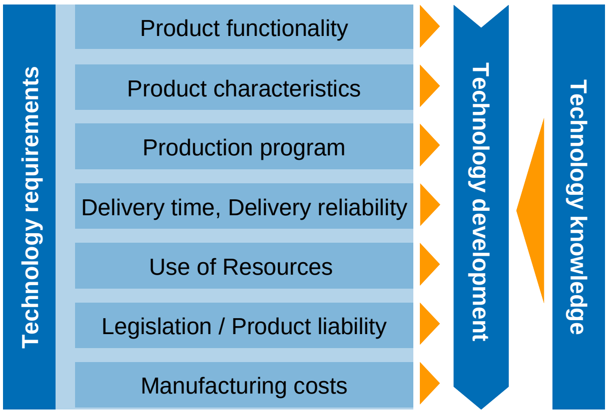

Figure 2: Manufacturing technology requirements.

In specific terms, these requirements translate into the need for efficient manufacturing towards good and cheap products, which are delivered in the minimum possible lead time by using the least amount of energy and natural resources. Further considerations entail the associated emissions, recyclability, flexibility and robustness. In relation to the manufacturing costs the ability to integrate technology platforms is becoming increasingly crucial. A typical example that embodies the aspects above is the innovative use of a laser for local and selective transformation hardening of components in a metal cutting machining centre as opposed to conventional case hardening in a furnace.

Considering the constantly changing business environment in which manufacturing industries operate, production systems have to be evaluated and modified on the fly to align with the market conditions. The major trends that underlie research in production technology can be categorized into:

- capability for dynamic production characterized by system adaptability,
- flexible production that can handle a large number of product variants,
- near net shape manufacture for resource saving production, and
- production of new materials, new product functionalities, high quality and accuracy.

As rapidly changing technology requirements warrant flexible and versatile production systems, it is increasingly imperative that existing technology knowledge is used effectively for the fast adaption of manufacturing systems to suit new demands. Some of the solutions to this end refer to the design of application of new materials and energy fields, hybridization of production systems and multi-level technology integration.

4 EVOLUTIONARY TECHNOLOGY ENHANCEMENTS

Technology enhancements, in general, can refer to either optimization at the process level or fundamental changes at the system level [7]. Optimization is characterised by the tailoring of single processes for specific applications by tuning system elements or features within the confines of the operating envelope of the process, so as to realize optimal performance. Fundamental system changes, on the other hand, are characterised by the substitution or addition of elements, subsystems or mechanisms to a system. In the context of this paper the latter case represents the evolutionary technology enhancements, which are a precondition for innovations. This case is shown in Figure 3.

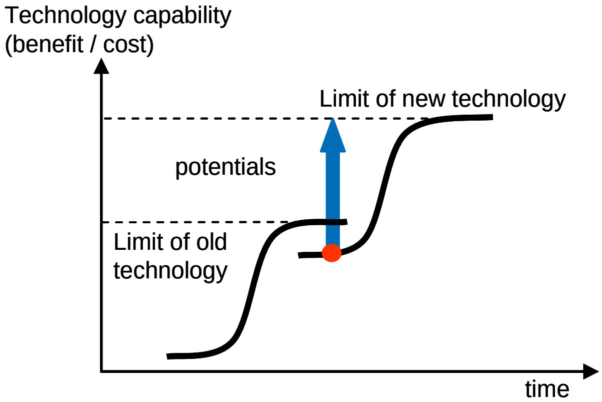

Figure 3: S-Curve model [4].

Several technologies related to the development of cutting tools have followed the S-curve model above. A typical example is the development of rotary cutting tools that entail inserts that rotate about their axis during the course of machining (Fig. 4). The motivation for the development of this tool was a problem with conventional cutting tools wherein the same segment of the cutting tool edge is repeatedly involved in the material removal process. An approach to improving this is to translate the cutting edge laterally such that the segment of the cutting edge engaged with the workpiece is continually changing during the course of cutting. This does not only distribute tool wear along the entire tool profile but also results in the tool incurring reduced wear as a particular section of the tool is not subject to prolonged heating as in conventional tools.

In the concept above the transverse tool motion corresponded to the reciprocation of the along the cutting edge. A more effective kinematic configuration would be the extension of such a tool edge to correspond to a circle such that the tool can rotate about its axis. In the first generation of such tools, the inserts were driven about their axis by an auxiliary electric drive. Application of such tools in industry was seriously limited by the cumbersome physical configuration of the tool and issues with tool vibration. This tooling configuration therefore evolved to rotate the inserts by inclining the tool insert appropriately, so as to derive the energy from the cutting process by appropriately controlling the engagement of the tool with the workpiece. Issues with vibration in such tools have also been lately addressed paving the way for their recent commercial exploitation. At the present time, such tools are used predominantly in the turning and milling of nickel alloys for aerospace applications wherein tool life is severely limited by the relatively high cutting temperature.

Figure 4: Rotary cutting tool [8].

4.1 Evolution principles in manufacturing technology enhancement

In this section, developments related to manufacturing are reviewed in the context of known TRIZ solution principles using the example of surface hardening.

In such applications as in the manufacture of gears, components are required to have a hard and wear resistant surface layer while the workpiece core needs to be ductile in the interest of maintaining toughness. Here a furnace is generally used to heat the workpieces in a carbon-enriched atmosphere. Starting with such a case hardening technology, other surface hardening technologies have been developed such as flame hardening, induction hardening and laser hardening process. These technologies represent different evolution steps in the case of surface hardening. A high integration capacity is a technology requirement that assumes increasing importance for production systems (Figure 5).

Indeed a key surface engineering application of lasers is case hardening which refers to the rapid heating and self-quenching of the surface layer of a material to induce phase transformation without any melting of the material. The primary advantages of this technology are the capacity to accomplish rapid, selective and local hardening without an external quenching medium and the ability to consistently obtain thin, controlled cases with minimal part distortion in a flexible manner.

Conventionally case hardening of a component is accomplished between rough and finish machining cycles and it is not uncommon for the heat treatment and machining operations to be carried out at geographically different locations. The emergence of laser hardening has paved the way for integrating case hardening and machining in the same machine tool. This presents several advantages such as the capability for selective heat treatment, in addition to better logistics and material flow, which in itself represents a significant improvement in production efficiency. In fact, local hardening of steel components has also been used to manage burr formation in critical components.

Case hardening applications have recently been further advanced by integrating it with grinding operations. In this highly integrated technology, the heat generated in the grinding process is utilized for case hardening.

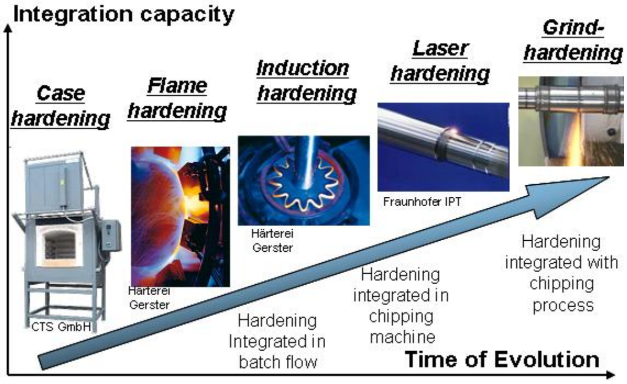

Figure 5: Development of surface hardening technologies.

It is interesting to note that recent developments in laser technology have had a significant influence on the technology of laser integrated manufacturing. Although there were several attempts to integrate lasers into machine tools in the past, the physical size of the CO_2 laser and issues with the conveyance of the laser beam have precluded the widespread application of this technology. The outlook for the application of this technology has appreciably changed since the advent of solid-state high-power diode laser (HPDL) technology as it is readily integrated into a machine tool on account of its significantly reduced size of the laser head. This laser is further relatively efficient, reliable and maintenance-free. It features good temporal stability and a beam energy distribution that is well suited for surface modification. HPDLs are also capable of beam transport through an optical cable which enables the time sharing of the laser between machine tools for increased utilization.

4.2 Solution transfer in machining technology enhancement

A significant aspect related to quality in metal cutting is the time dependence of process responses due to the wear of cutting tools. As machining proceeds, the cutting tools incur wear which translates into an increase in forces that affects machining accuracy and a deterioration of the finish of the generated surface.

It turns out that the problem with non-stationary forces in cutting can be solved by adapting the tool geometry. Figure 6 shows what is known as the ledge tool that comprises a protruding lip of a certain thickness that extends along the tool width such that the tool wear can never exceed the thickness dimension. This corresponds to a fairly uniform performance through the life of the tool.

It is interesting to note that such a tool has a parallel in the design of a mechanical pencil. The thickness of the line drawn using such a pencil is essentially constant as the lead wears, as opposed to a conventional pencil wherein the line thickness continually increases with lead wear.

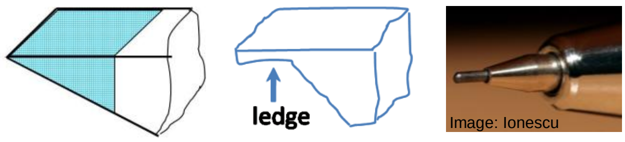

Figure 6: Concept of ledge tool.

The problem of time dependent performance is also manifest in grinding operations. Wear of the abrasive grits results in the formation of flats in them which leads to an increase in the grinding forces and the incidence of grinding burn. In sol-gel aluminium oxide, the abrasive grains have a random structure comprising several micron-sized crystals. Such a structure facilitates micro-fracture of the grains when the force on the grain increases due to wear, resulting in the generation of new cutting edges. This establishes a self-regulating mechanism controlled by the force on individual grits to negate the influence of grit wear.

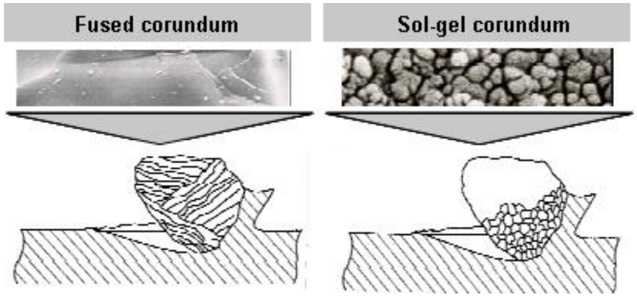

Figure 7: Comparison of the microstructure and fracture properties of fused corundum and sol-gel corundum [9].

It is possible to induce a similar effect in cutting operations through the application of a class of tool materials known as cermets with a tendency to micro-fracture to counteract the effect of tool wear. Consequently, cermet cutting tools provide a good surface finish. However, their wear resistance is not as good as the counterpart tool material known as cemented carbide. The contradiction between the capability to generate surfaces with a good finish and also provide a good tool life is solved in ball end milling operations by separating these functions in space, as explained in Figure 8.

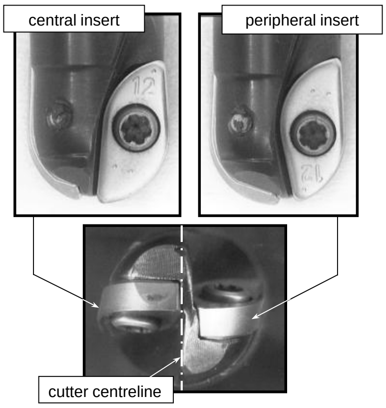

Figure 8: Composite ball nose end-milling tool [10].

The innovative concept exploits the asymmetric geometry of the indexable insert ball nose end mill. As it can be seen in Figure 8, the central insert, as the name implies, extends to the centreline of the cutter and is involved in surface generation while machining. The peripheral insert on the other hand stops short of the centre and thus does not have a role in surface generation. In practice, it is observed that the peripheral insert sustains a higher rate of tool wear compared to the central insert. Hence, it is evident that while the peripheral insert needs to be wear resistant, the central insert would need to generate surfaces with a good finish. This is accomplished by using two different tool materials in the same cutter body: cemented carbide and cermet inserts in the peripheral and central insert positions, respectively [10].

Application of models for surface quality enhancement

Examples are presented in the following to highlight the development of innovative tooling concepts that have resulted from consideration of a simple kinematic model for surface roughness in a turning process. A transverse profile of the surface generated in turning comprises scallops of material that are generated by the nose of the cutting tool, as it traverses a helical path along the circumference of the machined component (see Figure 9). Based on geometric considerations alone, the lower bound for the peak-to-valley height *Rt* of this profile can be shown to be related to the lateral tool feed per revolution *f* and the nose radius R_n as: $Rt = (f^2/8R_n)$.

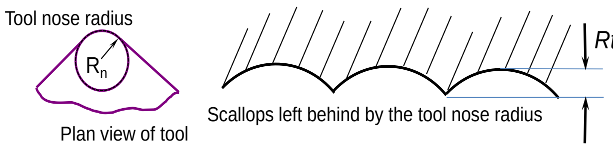

Figure 9: Roughness model in cutting.

The model indicates that the roughness can be improved by either decreasing the feed per revolution or increasing the nose radius. Decreasing the feed rate to improve surface roughness corresponds to an increase in the machining time, and hence is not an ideal solution. Indeed, in machining operations, a high production rate in general conflicts with surface quality. However, the model further indicates that the roughness is not affected by the depth of cut, which can be maximized to enhance the material removal rate, provided that such a measure does not affect process dynamics. It is further clear from the model that the finish can be enhanced without compromising productivity by increasing the nose radius of the tool. In fact, the peak-to-valley height approaches zero as the profile of the tool nose is rendered linear, which relates to an infinite tool nose radius.

Increasing the tool nose radius indefinitely beyond a certain threshold value however presents the issue of undesirable chatter due to the significant increase in the thrust forces, depending on the system stiffness. This negatively influences the surface quality. Hence, it is desirable to develop innovative solutions to address this contradiction and allows for the use of a tool with a large nose radius, without being affected by machining chatter.

The thrust force in machining is given by $F_t = k{\cdot}t{\cdot}b$ where *k* is the specific cutting force that depends on such factors as the workpiece material and cutting geometry, *t* is the uncut chip thickness (feed/rev in this case) and *b* is the machining width. The product $t{\cdot}b$ therefore refers to the contact area between the tool and the workpiece. A possibility to reduce the thrust force and hence the propensity for chatter is therefore to explore possibilities for limiting the contact area, preferably by reducing the width of machining *b*. Such an innovative turning process kinematic entails a tool traverse that is different from the conventional longitudinal traverse along just the component axis (Z direction), and is explained with reference to Figure 10.

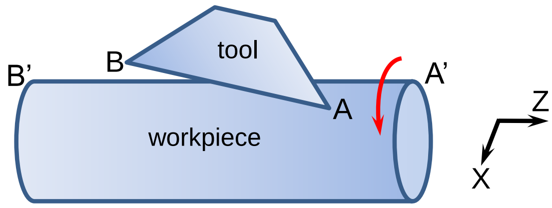

Figure 10: Innovative turning kinematic with a flat face tool.

In this novel configuration, the tool of an infinite nose radius (flat face tool with cutting edge AB) is presented to the workpiece at an oblique angle and is fed simultaneously across the turned surface in the X direction while it traverses axially along the Z direction. The tool edge A thus engages the workpiece at A' and as the tool is fed axially to the end of the workpiece B', the tool is advanced tangentially such that edge B of the tool corresponds to end B' of the workpiece. This kinematic thus reduces the frontal contact area between the tool and the workpiece, facilitating the use of a tool with a large nose radius with no chatter issues. This is due to the significantly reduced thrust forces on account of the oblique contact between the tool and the workpiece. Owing to the lateral motion of the tool, this kinematic is also advantageous in terms of distributing tool wear across the entire width of the tool.

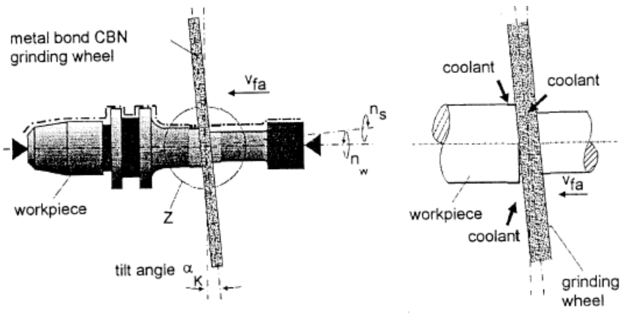

Figure 11: Quick-point grinding **Error! Reference source not found.**].

It is interesting to note that a similar process geometric configuration has also been employed in cylindrical grinding known as quick-point grinding (Figure 11), wherein the wheel is tilted about the vertical plane with respect to the component axis to reduce the area of contact between the wheel and the workpiece. This is beneficial in terms of simpler work holding (just the friction at the centres has been found adequate in most applications to drive the workpiece), facilitating better ingress of the cutting fluid into the grinding zone for enhanced cooling and lubrication as well as enhanced precision due to the reduction in grinding forces.

The solution presented in Figure 10 involves additional hardware for implementing the tool kinematic. To this end, a compromise solution to resolve chatter issues associated with a tool of an infinite nose radius is the innovative design of the so-called wiper inserts whose cutting edge profile integrates a radius and a small flat. To be effective, such a tool need be used at a feed per revolution less than the width of the flat for it to be able to remove the scallops left behind by the tool nose in the previous pass. Such inserts are currently used both in turning and milling applications.

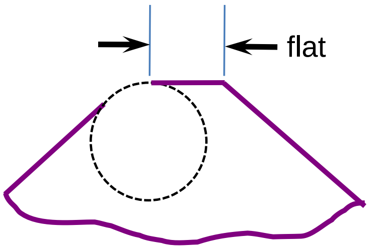

Figure 12: Wiper insert geometry for cutting.

5 TECHNOLOGY KNOWLEDGE AND TECHNOLOGY MODELS

As shown by the examples above, new solutions in manufacturing technology enhancements often represent an integration of knowledge from different technology domains. The knowledge of technology is represented in different kinds of technology models. Thus in interdisciplinary solutions, different technology models are brought together, so that a new solution can be described or explained. At the present time, although the mechanisms of single technologies have been thoroughly investigated and modelled in detail by several experts, interdisciplinary solutions are hardly found. The reasons for this are the limited individual knowledge concerning other disciplines or technologies, as well as psychological barriers (psychological inertia vector).

While the research and development of new technology solutions is mostly characterised by randomly discovered effects – often described as an "accident" – followed by model generation, a systematic and more efficient approach is missing. In order to increase the probability of interdisciplinary solutions in production technology research and development, the linking of different technology explanation models is vital, as shown in [7]. Although experimentation remains the most essential tool for manufacturing technology development, a systematic use of known models prior to experimentation can improve the efficiency of the development process. Assuming that the technology knowledge that is necessary for finding and modelling new technology solutions already exists; this knowledge has to be made available for solving specific technology problems or limits. Due to the fact that the manufacturing technology knowledge needed for technology enhancements is contained in models, these models are classified into different model types as shown in Figure 13.

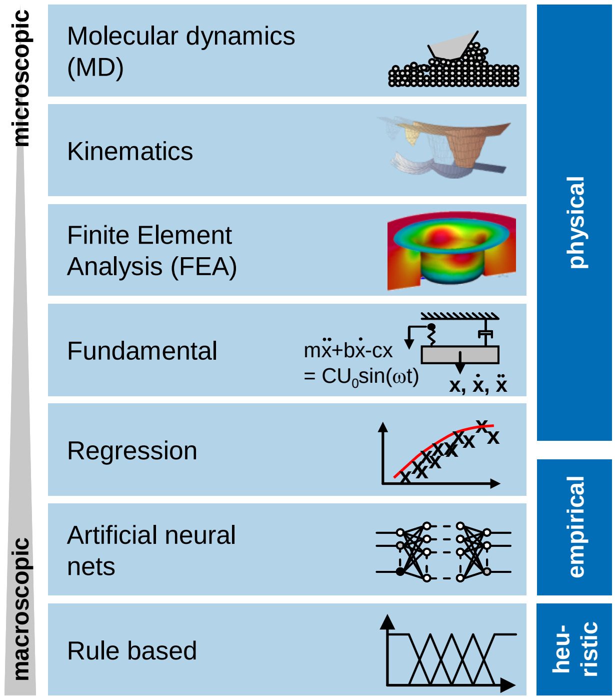

Figure 13: Models for manufacturing technologies [12].

Analytical-physical models are based on physical laws or functions. The original type of physical models is the fundamental-analytical model, which is mainly based on basic physical equations and only to a minor extent on empirical interrelations. Since the age of computers has found its way into the modelling of manufacturing processes, numerical simulation methods have been used based on finite element models, kinematic-geometric models or molecular dynamic approaches. These approaches are among physical models.

The empirical models are based on experimental data that is analysed statistically. The most common empirical model is the regression model, which describes the relations between a dependent variable and one or several independent variables. An empirical model type developed of late is described by an artificial neural network. It is used for the prediction of output variables depending on input variables and the system model of the process. While the relations between input and output are hidden in this model, the model is created "automatically".

The third model type is represented by heuristic models. This type of models is based on experiences that often cannot be described in the form of exact quantities but by a rule based link between process characteristics. With help of fuzzy logic the information can be transformed to mathematical expressions and thus be used for statistically reliable prediction of process results. Usually, current heuristic models often describe relations between input and output of a technical system or setting parameters and machining results in the case of a manufacturing process respectively. Besides, technology specific knowledge of an expert concerning the causes and effects of technology behaviour and mechanisms is also often described by heuristic models.

The common thread in all models is that they contain information that could potentially be used for the purpose of improving different manufacturing technologies in accordance with general TRIZ principles.

6 INTEGRATION OF TRIZ & MANUFACTURING TECHNOLOGY DESIGN

As shown previously in the analysis of manufacturing system developments, fundamental innovations in production technologies can be realised by the combination of different technologies and technological knowledge from different technology domains. Thus the human feature of creativity and knowledge transferability is an important factor which has to be supported.

Solving a problem requires the availability of an adequate amount and type of information about the considered system and about potential solution approaches as well. As per information theory different kinds of information are distinguished. The information important here in terms of the new solution is the “pragmatic information”. This information is quantified by the grade of information that becomes effective on the part of the problem solving person. According to this definition the pragmatic information features a maximum between total newness and total redundancy, see Figure 14.

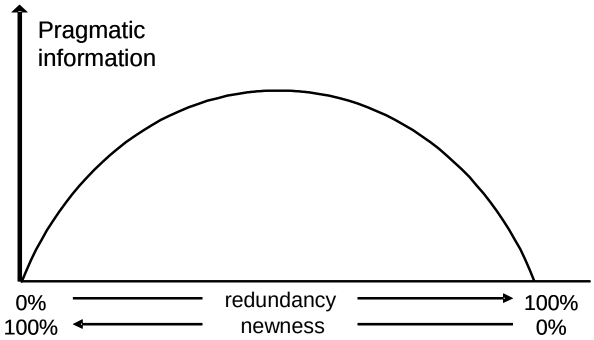

Figure 14: Principle of pragmatic information [11]

In terms of a problem solving process in manufacturing process design, higher pragmatic information about both the problem and potential solutions increases the efficiency of the design process. For high pragmatic information it is vital that the receiving person knows the language in which the information is transferred. In the context of technology modelling, this implies a common model language. In section 5 different kinds of manufacturing technology models have been shown that often cannot be combined even within the same technology domain. Thus a common language has to be used to apply the knowledge of technology specific models in order to find interdisciplinary solutions.

6.1 Integration of TRIZ and manufacturing technology development

As shown in [7], the herein aimed approach of manufacturing technology design and TRIZ show common general characteristics for the purpose of solving problems in accordance to [2]

[13] [14] [15] [16] [17]:

Interdisciplinary solutions

For the purpose of finding inventive manufacturing technology solutions, the combination of different technology models is necessary. A combination of different models can lead to a common technology unspecific language of problem analysis as well as the integration of “technology-foreign” knowledge, which can lead to new solutions.

The ideal solution

Both TRIZ and the manufacturing design process aim at the “ideal solution” instead of accepting early compromises. In order to achieve a technology improvement with higher ideality compared to conventional optimisation, at least two conflicting output criteria of the manufacturing system have to be improved at the same time.

Analogies

The analogy approach is based on the assumption that most problems already have been solved in other (manufacturing) technology domains. In order to support the creative part of specific solution design, analogies are used to deflect the focus of possible solutions off the field of the psychological inertia vector (PIV).

Abstraction

Known specific solutions can be used to identify standard solution strategies, that can be used to find a solution for another specific problem. The linking of solution and problem is enabled by an abstract modelling of specific problems and solutions. This principle is reflected originally within TRIZ by the idea of standard problems and standard solutions. In order to integrate different technology knowledge, technology models must be transformed within a step of abstraction. Thus the information of the technology models is reduced, but the important information about the mechanisms that lead to problems as well as potential solutions needs to be retained while the model is transformed.

The above mentioned parallels between the principles of TRIZ and manufacturing technology design in the context of changing trends of production technology developments show a high potential for the use of a manufacturing design methodology aligned with TRIZ. Summarizing, the main parallels are expressed as: ***The challenge of finding inventive and interdisciplinary solutions that follow the direction toward current multi-criteria definition of ideality*.**

Although the application of TRIZ in manufacturing process design is promising, it is either not applied or even unknown in most instances. Potential reasons are the time consuming methodology learning efforts and limited transferability of TRIZ methods to the analysis of manufacturing technology limits and its root causes. Reasons are complex mechanisms and interactions of many manufacturing technologies that are either unknown or cannot be explained in terms of problem description models in accordance with TRIZ. Furthermore, abstract solutions that are generated using TRIZ methods offer many degrees of freedom. This high level of ambiguity (which is desired in many TRIZ applications) often overstrains the user and thus reduces the probability of a specific solution. Moreover, analogies and solutions described here are often not applicable to specific manufacturing technology problems or they seem to be trivial. A manufacturing design methodology aligned to TRIZ but with lower abstraction level that is focused on the mechanisms of manufacturing technologies in a first step might be a promising approach for the integration of TRIZ and manufacturing technology development.

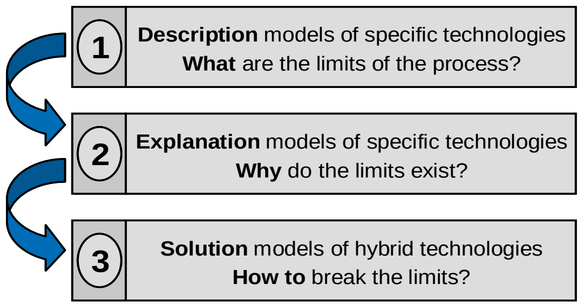

Figure 15: Steps of the design methodology approach for integrated manufacturing process enhancement [7].

In [7] a design methodology approach for hybrid manufacturing technologies was introduced for the purpose of finding inventive (hybrid) process solutions. Figure 15 shows the main structure of the introduced design methodology. The description of the process limits can be done phenomenologically by black-box models of the manufacturing system. For this purpose a description model that only considers the input and output of the system can be used, while input and output can be material, energy and information according to the definition of an EMS model [18]. In the case of a manufacturing process, the function of the system is defined by the desired transmutation of the workpiece characteristics and the amount of required resources such as tools, energy and time. Technology limits can be described and realised by technical contradictions of those input and output parameters, but often the original mechanisms and effects of the technology limits are described implicitly and cannot be identified in detail.

Every production technology uses specific mechanisms in order to transmute a workpiece from one state into another state and thus creates added value. The transformation of the workpiece describes the effect of the manufacturing technology. In order to explain the effect of the technology detailed an in-depth knowledge is desired in order to identify the root causes and hidden system contradictions within the whole cause and effect chain. Thus the black box description of the manufacturing process has to be replaced by an explanation model, which considers the knowledge about the system structure including process characteristics and mechanisms (see Figure 16). If the required knowledge for the analysis of the technology is contained in different models, reduced information of these models has to be integrated in one model. The method of generating this model must be able to represent the view of the technology expert, to interpret his technical language and use his technology specific knowledge. In order to complete the cause-and-effect (CAE) model several influences have to be studied by a review of single models, diagrams or expert knowledge. In a next step, the critical cause-and-effect chains are identified and root causes are analysed in terms of technical or physical contradictions. Based on this system analysis within a problem solving process the “real” contradictions that causes a technology limit can be addressed.

Manufacturing technology cause-and-effect model

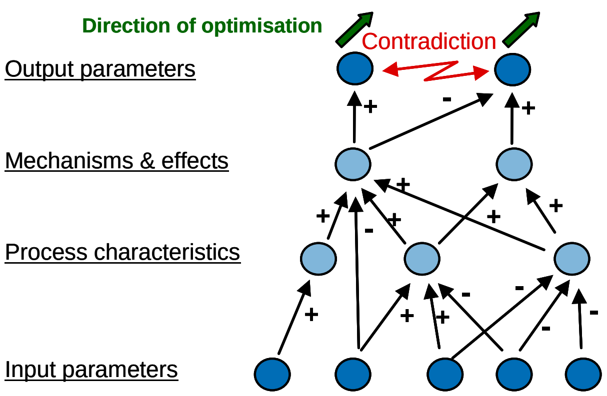

Figure 16: Abstract manufacturing process model for the explanation of technology limits.

Important abstract solution principles, which could be identified in radical technology solution, are:

- Make the system more flexible or efficient by changing or controlling system elements or interrelations that can influence the core contradiction that have not been influenced yet.
- Add subsystems that can influence the contradiction elements of the systems or even can change undesired effects into desired effects (e.g. adding a new energy as in laser-assisted machining or ultrasonic-assisted machining).

Once the critical cause-and-effects are identified, they can be also shown by means of a substance field (SF) model. A comparison of the manufacturing CAE model with the SF Model shows some important similarities. Most of the input and output parameters that are separated in the CAE model are properties of the substances in the SF model. The process characteristics (e.g. temperature, forces, electrical current) are represented in the fields and the mechanisms are described by effects in a SF model.

Comparison of CAE model and SF model

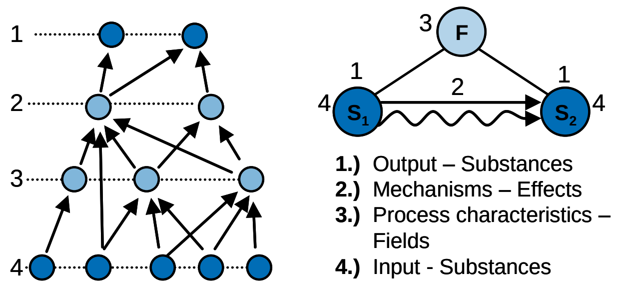

Figure 17: Similarities between CAE and SF model.

Thus the capability of SF analysis and the related standard solutions can be used in combination with a detailed manufacturing technology analysis while using expert knowledge about process characteristics and mechanisms. Besides SF analysis other TRIZ methods can also be useful for solution generating at this point as shown in [7]. For people with detailed technology knowledge this combination promises a better access to the TRIZ methodology and increases the probability of new technology solutions.

6.2 Open questions in using TRIZ for manufacturing technology development

Although first approaches have been developed there is still much research required in order to use manufacturing technology knowledge for TRIZ-based technology enhancements. One specific challenge in the case of manufacturing technology development is the fact that technology evolution steps are characterised by a change of mechanisms or a change of quantity and durations of process mechanisms. Considering that the interactions and mechanisms of a technology application are dynamic, time separated processes phases have to be described in order to explain a manufacturing technology comprehensively. This will be shown in the following by the example of an electrical discharge machining (EDM) process, see Figure 18.

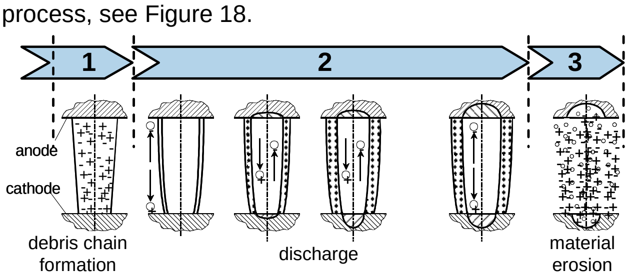

Figure 18: Electrical discharge process model.

The EDM process features highly dynamic interactions that can be simplified into several phases. Regarding the main mechanisms of this machining process these phases can be reduced to three process phases: debris chain formation, electrical discharge and material erosion.

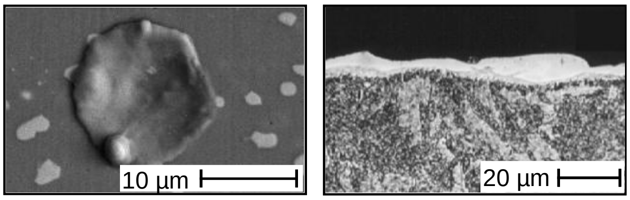

Figure 19: Micrographs showing melting and recast formation in EDM.

In the example of an EDM process, the initial problem that should be analysed is the contradiction between high material removal rates and low recast layer generation (Figure 19). Based on an analysis of the cause-and-effect chains of the EDM process the SF models were derived as shown in Figure 20.

In the first process phase the voltage between tool and workpiece causes a debris chain formation in the dielectric fluid. The properties of the electric field influence the following effects as “classical” input parameters of the EDM process. But also the properties of the dielectric fluid are important input parameters.

In the second phase of the process electrical discharge appears and leads to a thermal field that has an effect on both the tool as well as the workpiece. Concerning the above described problem only the workpiece influencing effects are shown. Here mainly two mechanisms are identified: material heating in the sub-surface and material melting on the surface. Thus two substances are separated in process phase 2 out of one substance in phase 1. Here the system structure of the process has changed. In reference to the substance field analysis an effect should be evaluated as desired or undesired. Due to the relationships between extent of material melting and the effects of the following phase 3, the effect of material melting is both desired and undesired in terms of a physical contradiction. On the one hand the material melting effect should be maximised for an optimisation of productivity, on the other hand it should be minimised for a better surface integrity. The progression of time is not immediately evident in this SF model that is essentially static in nature.

The next phase of the process has to be considered in terms of two SF models that are indeed related and can be separated in space. The core problem can most effectively be shown by the link between elements of phase 2 and phase 3. While the mechanism of material melting is described by a physical contradiction The ideal solution is to realise an infinite material removal without sustaining any recast. The different SF models finally have to be linked over the time in order to account for the dynamic character of manufacturing processes. The ambiguity of the material melting mechanism thus can be explained by a time-delayed pair of different physical mechanisms that are related and describe a contradiction.

The functions of material removal and removal of the recast layer can be separated in time by employing a roughing process to maximise the material removal followed by a finishing process that focuses on removing the recast. Another and more ideal solution to the contradiction is to maximise the ratio of the molten to the recast material. As known from other technology models several aspects could be helpful to avoid the mechanism of material adhesion by the application external fields such as ultrasonic vibration, abrasion or high speed fluid flow.

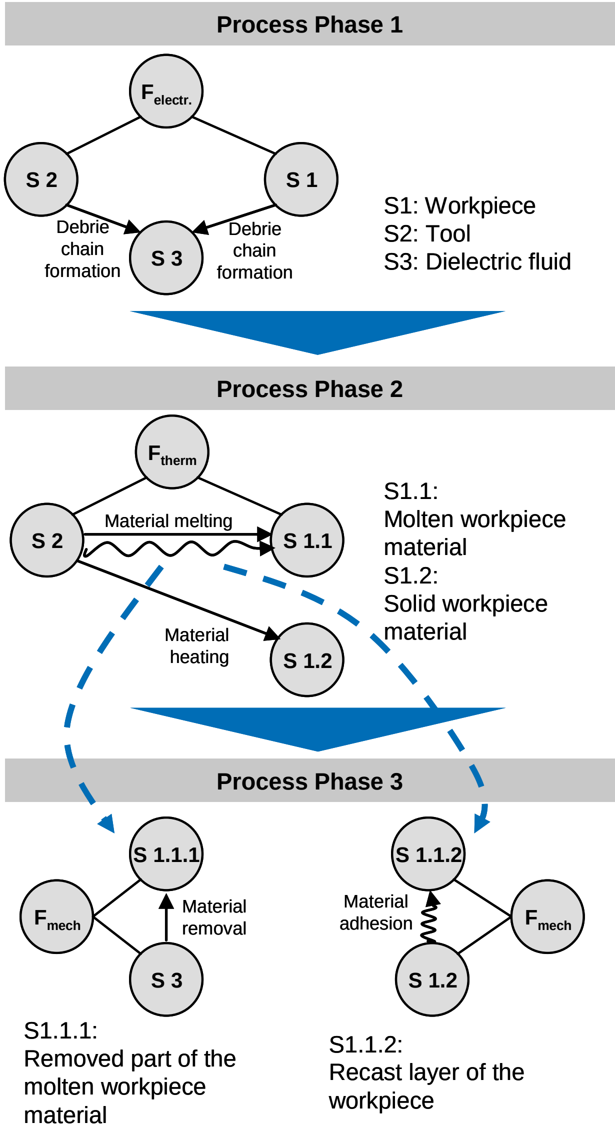

Figure 20: SF model of an EDM process concerning the problem of recast layer generation.

7 SUMMARY

Innovation is the key to ensure manufacturing competitiveness especially in western countries as a consequence of globalisation. It is essential to exploit the potential for innovation that is present in the knowledge base. Most of the existing knowledge about specific technologies is not applicable to other technologies because the technology models are not transferable. A common semantic for the explanation of limitations and solutions of different manufacturing technologies is needed for interdisciplinary manufacturing process design approaches. A review of several innovative manufacturing technologies has indicated that they evolve towards increasing ideality, while the scope of ideality itself is dynamic. Similar solution principles have been shown to underlie technology developments in diverse process domains, which indicate the potential of formulating standard solutions as those in TRIZ for further process development. Although the parallels of TRIZ and requirements of manufacturing technology development are evident, still further research is warranted in order to better align TRIZ with manufacturing technology development. System models describing and explaining technology problems should be enhanced in order to benefit from detailed knowledge about the mechanisms of specific manufacturing technologies when applying TRIZ in order to find the solution.

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Eco-design with TRIZ Laws of Evolution

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Abstract

Sustainability is one the most recent theme designers have to deal with and sustainability parameters are quickly gaining the top of the list of the requirements any product has to fulfil. Due to standards, legal regulation and customer growing awareness of environmental issues, engineers cannot avoid turning their everyday activities from design to eco-design. By the way, a significant drop of environmental impact of products cannot be achieved by simply adding a 'green' constraint to the already overpopulated list of design constraints. To answer to this issue a plurality of methods are available helping the designer (or pretending to) to assess product lifecycle or to provide suggestions on how to innovate the product or process according to sustainable goals. Within this context, the present work describes a way of using TRIZ concepts and tools in order to both assess and innovate a technical system so that some practical activities to ensure sustainable results can be easily embodied into everyday design practice. The main novelty on the operative level consist of an original method based on a set of Guidelines derived from Laws of Technical System Evolution (LTSE) in order to assess the value of existing solution (e.g. using Resources and Functionality as a metric of evaluation), to understand the most promising directions of improvement and to improve said solution also according to sustainability requirements. The paper will show the way Guidelines are applied with practical examples and an industrial case study will be presented and discussed.

Keywords

Eco-design, LTSE, Resources, Eco-guidelines

1 INTRODUCTION

Eco-design represents a challenge technicians are trying to face since the cost of products or processes has started being calculated including the total environmental cost. From a TRIZ point of view eco-design is mainly a matter of Resources (exploitation or saving), and a design properly based on this concept can lead to notable "green" results even without using any ad-hoc "green" methodology. There are several reasons, not necessarily technical, why actual systems generally make a bad use of resources; the most frequent are the following:

- Starting requirements are overestimated due to a lack of knowledge or excessive assurance or useless extra features.
- Design of sub-systems is done separately and, as a result, some resources will be inefficient or redundant and sub-systems will scarcely interact one each other.
- Unsolved problems bring over complication of product or process and imply poor cooperation of parts and several elements not contributing to the final function the system has to perform.

These and some other causes deeply impact on sustainability of the final result of design. Actual products waste a significant amount of material, energy and space that could be saved to decrease their impact on the environment. Thus, an adequate methodology to address eco-design issues must be as strong in assessing as-is situation as in providing new answers to push evolution toward the right direction.

Nowadays design methods dedicated to sustainability can be divided in two groups: the firm are focused on eco-assessment through statistical elaboration of past data (e.g. Life Cycle Assessment, Life Cycle Design Strategy Wheel), the latter, mainly experience driven, are intended for innovating the system to gather a better eco result (e.g. Ten Golden Rules, Companies Eco-Guidelines) [1-11]. What is missing is an in integrated method answering both issues with a systematic, practical and efficient method. The aim of this paper is to fill in this gap with a step by step procedure developed on the base of TRIZ fundamental concepts and tools. In particular the schema represented by the LTSE and their corollaries has been adopted to elaborate an operative set of Guidelines and some suggestions in form of "rules". The Guidelines constitute a new way of performing the statement and solution of a problem concerning sustainability, for which it's not necessary to master TRIZ tools to gather good results.

2 BACKGROUND

The attempt to integrate TRIZ tools in an eco-design framework comes both from eco-design experts and from TRIZ community.

From eco-designer perspective, a comparison among eco-guidelines and TRIZ problem solving tools (especially 40 Inventive Principles [18]) has been performed to find out similarities rather than integrations. Sometimes it is used in combination with other improvement eco-tools, such as Eco-Compass [19].

Some researchers from the TRIZ community put particular attention to the analytical stage of assessment, not completely and effectively covered by TRIZ, at least in its classical version. This lack could be overcome by integrating TRIZ with other methods such as Lean [12-14] TPS or LCA [15], QFD, Taguchi method, FMEA, Design for manufacture, for assembly, for disassembly, Axiomatic design [16], etc. Some other works have been done in the past, concerning the search for analogies among Problem Solving tools and rules and suggestions coming from Design for Disassembly, Sustainability or Reuse [17] or with the aim of interpreting the 40 Inventive Principles in an ecologic perspective [18]. Jones and Harrison [19] used the Functionality concept and the Matrix Parameters within the Eco-compass method to highlight contradiction dealing with sustainability. Mann in [20] introduced TRIZ trends and evolutionary radar plots to assess and compare the sustainability of existing technical solutions. In general, known works are either focused on assessment of sustainability of present technical solutions or propose the use of classical TRIZ problem solving tools (mostly Inventive Principle and the Matrix) on an ecologic problem. Nowadays there is not an integrated design approach that builds sustainability in each step (since the very first) of product/process development differentiating from any inadequate end-of-pipe methods. In such a context, the authors propose to consider some TRIZ fundamentals, mainly Laws of Technical System Evolution and Resources, to obtain an independent set of eco-guidelines to support both assessment and improvement of products and processes from an eco-design perspective.

3 TRIZ TOOLS ADOPTED

3.1 Laws of evolution [21,22]

Law 1 Completeness of the parts of the system

Every technical system should consist of four components: engine, transmission, control unit and working unit. If any component is missing, the technical system does not exist, if any component fails, the system does not survive.

Law 2 Energy conductivity

Prerequisite to viability of a system is the free flow of energy through all system parts. As every technical system transforms energy, this energy should circulate freely and efficiently through its four main parts.

Law 3 Harmonizing the rhythms of parts of the systems

Prerequisite to viability of a technical system is coordination (or purposeful de-coordination) of rhythms (e.g. vibration frequencies, periodicity of operation, etc.) of all parts in a technical system.

Kinematic laws defining how technical systems evolve regardless of conditions (technical or physical factors):

Law 4 Increasing the degree of Ideality of the system

All systems evolve towards the increase of degree of Ideality.

Law 5 Uneven development of parts of a system

The development of parts of a system proceeds unevenly: the more complicated the system, the more uneven the developments of its parts. Uneven development of the parts is a reason for the occurrence of technical and physical contradictions and hence inventive problems.

Law 6 Transition to a super-system

During evolution, technical systems merge and form bi- and poly-systems. When a system exhausts the possibilities of further significant improvement, it is included in a super-system as one of its parts and a new development of the system becomes possible. Dynamic laws defining how technical systems evolve according to technical or physical factors:

Law 7 Transition from macro to micro level

The development of working organs proceeds, at first, on a macro and then on a micro level.

Law 8 Increasing the S-field involvement

Non S-Field systems evolve to S-Field systems. Within the class of S-Field systems, the fields evolve from mechanical fields to electro-magnetic fields. The dispersion of substances in the S-Fields increases. The number of links in the F-fields increases, and the responsiveness of the whole system tend to increase.

3.2 Resources [21-24]

The concept of resource is crucial to conceive more sustainable products. A good exploitation of resources can be an effective check parameter to assess the real efficiency of a system. Looking at the way the initial system uses resources, and what type of resources is still to be exploited it is also possible to modify the system to make it better.

Due to the fact that the proposed method strongly uses the concept of resource we propose some TRIZ definition and classification.

For TRIZ any system that has not reached Ideality still has some substance or field resources that are:

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

The concept of resource was born from the assumption that a system possesses more capabilities of what is necessary for normal functioning. The formal concept was introduced in Ariz85 (point 2.3) by Genrich Altshuller in the form of "substance field resources". In this form a first classification is provided:

- Internal resources: things, substances, and fields reachable in the conflict area or operative zone during or before conflict time or operative period.
- External resources are things, substances, and fields near the conflict area or phenomena that occur before conflict time.

Altshuller indicated also super-system or other accessible, inexpensive resources, and resources coming from temporary modifications of the object. Later, this concept was expanded to include other types of resources such as functions, information, space, time, change, etc. A further classification was introduced with readily-available and derived resources to distinguish ready-available resources for solving a problem from those usable only after some sort of modification. Igor Vikentiev introduced a definition of differential resources (resources produced by the difference in the properties of a substance or field, such as the voltage created by a difference in electrical potential); Zinovy Royzen suggested change resources (resources produced by a change to the system). Vladimir Gerasimov and Dr. Simon Litvin introduced the concept of a super-effect – an additional benefit (resource) resulting from innovation that often goes unrecognized.

4 METHODOLOGY PROPOSAL

In eco-design it is a common practice to under evaluate the importance of resources; actually, most of the methods focus only on Material and Energy and with quite a superficial attitude. For instance the "companies' guidelines" for the choice of material are limited to a simple classification that goes from good materials to be used freely to awful materials not to be taken into account.

For any TRIZ user it's clear that any resource should not be discarded beforehand and it's not always true that a "bad" resource represent a bad solution, e.g. an infinitesimal amount of a toxic material may solve a problem in a better way for the environment than using generally prescribed material. Evaluating resources without considering their contribution to the function to perform or to the potential combination with others or super-effects means reducing the solution space and missing potential breakthrough ideas.

Starting from these considerations and working on the Laws of Technical System Evolution, 8 Guidelines have been created to reach the goal of assessing and eco-innovating system in a more efficient way. The guidelines, being extracted from the laws of evolutions, are ordered according to the natural evolution path of any system. The first two are focused on measurement and evaluation of the resources used in the systems, while the followings are aimed at reducing resource consumption, increasing efficiency also by means of new technologies and physical effects.

The procedure explained in the followings is intended for non TRIZ experts and some practical rules are given for each step (Table 1).

GUIDELINES	RULES	
N. Name	N.	Short Description
ASSESSMENT		
G1 System modelling	R1.1	Main Function identification
	R1.2	Physical description
G2 Resource assessment	R2.1	Resources exploitation indexes
	R2.2	Analyze present/past system condition
	R2.3	Identify external resources
INNOVATION		
G3 Resource saving	R3.1	Use IFR concepts
	R3.2	Reduce Energy conversion to zero
	R3.3	Explore other technologies
G4 Components interaction	R4.1	Make the actions resonant
	R4.2	Coordinate Fields
G5 System dynamization	R5.1	Dinamyze the system
G6 System simplification	R6.1	Eliminates useless components
	R6.2	Solve contradictions
G7 External resources exploitation	R7.1	Merge technical systems
	R7.2	Shift to super-system
G8 Fields cooperation	R8.1	Increase S-Field involvement

Table 1: Eco-guidelines and rules

G1. System modelling

This first phase recommends a problem reformulation to a higher abstraction level, removing specific features and modelling it by an easy schema. This schema has to be able to identify the Main Function and the required input resources able to change the object into the desired product.

R1.1. Main Function identification

Classic theories of Design modelling, like Energy Material Signal (EMS) [25] model, are recommended frameworks to identify the right abstraction level of the system. EMS model describes a system like a transformer of Energy, Material and Signal. The main useful function is identified by analyzing the Minimal Model (tool-transmission-source-control) in order to identify which changes have transformed the object into the product (fig. 1).

R1.2. Physical description

In order to have a clear map of the system it is fundamental to understand its functioning from a basic point of view. In particular the scientific laws (i.e. physical, chemical, etc.) on which the technology of the system is based must be identified and compared with the laws characterizing its natural behaviour. In other words we must clearly identify the role of the system from the point of view of the natural laws preventing the object to turn into the product by itself. To do so we distinguish Technical Effects those are caused by the system, from the Natural Effects due to the nature of the object and its environment. Figure 1 show the schema used to find out the Main Useful Function (MUF) according to R1.1 and R1.2.

G2. Resource assessment

Once defined what is the real task for which the system exists, we can proceed to understand the way resources are used. There are three directions to look for to accomplish this goal:

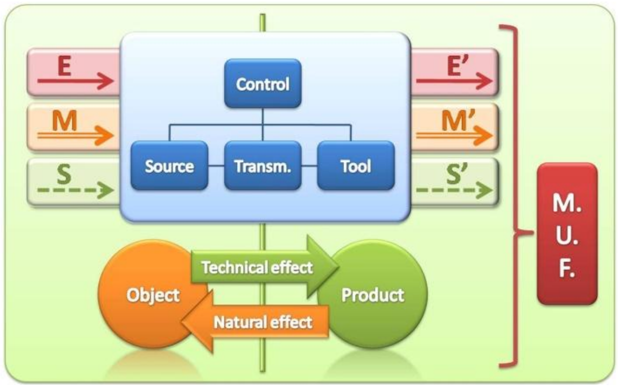

Figure 1: EMS with Minimal model and Object-Product transformation Effects are used to define the MUF.

- Identify actual level of resources exploitation;
- Analyse hidden potential resources of the system;
- Identify available external resources.

R2.1. Resources Exploitation Indexes

Energy, material and space are analyzed one by one separately. Resource exploitation is assessed by means of three specific indexes that compare the actual system, the best known system and the ideal system. Table 2 shows how to calculate such indexes.

	I_1	I_2	I_3
Energy	E_{best} / E_{curr}	E_{ideal} / E_{curr}	E_{ideal} / E_{best}
Material	M_{best} / M_{curr}	M_{ideal} / M_{curr}	M_{ideal} / M_{best}
Space	S_{best} / S_{curr}	S_{ideal} / S_{curr}	S_{ideal} / S_{best}

Table 2: Indexes comparing current system configuration (curr) with the best in class (best) and the ideal (ideal).

I1 measures the gap of efficiency existing between the system under investigation and the best available on the market. Analogously, I2 compares the resources of the current system versus the ideal one. I3 can be used to evaluate the gap between the best in class system and the ideal one. These indexes permit to highlight the margins of improvement of system according to the specific resources. Comparing I1, I2 and I3 we create a picture of resources used by our system, the best competitors' and the ideal one.

Let see for example the case of the energy (E) exploitation:

$$I_1 = E_{best} / E_{curr} \quad (1)$$

where:

- E_{best} is the energy used by the most efficient system on the market or the highest value reported in the standard efficiency tables (for an example see fig.2).
- E_{curr} is the total energy used by technical system during standard functioning (to provide all functions).

Table 3 shows what is meant for current, best and ideal systems for Energy, Material and Space in the case of a home vacuum cleaner.

R2.2 Analyze present/past system conditions

Use check lists and resources classification to identify all available (ready, differential, derivative, etc.), resources hidden in the system (e.g. instead of waste exhaust gas from an engine put again into the engine to create a turbo effect, use body energy due to vibrations during a march to recharge equipment's batteries, vapor ejected from an iron can be saved and used into the iron boiler etc.)

Analyze past conditions in order to understand how resources have been modified since now.

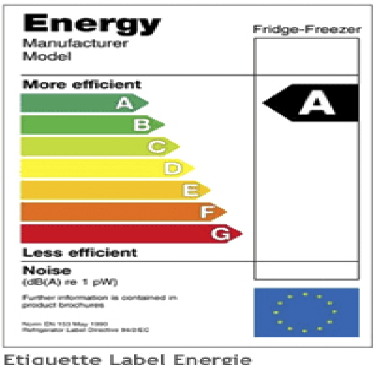

Figure 2: European freezer efficiency standards.

	curr	*best*	*ideal*
E	…for creating suction flow passing through the filter	…for creating suction flow in the best vacuum cleaner	…to collect only dust particle into the filter
M	… required by the entire system	…required by the entire system	… to contain only dust
S	…required by the entire system	…required by the entire system	…to contain only dust

Table 3: Determination values to calculate indexes for a vacuum cleaner

R2.3. Identify external resources

Use check lists and resources classification to identify all available (ready, differential, derivative, etc.), resources in the system environment.

G3. Resource saving

Guideline 3 offers indications to choose between current and future technologies in competition.

R3.1. Use IFR concept

Technical system should not only be a suitable power conductor, but should also operate with minimal energy losses (such as losses incurred by transformation, production of useless wastes, and withdrawal of energy with ready-made artifact). System should use energy only to provide the main useful function in according to IFR concept.

R3.2. Reduce Energy conversion to zero

It is desirable to use one field (i.e. one kind of energy) for all processes of system operation and control. As the technical system evolves, each new subsystem should use energy that circulates in the system, or energy that is available free of charge (energy of the environment, wastes of another system). The "Reduce Energy conversion to zero" Trend of evolution should be taken into account.

R3.3. Explore other technologies

G1 and G2 force the examiner to assess the scale of phenomena through which the Main Function is performed between tool and object. In order to find systematically a list of alternative technologies, making the same function and working at a different detail level, use **TRIZ Standard 3_2_1**: *"Efficiency of a system at* any *stage of its evolution can be improved by transition from a macro level to a micro level: the system or its part is replaced by a substance capable of delivering the required function when interacting with a field*".

If the substances of the parts can be replaced, then the field with sufficient controllability should gradually replace the field with insufficient controllability in the following order: gravitational, mechanical, thermal, magnetic, electric, and electromagnetic. Replacement of fields is carried out together with replacement of substances or introduction of the admixture that secure good power conductivity (the substance should be transparent for the chosen field). A specific Patent analysis, (better if based on FOS and using semantic parsers) is strongly suggested.

G4. Components interaction

This Guideline aims at improving technical system efficiency, changing functioning and behaviour of the system. Such a change is produced by coordinating rhythms of technology used by the system with the ideal rhythm of the desired solution; in other words we want to coordin total environmental ate the rhythm of the Main Function that tool performs on the object with the physical natural laws of the object.

R4.1. Make the actions resonant

Replace continuous actions with periodic or pulsating actions, and then to resonant so that the technical system operation is optimized through mere modification of its component (dimension, mass, and frequency). Nothing is introduced into the system in order to improve the main useful function and efficiency according to the energy conservation. The frequencies of vibration, or the periodicity of parts and movements of the system should be in synchronization with each other, or coordinated (or de-coordinated) with natural frequency of the product.

R4.2. Coordinate Fields

Frequencies of fields used in technical systems should be coordinated or de-coordinated. If two effects are incompatible (e.g. transformation and measurement), one effect should be exerted when the other effect pauses. More generally, a pause in one effect should be filled by another effect.

G5. System dynamization

R5.1. Dynamize the system

Try to dynamize the system or some subsystems:

- Allow a system or object to change to achieve optimal operation under different conditions.
- Split an object or system into parts capable of moving relative to each other.
- If an object or system is rigid or inflexible, make it movable or adaptable.
- Increase the amount of free motion, then pass to liquid, gas and some kind of field; i.e., pass to a more flexible, rapidly changing, and adaptable structure (e.g. blade cut, flexible cut, water cut, laser cut).

G6. System Simplification

When a new system appears, at first complexity raises up and resources exploitation is inefficient, uncontrolled, and not harmonized (expansion phase). Afterward, energy consumption tends to be optimized; global efficiency grows while system is simplified by trimming components and transferring functions to the super-system.

R6.1. Eliminates useless components

If they exist, eliminate useless components. Trimming activity can be associated to a traditional TRIZ functional analysis. Systems at the beginning of their existence increase the number of parts, thus they are using resources in a not very reasonable way. In this phase it is useful to build a functional model of system by suitable diagrams, so it is possible to provide trimming of components, unifying more functions under a lower number of components, this means that system is simplified through a convolution (we try to advance the convolution phase of system taken into account, see figure 3).

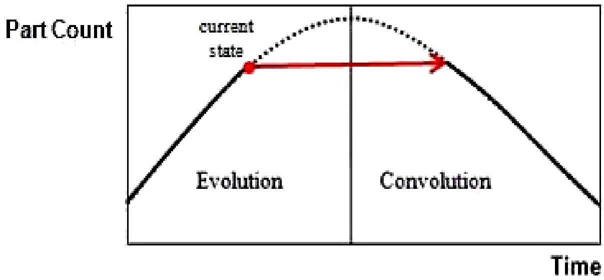

Figure 3: A new path of evolution, where the system evolves from the current state of evolution (not yet complete) directly to an advanced convoluted phase.

R 6.2. Solve contradictions

Find and eliminate contradictions due to the uneven development of parts of a system using traditional TRIZ Separation Principles.

G7. External resources exploitation

If the system already reached its maximum development, it will aim to delegate functions from inside the system to outside to the super system; next step of development continues at super system level, or in the environment.

R7.1 Merge technical systems

Merge technical systems and anticipate future bi- and poly-systems

R7.2 Shift to Super-system

Implement the concept of Ideal System that is a system that does not materially exists anymore, while its function is still performed. To do this try to transit the system to super-system.

G8. Fields cooperation

R8.1. Increase S-Field involvement. Develop the system increasing the S-Field involvement.

The new fields are introduced as fields that cooperate with the main field already existing in order to realize the same Main Function. This integration is useful when different fields can work together with synergism.

5 CASE STUDY- VAUUM CLEANER

In order to show how the guidelines work, a vacuum cleaner used to remove dust on a carpet has been selected as case study. The vacuum cleaner taken into account is the one shown in figure 4.

G1. System modelling

R1.1. Main Function identification

EMS model suggests visualizing two different flows:

- Electric energy (electric current) is converted by the system in kinetic energy (velocity of air).
- Dirty air in input is transformed in clean air.

A vacuum cleaner is a system able to create an air flow by depression (converting electric energy), and this air moves dust particles towards the filter; in this way dirty air is filtered and dust particles are separated from air. The Main Function identified is: move dust particles (from carpet to the filter). The tool is the air and the object is the dust particle. The product of the system is the dust particles moved/dragged.

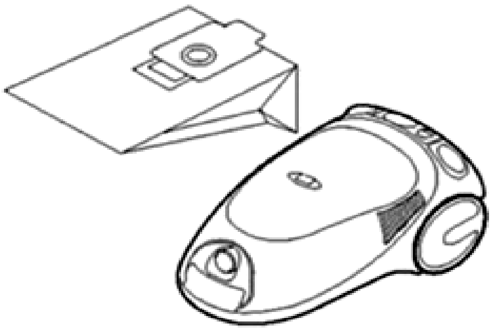

Figure 4: A classical vacuum cleaner with paper filter.

R1.2. Physical description.

The physical law avoids obtaining the desired product: the force of gravity and the force of adhesion keep dust on the carpet

G2. Resource assessment

R2.1. Resources Exploitation Indexes

At first an evaluation of the Energy assessment is proposed; first step needs of calculating the efficiency in terms of Energy according to the European standard test for vacuum cleaners on a carpet test (dust mass=0,035kg, height from carpet to filter= 0,4m and time test= 180s).

Table 4 and 5 show the amount of considered resources and the resulting indexes.

	current	*best*	*Ideal*
Energy	324 k J	<150kJ	0,14 J
Material	5 kg	2 kg	Minimal quantity of material to contain 35g of dust (i.e. a plastic bag < 1g)
Space	30 dm^3	8 dm^3	Space/volume to contain 35g of dust (20 cm^3)

Table 4: Amount of resources used by current, best in class and ideal system

	I_1	I_2	I_3
Energy	0.46	4.3*10^(-7)	9.3*10^(-7)
Material	0.4	2*10^(-4)	5*10^(-4)
Space	0.27	6.6*10^(-4)	2,5*10^(-3)

Table 5: Indexes values for the vacuum cleaner

The selected Vacuum cleaner doesn't belong to the optimum class of European efficiency standards as I1 shows (I1_Energy= 0,46). Even if it were the best on the market (I1=1) the other indexes show a radical different situation. In particular I2 and I3 are quite zero as a consequence of the low efficiency of the Main Function: "the system removes a small quantity of dust through an huge air flow".

Material and Spatial assessment:

Although the system evaluated is compact and light the indexes I2 and I3 are lower because the ratio between volume occupied only by the dust and the volume occupied from the whole vacuum cleaner is lower, as well as the ratio between the weight of the plastic bag (to contain the small quantity of dust) and the weight of vacuum cleaner. Also for material and spatial assessment the evaluations are almost the same even if we take into account the best vacuum cleaner on the market.

R2.2. Analyze present/past system conditions

Analyze environment conditions in order to understand how dust is created how it falls down naturally or how it disposed on the carpet for the test.

New resources internal to the system are:

- Dust (full/empty bag) - the dust could attract other dust particles by their residual charge.
- Exhausted air could be used to accelerate fresh air inside the suction duct (by injecting exhausted airflow of vacuum into the suction port).
- Air humidity could be used to compact dust
- Heat (produced by functioning) could be used to heat the air creating a greater lifting force (upward vertical)
- Fan rotation could be used in accordance with a brush.

R2.3. Identify external resources

Some external resources, useful for cleaning or to maintain clean a room, could be: an electrostatic carpet attracting dust particles, a charged floor to direct dust particles where you want or a blow dust particles towards a window.

G3. Resource saving

R3.1. Use IFR concept

We have to think to a vacuum cleaner with lower pressure losses, that implies short pipe, big diameter, low roughness, efficient engine, etc. Applying the IFR means to investigate the dust particle's behaviour before their removal; how to increase collection by means of reciprocal interactions from particles. By such a way pressure and air flow could be saved. The highest abstraction level of IFR suggests: *dust particle moves by itself from the carpet to a "filter"*. The following rules R3.2-4 could help designer to find technologies, physical effects and principles to be used in order to realize IFR target (*To create for example a muddle of dust on the floor to be easily swept out, etc.).*

R3.2. Reduce Energy conversion to zero

The current system converts electric energy into kinetic energy, thus it performs only one conversion.

Could you think a system that used only electric or mechanical energy, without conversion?

- Dust removal system using static electricity (JP60156565).
- Travelling-waves which can lift and convey charged particles (US3930815).
- High-frequency waves (ultrasonic, megasonic, etc.) push away dust (US6058945).

R3.3. Explore other technologies

Decrease the interaction between tool and object means reduce the interaction between *air* and *volume around dust particles*. Thus in this case shifting from macro to micro means that the air will interact in a smaller space around the particle, then with the external surface of the particle, then again with a portion of external surface of the particle and so on.

The author suggest to perform a specific patent search, and to use the *TRIZ pointer to effects*. Here only some exemplary results are reported: dielectrophoretic forces, electrostatic forces, force of buoyancy, polarization, sublimation, chemicals, thermal field, etc.

G4. Components interaction

R4.1. Make the actions resonant

You have to coordinate the MF of the system; air *drags* dust particles, with the physical law avoiding us to obtain the desired product: *dust particles are kept down*.

The dust particles trapped by the carpet fibres are subjected to gravity, friction and adhesion forces that constrain it into the carpet. To coordinate function and object you can move from continue action to pulsating action, then to resonant action. In the current system dust particles are dragged by a continue action, so move towards a pulsating one. It could be figured out an agitation device (e.g a vibrating brush) able to hit the carpet with a certain frequency or a pulsating air suction flow to better move dust particle away from the carpet.

R4.2. Coordinate Fields

The functioning of the vacuum cleaner requires the brush to be moved back and forward several times during the cleaning activity. So it is possible to coordinate functions according to the movement of the brush, exploiting pauses: e.g. pulsating suction user can more easily move brush between a suction peak and the following one.

G5. System dynamization

R5.1. Dynamize the system

Vacuum cleaner modifies suction power according on the surfaces to be cleaned (smooth floor, wrinkled floor, carpet, etc.) or depending on the different zones of the room (corners, flat surface, space under furniture, etc.); dynamization acts in order to reduce energy consumption when and where not needed.

G6. System simplification

R6.1. Eliminates useless components

Examples of already existent trimmed products are electric broom and robot vacuum cleaner.

R6.2. Solve contradictions

Some contradictions were found and here just two examples are reported:

- I want to increase the suction power but I do not want to lose the ease of handling. A possible solution comes by separating in time. We can use a pulsating suction so the suction forces of the single pulse can be greater and the user can more easily move the brush between a suction peak and following one.
- I want to increase the suction ability but I do not want to increase the power used by vacuum cleaner. It is possible to reuse the exhausted airflow for pushing the air in the suction duct.

G7. External resources exploitation

R7.1. Merge technical systems

Mono-bi-poly system: multi-suction ducts, suction duct combined with blowing duct, suction duct and blowing+ heating duct, etc.

R7.2. Shift to Super-system

It could be suitable to shift the function of cleaning/sucking to the building itself as for central vacuum cleaner systems, or to an electrostatic carpet able to attracts and collect dust particles.

G8. Fields cooperation

R8.1. Increase S-Field involvement

The current field used is mechanical, so to increase efficiency it is possible to add other fields to the existing one. For example mechanical field can cooperate with:

- Thermal field to help dust particles floating in the air.
- Electrostatic field added to the suction duct in order to improve the pickup ability.
- Electric device with combined corona electrodes for removal of dust from gases.
- Chemical: dust is removed by primarily spraying an alkaline solution to air flow.

- High-frequency wave device to move dust before sucking, etc.

6 SUMMARY

TRIZ methodology has been evaluated as a potential allied for existing eco-design methods. Some TRIZ tools, such as Ideality, Resources and Laws of technical evolution, have been re-organized in the form of practical eco-guidelines for product innovation. The overall procedure has been clarified by means of one case study dealing with a vacuum cleaner. Guidelines have been applied and checked with success by authors into the area of household appliances and then proposed to students of the University of Bergamo in order to evaluate how the method works also without a TRIZ experience. The good results obtained encourage us to further develop the method.

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Quantifying and Formalizing Product Aspects through Patent Mining

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Abstract

Like most front-end design methodologies, TRIZ is characterized by the need of an abstraction level to apply the methodology. Users of these methodologies rely on intrinsic skills to map a specific situation to a abstracted one, analyze it through the methodology, and, if applicable, map it back to a specific situation. A methodology and algorithm are proposed that eliminate this subjective and difficult to perform mapping by formalizing automatically identified, fine-grained product dimensions or Aspects. These Aspects can be applied in idea generation and problem solving contexts, e.g. building a function database, performing trends analysis and searching for similar products.

Keywords

TRIZ, Patent Mining, Function Database, Functional Basis, Product Properties

1 INTRODUCTION

The Theory of Inventive Problem Solving (TRIZ) is based on the manual analysis of what TRIZ practitioners estimate to be around 40,000 innovative patents. By deductive reasoning, the applied specific innovative solutions were mapped to a small number of extracted abstract inventive principles. This specific to abstract mapping was the basis for a methodology and a set of tools for generating innovative solutions. The most popular TRIZ tools are [1]:

- the Contradiction Matrix to solve Technical Contradictions;
- the Separations Principles to solve Physical Contradictions;
- Substance-Field (SU-Field) modelling and the Inventive Standards to transform technical systems;
- ARIZ as a list of logical procedures for eliminating contradictions; and
- TRIZ Trends as a system of laws that govern engineering system evolution.

Before using any of these tools, TRIZ users rely on their experience and skills to map a specific problem to a more abstracted problem formulation. After applying the tools, TRIZ users map the obtained abstract solutions back to their specific situation. The black arrows in Figure 21 illustrate this approach.

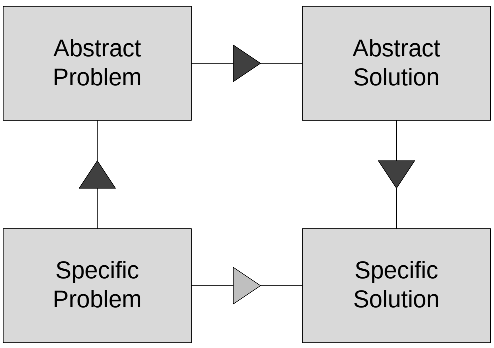

Figure 21: Mapping between specific to abstract formulation.

The mapping to and from the abstraction level is crucial to using TRIZ, but also difficult to learn and apply. To circumvent this subjective and difficult to perform mapping, a methodology and algorithm are proposed that use fine-grained, automatically identified product dimensions allowing discovering direct links between specific problems and related specific solutions, indicated by the light-grey arrow in Figure 21. In the remainder of this paper, these dimensions will sometimes be called Products Aspects.

These fine-grained Product Aspects encompass product properties, functions and technologies. Even more importantly, the resulting Product Aspects interlink these concepts. These Aspects can therefore be considered as a basic framework for accomplishing, among others, the following semi-, or fully automated tasks:

- **problem solving**, searching for products implementing specific solutions similar to the unknown abstract solution for your specific problem [2];
- **trend analysis** based on sequences of product Aspects [3];
- using, proving and updating the **contradiction matrix**; and
- searching for properties, processes or technologies which can deliver a certain desired function, similar to the TRIZ **Function Database**.

In this paper, the latter task is chosen as an example of the usefulness of the obtained Product Aspects. It is noteworthy that the proposed methodology and algorithms are meant as a supporting tool for starting TRIZ users, or as a completeness check for advanced TRIZ users. It can, however, not be the aim to replace abstraction as a central problem solving concept from the TRIZ methodology.

The remainder of this paper is organized as follows. Section 2 overviews related research on Product Functions and Product Properties. Section 3 describes the proposed methodology, and Section 4 illustrates, interprets, and compares the obtained results to another functional classification. The conclusions are formulated in the final section.

2 RELATED RESEARCH

2.1 Functions and Properties

Pahl et al. [4] describe the overall function as the intended overall relationship between inputs and outputs of a plant, machine or assembly, which is independent of any practical solution. This definition is similar to the TRIZ concept of Main Useful Function. This overall function can be broken into sub-functions forming a function hierarchy, which often resembles the component, or modular hierarchy for adaptive designs. From this, it is clear that from a practical point of view, (sub)functions of a system are often closely related to its components or building blocks.

These subfunctions can be provided by physical, chemical or biological processes, which in turn are realized by a working interrelationship between physical, chemical or biological effects, and geometric and materials characteristics [4]. In a TRIZ context, this can be interpreted as the function database, e.g. physical effects, and as the properties of the product or artifact [1].

2.2 Categorization of Functions

Pahl et al. [4] also developed a classification of functions and flows, in which functions are divided into 5 types, Channel, Connect, Vary, Change and Store. The flows are divided into three types, Energy, Material and Signal.

This classification was elaborated further by Stone and Wood [5], introducing a consistent classification scheme, the functional basis, which describes each product or artifact function in a verb-object (function-flow) format. Stone also explicitly states that this methodology contributes to several product design areas, including systematic function structure generation, comparison of product functionalities, and creativity in concept generation. These contributions are similar to the task list in the Introduction Section.

Another effort was performed at NIST, which developed a hierarchical taxonomy following the approach by Pahl et al. [4]. The NIST taxonomy provides a set of terms that are atomic, but also generic enough to allow modelling of a wide range of engineering products or artifacts [6].

Later, Hirtz et al [7] reconciled and compared the NIST effort, the Functional Basis, the Systematic Approach of Pahl and Beitz (SAPB), a 6 function classification from Hundal [8], and TRIZ. Another comparison of TRIZ and SAPB can be found in Malmqvist [9], which proposes to restructure the vocabulary of TRIZ using the top level hierarchy of SAPB.

Although classical TRIZ only defines the concept of Main Useful Function (MUF), later additions or variants have included the concept of auxiliary or subfunctions [10]. Although not explicitly, a function categorization can be found within TRIZ as the databases of effects, subdivided in Physical, Chemical, and Geometrical effects [1].

This database was later reorganized into a matrix format listing, with on the one hand different kinds of functions, and on the other hand a categorization of the object or flow into solid, fluid and gas. This database, the CREAX Function Database [11], was furthermore extended with more effects, and will be used as a reference for the results obtained from the proposed methodology. Therefore, in this remainder of this paper, this database is referred to as the Function Database.

3 PROPOSED METHODOLOGY

The research proposes an algorithm and framework that, through analysis of term occurrences within patents, extracts information concerning product properties and functionalities. The methodology also allows discovering links between properties, between functionalities, and between properties and functions.

3.1 Gathering properties and functions

The EPO Worldwide Patent Statistical Database (PATSTAT) [12] used in this research is aimed at researchers and contains most patent fields such as dates, citations, and abstracts. However, in its original form, the database does not contain full text descriptions. Since other research [13] [14] shows that the inclusion of a certain number of words of the description can be beneficial to text-mining in a patent environment, these descriptions are downloaded from other sources and inserted into the PATSTAT database applied. Currently, the database contains around 150,000 random patents with full text description sections.

In the proposed approach, only the description sections are retained for further processing, although the additional benefit from processing the claims and abstract section too will be analyzed at a later stage.

In order to allow fast querying, the full text description of each patent is pre-processed, which encompasses a filtering step and linking step. The filtering only retains words occurring in Wordnet. Since Wordnet's vocabulary contains a large number of both technical and non-technical words in different spellings, this has the effect of eliminating only misspelled words.

The filtering furthermore allows retaining only terms with specific Wordnet categories, such as noun, adjective or verb categories. This is beneficial to storage or processing requirements, and also leads to less noisy results since the structure to be extracted from the data is mainly related to adjectives and verbs [2] [3] [10]. The nouns are also stored because these directly relate to products or product families.

To further reduce the noise level, all terms from the Wordnet adjective and verb categories which do not contribute valuable information about the structure or workings of a product are manually discarded from further processing. This step divides the number of terms to process by three. This step however does not have a high impact on the structure obtained from the results, as it are not the specific terms that matter, only their co-occurrence within the patents. The reasoning was validated by comparing the results with and without the manual filtering, which clearly illustrates the same structure. However, the results obtained with manual filtering are much more interpretable as a large amount of noise was cancelled.

The second pre-processing stage links each retained term to all patents in which it occurs, and stores this information in a table added to the PATSTAT database. This pre-processing allows fast retrieval in response to the queries in subsequent processing steps explained below.

3.2 PCA

The PATSTAT database is queried from MATLAB, and transformed into a standard term-document matrix format, in which each element Aij represents the number of times term i occurs in patent j. This matrix is weighted with a Term Frequency Inverse Document Frequency (tf-idf) scheme [15] and normalized to account for different patent text lengths.

In a next step, certain Wordnet categories closely related to products, such as noun artifact and noun body, are discarded from further processing. This is done to bring out structure related to the properties and functions of products, and not structure related to products themselves.

The resulting term-document matrix is subjected to a Principle Component Analysis (PCA) [16], a technique closely related to Singular Value Decomposition (SVD) [17] [18]. This analysis allows extracting a given number of Principle Components (PCs), of which the first PC is the linear dimension oriented in such a way that it explains the maximum amount of the variance in the data set. Each succeeding PC represents as much of the remaining variability as possible, taken into account that all PCs are orthogonal to each other.

Before applying PCA, a term is represented as coordinates in the tf-idf weighted term-document matrix, in which each coordinate can loosely be interpreted as the number of times the term occurs in a document. These coordinates are expressed in correlated variables, as the number of times a term occurs in a certain document can be related to the number of times it occurs in other documents.

After PCA, all terms are expressed in a smaller number of uncorrelated variables or PCs, resulting in a term-PC matrix. For testing and analysis the number of resulting PCs is set arbitrarily to 300. In case this number is augmented, the first 300 PCs will remain the same, but more variance will be explained overall. Figure 28 in Annex A depicts terms in a coordinate system formed by two PCs. In this figure different concepts can be discerned, of which “digital data transport” and “molecular biology” are indicated with a dotted oval. It is however difficult to interpret the meaning of the PCs, a goal which can be obtained through the techniques in the next subsection.

3.3 Varimax

Varimax rotation is the most used variant of all techniques aimed at rotating the PC coordinate system to a new coordinate system which is easier interpreted. For Varimax this is done through orthogonal rotation maximizing the sum of the variance of the PCA loading vectors. After rotation each term can be approximately described by a linear combination of few PCs. By comparing the coordinates of term “heat” in a Varimax rotated PC coordinate system in Figure 22 with the same coordinates without rotation in Figure 23, it is easily seen that the Varimax rotation indeed allows terms related to heat to be interpreted in fewer components.

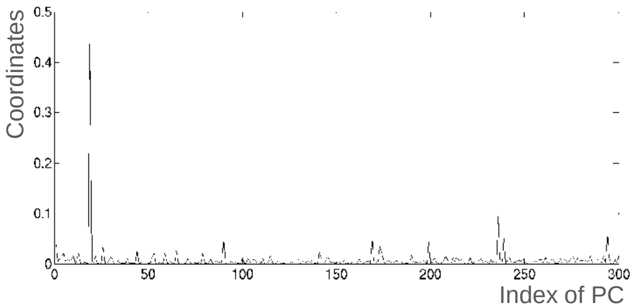

Figure 22: Coefficients of terms related to “heat” in rotated PC, or Product Aspect, coordinate system.

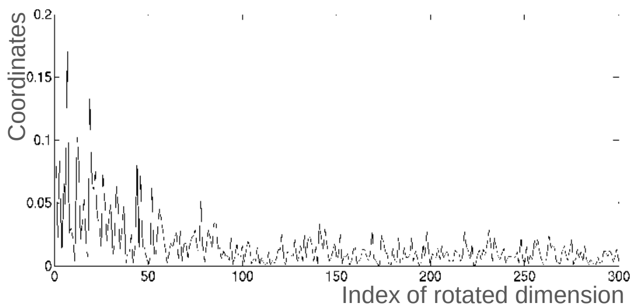

Figure 23: Coefficients of terms related to heating in non-rotated PC coordinate system.

As can be seen from Figure 24 compared to Figure 25, each rotated PC also contains fewer high value coordinates, and this eases manual interpretation of the rotated PCs.

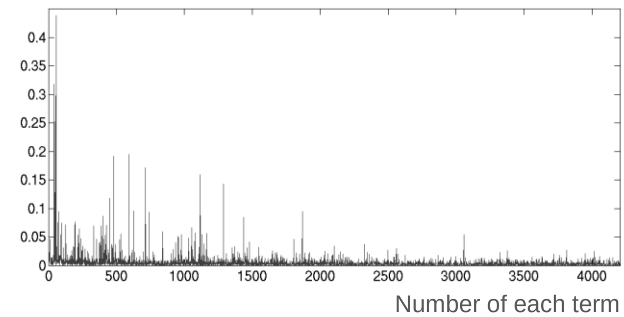

Figure 24: Coordinates of all terms in the Product Aspect related to heat, being rotated dimension 18.

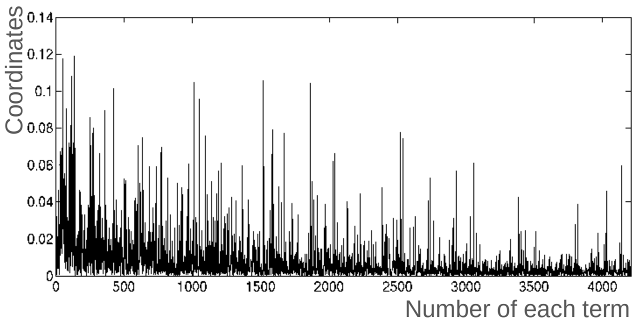

Figure 25: Coordinates of all terms in the non-rotated dimension 18 (related to heat).

It is noteworthy that, although Varimax rotation does not alter the total amount of variance explained, it does not necessarily leave the ordering of the PCs intact. Therefore, it is coincidental that the dimension related to “heat” is the 18th dimension in both the rotated and non-rotated coordinate systems in respectively Figure 24 and Figure 25.

4 RESULTS

4.1 Raw Results

Due to the high dimensionality of the results, it is difficult to illustrate the overall results in one or more figures. For this reason, the figures in this section only describe certain concepts, which are mapped to a low number of dimensions, called Products Aspects, by the Varimax rotation, e.g. the “heat” concept can be illustrated by inspecting only Product Aspect, or rotated dimension, number 18.

Figure 26, of which a larger version can be found in Annex A, shows only the terms with a coordinates higher than the 99.98% percentile on both the second and the third Product Aspect. This is a standard way to display the results of a PCA analysis, which clearly illustrates that Product Aspect, or rotated dimension, number 2 is related to the concept of “linear or volumetric dimension” through terms such as inch, centimeter, millimeter, dimension, length, micron, and milliliter. Product Aspect number 3 is related to “molecular biology” through terms such as bind, binding, fusion, biological, moiety, pierce, regulate, immobilization, helix and transduction.

The 99.98% threshold is chosen arbitrarily, but set high enough not to encumber the figure by the number of terms displayed. Furthermore, a term with a high coordinate on a Product Aspect is said to be highly loaded on that Aspect, and hence is much related to the latent concept captured by that Aspect. Therefore, the approach proposed allows to display terms in order of importance in a table-like format. This format is used in the subsections below.

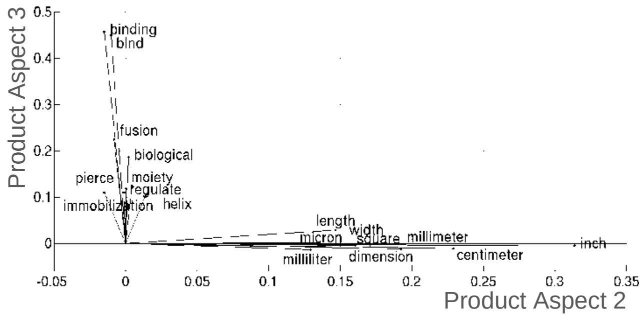

Figure 26: Terms in Product Aspects 2 and 3.

4.2 Interpretation of the results

Table 1 below illustrates the results of manually interpreting the first 10 Product Aspects through the analysis explained in the previous subsection. A more detailed version with the first 30 Product Aspects including the top loaded terms on each Product Aspect can be found in the Table 3 in Annex B.

Number of Product Aspect	Interpretation of Product Aspect
1	Linear/volumetric dimension
2	Mixing and filtration
3	Molecular biological
4	Conical/concentric/groove/lubrify to perform sealing
5	Stretching and breaking
6	Properties of CMOS and bipolar technology
7	Breaking of light
8	Rotation and impact on friction/grinding/cutting/inertia
9	Capacitance related to electrical circuits
10	Different types of shapes

Table 1: Manual interpretation of the first 10 Product Aspects

From the analysis of the results, it can be seen that the proposed methodology allows extracting meaningful concepts from the global patent database. The concepts can broadly be subdivided into the following groups:

- general more ***abstract concepts***, e.g. linear/volumetric dimension;
- concepts related to a ***technology or field***, e.g. molecular biology;
- concepts related to ***general properties***, e.g. shapes;
- concepts related to ***specific properties*** in a technical field, e.g. capacitance in electrical circuits; and
- concepts related to a certain ***function***, e.g. sealing, and stretching and breaking.

The Product Aspects from the last group not only contain interrelated functions, but also the properties of the artifacts, processes or technologies useful for obtaining these functions.

4.3 Example use of Product Aspects

The methodology explained is illustrated here by semi-automatically searching for properties of the artifacts, processes or technologies which are useful to obtain the "heat" function.

First the words containing "heat" are fetched from the collection of indexed words, resulting in the words heating, heat, preheat, overheating, reheat, overheat.

In a second step, the coordinates of these words in all 300 Product Aspects are analyzed to extract the Aspects related to the heat concept. Figure 27 illustrates a graphical approach to extract these Aspects by plotting the result of multiplying the coordinates of all terms in each Aspect. From this it can be seen that only Aspect 18 is central to all heating related terms.

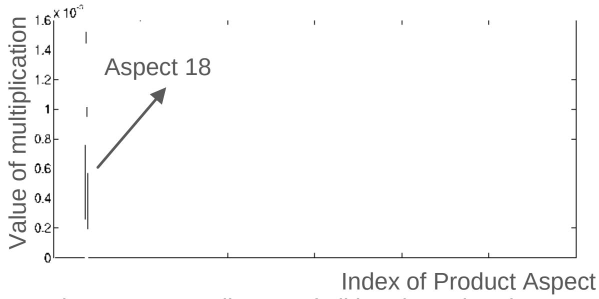

Figure 27: Coordinates of all heating related terms multiplied by each other in each Product Aspect.

Table 2 shows the 100 terms with the highest loadings on

1. heat	2. dissipate	3. sink
4. dissipation	5. thermal	6. cooling
7. heating	8. convection	9. temperature
10. conductivity	11. conduction	12. overheating
13. sinking	14. decay	15. flowing
16. asymptotic	17. electronic	18. expansion
19. absorb	20. radiate	21. overheat
22. condense	23. insulate	24. resistance
25. inlet	26. conditioner	27. steam
28. redshift	29. solder	30. resistive
31. vaporize	32. soldering	33. electricity
34. ruggedization	35. refrigeration	36. airflow
37. anemometry	38. insulation	39. evaporative
40. warping	41. convect	42. dollop
43. thermoelectrical	44. thermoelectricity	45. impermeableness
46. radiation	47. transferability	48. ceramic
49. enfold	50. slipperiness	51. turbulence
52. neutralisation	53. bump	54. regulate
55. joule	56. geothermal	57. astronomical
58. concavity	59. microwave	60. enclose
61. solar	62. optimize	63. standstill
64. attrition	65. thermostatic	66. seep
67. vaporization	68. poise	69. frustum
70. compactness	71. deformation	72. updraft
73. invariability	74. cooking	75. hydrodynamic
76. rapidness	77. crosscurrent	78. packaging
79. ventilation	80. sublimation	81. whiteout
82. infeasibility	83. structural	84. dehumidify
85. melting	86. melt	87. shrinkage
88. reformation	89. condensing	90. smoothness
91. dampen	92. seepage	93. loop
94. airt	95. flatness	96. frictionless
97. agility	98. convexity	99. flip
100. desalinate		

Table 2: 100 Terms with the highest loading on the Product Aspect 18 related to heating.

Product Aspect 18 and therefore assumed to be related to the heating concept more than any other extracted terms. This enumeration allows for a fast manual extraction of useful techniques, processes or properties to implement the heating functionality.

4.4 Comparison of results

The exact precision and recall of these results can not be easily determined by the application of simple formula, and are open for discussion because of the involved manual interpretation. In order to obtain an indication, the retrieved concepts are compared to the Function Database, which is based on the TRIZ function database and updated together with the Contradiction Matrix based on the manual analysis of 150,000 US patents [12].

Table 4 in ANNEX B gives an overview of 34 terms selected from the first 100 terms and directly relates them to ways to heat from the Function Database. The value of the matrix elements are:

- 0, or empty cell, if there is no apparent direct link between both the term and the concept from the Function Database;
- 1 if the link is clear between the term and the concept from the Function Database, e.g. “liquefying” is a phase change;
- 2 if exactly, or almost exactly, the same words are used, e.g. term “condense” and “condensation” from the Function Database.

It is clear that most known and documented properties, processes and technologies from the Function Database are directly found from the first 100 terms in the “heat” Product Aspect. The only missing concepts from the Function Database are “Exothermic Reactions” and “Strain Heating”. Further research is needed to clarify the reasons why these concepts are not mapped to Product Aspect 18 related to heating. However, overall the results can be considered consistent with the heating function in the Function Database.

The following properties, processes or technologies were identified, but could not be found in the Function Database:

- insulate,
- compress/expand,
- preheat,
- geothermal,
- electric/resistive,
- burning,
- thermoelectric(Seebeck / Thompson),
- anisotropic conductivity.

The reasons could be that some techniques, such as insulating, are not regarded as actually heating, or that the techniques are straightforward for a domain specialist and therefore can not be considered inventive.

5 FURTHER RESEARCH

Further research includes checking the hypotheses that most Product Aspects correspond to a main function, which is closely related to the highest loaded terms. The other terms in this Product Aspect are related to ways to deliver the main function or to technologies useful for delivering this main function.

Another direction for further research is to map nouns, related to products, into the Product Aspects, and to eliminate those Aspects which are only related to one product, or one product family. The same idea could be implemented through the mapping of the patent classification codes, such as IPC or ECLA codes, to the Product Aspects.

The obtained results can also be compared to other documented classifications of functions, such as the Functional Basis [7], but it is assumed that this mapping is much more open to interpretation as the Functional Basis is more abstract than the results obtained via the proposed methodology.

6 SUMMARY

It was shown that text-mining allows to extract meaningful structure from patents through analyzing the co-occurrences of certain Wordnet categories. The results of this analysis can be interpreted as fine-grained product dimensions, called Product Aspects, and encompassing properties, functions and technologies.

It was shown that these dimensions are consistent with the Function Database, and can be used to validate and check this database for completeness.

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ANNEX A

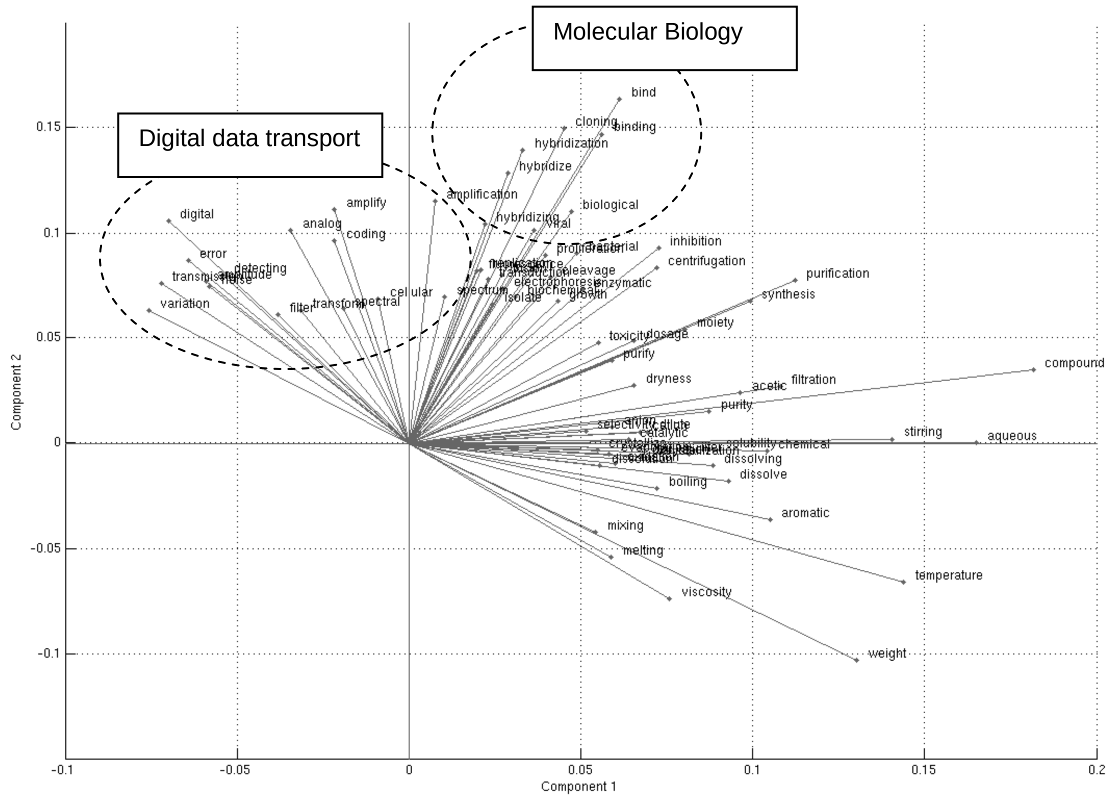

Figure 28: Terms with high coordinates in non-rotated dimensions (Principle Components) 2 and 3

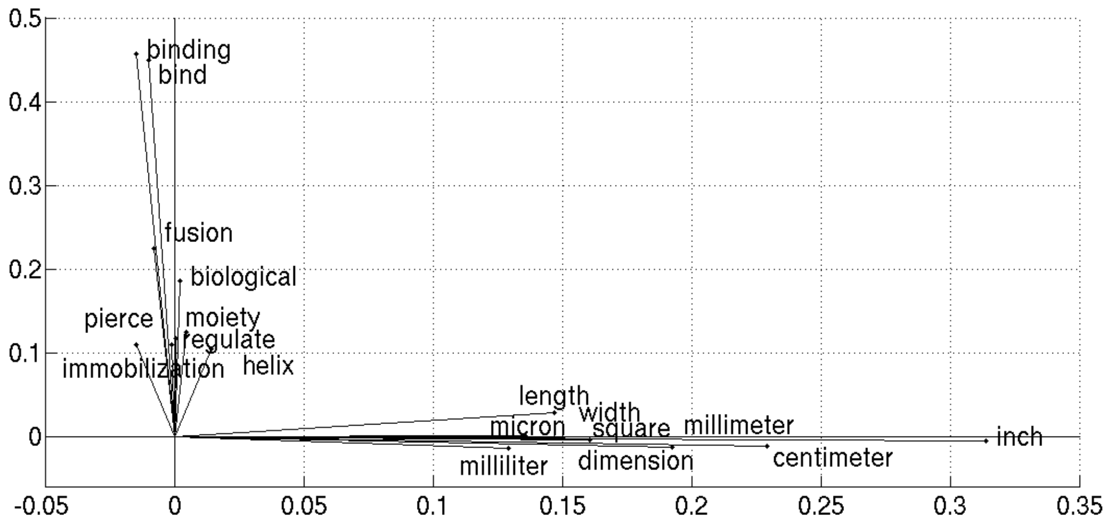

Figure 29: Terms with high coordinates in rotated dimensions 2 and 3

ANNEX B

Table 3: Manual interpretation of first 30 rotated dimensions

Number of dimension	Terms from pca										Interpretation
1	inch	centimeter	square	millimeter	micron	dimension	length	cross	polymeric	micrometer	Linear dimension
2	compound	stirring	acetic	synthesis	dryness	filtration	aqueous	tetrahedron	temperature	moiety	Mixing and filtration
3	binding	bind	biological	immobilization	fusion	moiety	fluorescence	immobilizing	pierce	biochemical	Biological binding
4	axial	radial	seal	sealing	groove	clearance	conical	cross	taper	deformation	Conical form/concentric/groove/lubrify to perform sealing
5	tensile	elongation	strength	ductility	break	toughness	blend	impact	secant	stretching	Stretching and breaking
6	breakdown	diffusion	conductivity	implantation	depletion	bipolar	voltage	isolation	diffuse	anneal	Properties of CMOS and bipolar technology
7	wavelength	optical	refractive	spectral	diffraction	refraction	diffract	collimate	spectrum	chromatic	Breaking of light
8	rotation	rotate	rotational	torque	rotary	clutch	angular	meshing	axial	roller	Rotation and impact on friction/grinding/cutting/inertia
9	capacitance	inductance	capacitive	impedance	inductive	parasitic	voltage	reactance	resonance	tuning	Capacitance ad related to electrical circuits
10	decagon	dodecagon	nonagon	octagon	heptagon	hexagon	octagonal	tetragon	intersect	ruggedness	Different types of shapes
11	oiliness	sulfurized	greasiness	overstep	viscosity	rust	viscometric	friction	emulsify	abate	Viscocity/greasiness and friction
12	dosage	inflammation	inhibition	congestive	milligram	dysfunction	prevention	homeostasis	toxicity	milliliter	Medical dosage and effects
13	transmute	transmutation	fission	neutron	incase	decay	burnup	subatomic	moderation	irradiation	Nuclear transmutation
14	measurement	measuring	measured	accuracy	meter	precision	detecting	inaccuracy	absorbance	deviation	Measurements, monitoring, precision and error
15	highlighting	navigate	graphical	textual	highlight	restructure	navigation	visual	numeric	electronic	Organisation and navigation of text
16	decompress	decompression	compress	decompressing	compression	compressing	sextant	piracy	alphanumerical	unpack	Compressing and decompression (mainly of data)
17	implode	rarefaction	implosion	communicative	metamorphosis	actuation	acoustical	lessen	overpressure	repositioning	Implosion / wave / acoustical / overpressure
18	heat	dissipate	sink	dissipation	thermal	cooling	heating	convection	temperature	overheating	Heat/Cooling, dissipation, convection
19	syntactic	clausal	prepositional	semantic	linguistic	canonical	interjection	rummage	textual	lexicalized	Linguistic, semantic, syntactic structures
20	sensitization	sensitizing	tabular	graininess	sensitize	phot	photomechanical	physique	spectral	desensitization	Photographical properties and processes
21	flame	retardant	flammability	flaming	dripping	burning	combustibility	drip	extinguishing	ignite	Fire, combustion and extinguish
22	hardness	toughness	tempering	hardening	quenching	harden	brittleness	sintered	forging	abrasion	Ways to form/harden/grind
23	hybridize	hybridization	hybridizing	amplification	amplify	nick	cloning	electrophoresis	fluorescence	polymorphism	Of hybrid nature
24	magnetic	magnetization	ferromagnetic	antiferromagnetic	magnetize	demagnetization	squareness	magnetism	anisotropy	saturation	Magnetic properties and related effects as hysteresis
25	mealy	crispness	abstractness	crispen	crinkle	frying	gelatinize	crunch	clop	gelatinise	Food properties and processes
26	color	luminance	brightness	gradation	colorimetric	chromatic	chroma	colorimetry	saturation	palette	Illuminesence and color
27	digital	analog	quadrature	amplitude	filter	multiplier	noise	distortion	sampling	linearity	Properties and functions related to noise, filtering, …
28	choppiness	attitudinal	skimming	recreation	skim	dunk	hydrodynamic	slick	smoking	warping	NOISE
29	sanitized	sanitization	sanitize	scald	sanitation	degauss	sterilization	smother	sterility	steam	Sanitizing/washing
30	pasteurized	pasteurization	pasteurize	unpasteurized	curdling	acidity	fermenting	homogenization	skim	reticulation	Pasteurization and fermenting

Table 4: Mapping of CREAX Function Database to retrieved concepts

	Phase Changes	Condensation Heating	Radiation	Air Impingement	Conduction	Convection	Shunt Effect	Combustion	Induction heating	Infra red Heating	Laser	Microwave Radiation	Peltier Effect	Radio frequency heating	Solar Energy	Ultrasonic Heating	Eddy Current	Light wave heating	Exothermic Reactions	Strain Heating
radiate			2							1	1			1		1				
radiation			2							1	1			1		1				
convection				1		2														
conductivity					2		1													
conduction					2		1													
induction									2								1			
solar															2			1		
condense		2																		
vaporize	1	1																		
sublimation	1	1																		
microwave												2								
vaporization	1	1																		
combustion								2												
convect						2														
condensing		2																		
evaporate	1	1																		
evaporative	1	1																		
vaporisation	1	1																		
evaporation	1	1																		
vaporise	1	1																		
melt	1																			
airflow				1																
transferability							1													
defrost	1																			
liquefy	1																			
sublimated	1																			
freezing	1																			
sublimed	1																			
blowing				1																
absorption			1																	
thermoelectricity													1							
thermoelectrical													1							
gasification	1																			
ventilation				1																

Industrial & Practitioner Papers

Innovative Design of a System of Temperature Control without the Correction Center

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Abstract

The paper presents the finite element analysis of the thermal effects of cutting on parts processed without correction in the center. There are presented the effects of high temperatures on structure changes, expansions and changes of superficial hardness and micro hardness. The paper presents methods for the automatic control of technological parameters of the process of grinding machines with advance without center cross, in order to maintain the temperature influence on the processing elements within the normal technological parameters.

Keywords

TRIZ Method, Heat, Grinding, Hardness, Finite Element, Control

1 INTRODUCTION

The quality and accuracy of the parts produced by centerless grinding, in general, and by centerless grinding with cross power feed, in particular, depend on many factors, and deviations from the geometry, microgeometry and correct position of the elements determine their availability to fulfill their destination.

Among the causes that lead to macrogeometric and microgeometric deviations from the correct theoretical forms and irregularities in the mutual positions of the various elements one can mention: the limited and variable rigidity of the elastic grinding machine, the defects and irregularities of the guiding elements, the wearing of various items of machinery for grinding without center, the irregularity in shape and position of the abrasive disc, setting errors, irregularity processing, an improperly cutting regime, the formation of chips, the vibration maintained and amortized of low or high frequency, the semi fabricated used through their physical and chemical parameters, assembly errors, the occurrence of uncontrollable thermal phenomena and many more.

The maximum temperature in the area of contact between the cutting abrasive disc and the part leads to parts dilation and hence the need to use the correction of the real-time response of active control systems and adaptive control of grinding machine without center, in the sense of compensating these deviations .

Also, a variation of the temperature in the processing area can lead to a multitude of undesired effects. We intend to improve the processing accuracy while keeping the processing temperature and force transverse advance constant.

The TRIZ method will be utilized in order to eliminate the contradiction: improving the functions of the systems (manufacturing precision – 29) concomitantly with the worsening of characteristic (temperature – 17) and another improving feature of the systems (manufacturing precision – 29) concomitantly with the worsening feature (force-10). The contradictions that have to be removed are 29/17 and 29/10 using the inventive principles recommended by contradiction Matrix: 19 (periodic action) eliminated the contradiction for 29/17 and 28 (mechanical substitution), 19 (periodic action) 34 (discarding and recovering), 36 (phase transition), eliminated the contradiction for 29/10. Using the presented method of adaptive command and the TRIZ method one can produce the best possibility to control temperature and transverse strength of advance. Thus the accuracy of processing increases. Studying the specialized literature one could not find that these issues have been treated in such a manner so far.

To establish and verify the practical impact of the phenomena occurring in thermal processing without correcting the center and the experimental determinations of thermal parameters of state there have been used a set of samples with different sizes, accuracy of previous processing, materials and heat treatments. The geometric shape of the samples was determined to be processed within the range of dimensions accepted by a model of the finishing machine without the center cross with advanced computerized automatic control of technological parameters of process, figure 1.The geometric shape of the samples is visible in figure 2.The materials used in the making of samples were: OLC 45, OSC 10, 90 VMn18, 18MnCr10 and C120, and some of the samples were heat-treated.

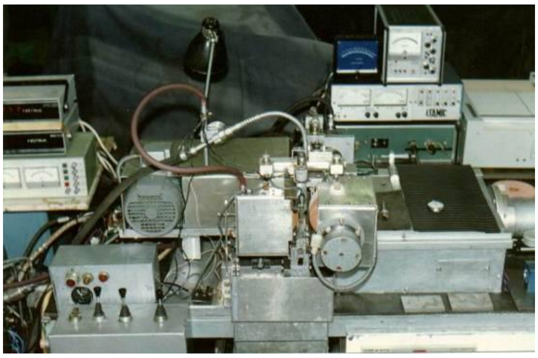


Figure 1: Model of machine centerless grinding to advance cross.

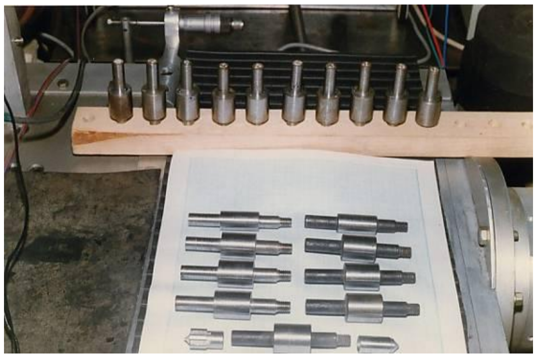


Figure 2: Parts processed by grinding.

2 ASPECTS OF CHANGING HARDNESS OF SAMPLES SUBJECTED TO PROCESSING OF CENTERLESS GRINDING MACHINE

The samples processed by the centerless grinder have undergone, with two exceptions, an increase between 1 and 25 units in hardness under the surface layer of processing.

The samples undergoing processing have been measured in the initial phase and final on the Rockwell hardness scales HRB (penetrated ball) and HRC (with penetrated with diamond) using a device of a type Rockwell hardness PH-C-01/02.

Increasing the hardness of the sample can be explained by modifying the physico-chemical properties of the layers in the immediate vicinity of the area under operation for rectification. Complex thermodynamic phenomena occur in this area, considering that on the surface of the processed sample the area of contact with the cutting abrasive disc is moving which can reach 800-1000 ^{0}C (0C even 1100). In this way the layers are affected by the heat produced from the sample surface and to a depth where the temperature reaches 820 - 850 ^{0}C to produce a phase of retempering the material and change its crystalline structure.

When repetiting crossings, the material layers behave similarly thus resulting in a repeated tempering, but that depends on the intensity and size of the processing parameters and thus on the temperature at which the material reaches the affected area.

Thus, most of the mechanical grinding is converted into heat and only an insignificant part is converted into energy to change the crystalline network of the material of the processed part. The heat is divided between the part, the cutting abrasive disc, the resulting splinters and cooling liquid according to the formula:

$$\frac{F_{aş} \cdot v_{aş}}{60 \cdot 75} = Q_p + Q_{da} + Q_a + Q_l + Q_r \quad (1)$$

where: Q_p is heat taken over by the part

Q_{da} - the heat taken ver the cutting disc;

Q_a - the heat taken ver the cutting disc;

Q_l - the heat taken over by the cooling liquid

Q_r - the heat transferred through radiation to the environment

In the process of adjustment one considers that only a small portion of the heat radiation is transferred to the environment and about 80% goes into the part. This heat is an important factor in the process of adjustment through the changes that may occur on the superficial layer of the part, and on processing by its direct action on the precision and quality of the parts.

The instant temperature that can produce changes in the structure of the parts is difficult to measure and even attempts to give mathematical calculation give quite different results.

The heat transferred to the part during the processing satisfies the following relationship:

$$Q_p = 0{,}885 \cdot Q_{\max} \cdot B\sqrt{\lambda_p \cdot c_p \cdot \rho_p \cdot v_p \cdot L} \quad (2)$$

where: $Q_{max.}$ the maximum temperature in the processing

B - the width of the cutting abrasive blade

λ_p - the thermal conductivity coefficient of the part

c_p - the heat capacity of the part

ρ_p – density of part;

v_p - the cutting speed of the part subjected to processing

L - contact arc length

The maximum temperature in cutting area leads to the thermal stability of the cutting process only if its value is lower than the allowable temperature, which depends, in its turn, on the maximum allowable values of the processing parameters (v, s, t) as in the relationship:

$$Q_{\max} = C_\theta \cdot v_{as}{}^{x_\theta} \cdot s_{av}{}^{y_\theta} \cdot t^{z_\theta} \cdot B^{p_\theta} \quad (3)$$

where: C_θ is a coefficient with values from 82,7 to 1398,5; x_θ, y_θ, z_θ, p_θ are constants that depend on the characteristics of the cutting abrasive blade and the part undergoing processing, with the following values x_θ =0,3; y_θ=0,21; z_θ=0,52; p_θ=0,16.

Given the experimental values obtained from processing parts: $D_{aş}$ = 148 mm; D_p = 25,15 mm; $n_{aş}$ = 2956 rot/min; n_p =280 rot/min; $B_{aş}$ = 40 mm; B_p = 19,8 mm; L = 2,5 mm; s_{av} = 2,45 mm/min; t = 1,54 10^{-3} mm/rot and: λ_p = 43,2 W/mK; c_p = 470 J/kg K; ρ_p = 7790 kg/m^3, result:

$$\begin{aligned} Q_{\max} &= (82,7 \div 1389,5) \cdot \left(\frac{\pi \cdot 148 \cdot 2956}{1000}\right)^{0,3} \cdot \\ &\cdot 2,45^{0,21} \cdot \left(1,54 \cdot 10^{-3}\right)^{0,52} \cdot 40^{0,16} = \\ &= 54,263102 \div 911,71198\ ^0C \end{aligned} \quad (4)$$

The heat transferred to the part is:

$$\begin{aligned} Q_p &= 0,885 \cdot (54,263102 \div 911,71198) \cdot 0,0198 \cdot \\ &\cdot \sqrt{43,2 \cdot 470 \cdot 7790 \cdot \frac{\pi \cdot 25,15 \cdot 280}{1000} \cdot 0,0025} = \\ &= 2812,325341 \div 47251,82695 \text{ J} \end{aligned} \quad (5)$$

As a feature of the above, the surface specific heat representing the heat transmitted to the part during the cutting, in relation with the area of contact and expressed by:

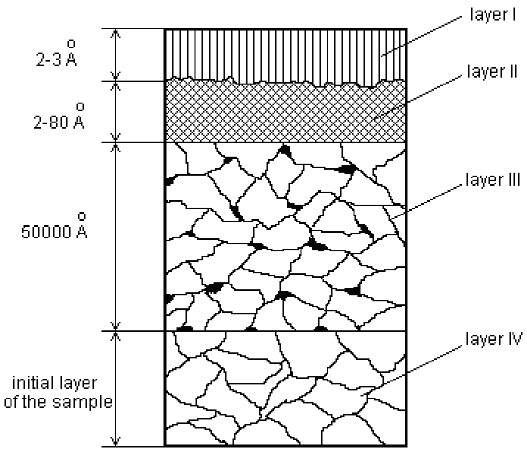
$$C_s = \frac{Q_p}{B \cdot L} \quad (6)$$

will result in changing the structure of the superficial layer of the part. So:

$$\begin{aligned} C_s &= \frac{2812,325341 \div 47251,82695}{19,8 \cdot 2,5} = \\ &= 56,814653 \div 954,582362 \text{ J/mm}^2 \end{aligned} \quad (7)$$

The superficial layer of the surface of the part subjected to correction, in general, and therefore to a correction without centers, is divided into three zones (fig. 3).

- The first layer is composed of gas molecules absorbed in the process of micro-cutting
- Layer II, composed of oxides, azotizes and decarbonize material is an amorphous layer to be removed in the finishing stages, without enhancing the abrasive process and therefore with a decrease in the maximum contact temperature θ_{max} .
- Zone III, Zone III representing the area with the largest width covers the crystalline grains deformed under the action of the abrasive blade
- Zone IV, is the area of basic material with unchanged properties.



structure of successive layers of parts subject to mechanical and thermo-chemical changes due to temperature influence on the contact piece- abrasive disc cutting

Figure 3

Due to the cold-hardening and phase transformations in the area of the superficial layer through thermal-mechanical processes of the processing microhardness, even an increased hardness of the general areas processed by grinding takes place which happened with the trial samples processed on the model of the machine corrected without center.

The test results are given in Tables 1 and 2 and histograms in figures 4 and 5.

The histogram tells that hardness increases faster in the samples whose material was tempered before processing (3 / 01, 3 / 02, 3 / 03 - from the OLC 45 and 3 / 1, 3 / 3, 3 / I of C 120) and less in those untempered.

Also the hardness is higher in the control samples computer-assisted processed, automatically (3 / 01, 3 / 02, 3 / 05, 3 / 11, 3 / I, 3 / 1, 3 / 3) than in those without control, where the deployment of chips was more intense, and the maximum temperature in the contact area was higher by overlapping multiple passes necessary to remove additives in the processing under variable process parameters.

3 FINITE ELEMENT ANALYSIS OF HEAT TRANSMISSION INTO PARTS DURING THE GRINDING PROCESS OF GRINDING MACHINES WITHOUT ADVANCE CENTER WITH TRANSVERSE

The heat effects resulted from the correction as well as other causes, which depend on the machine's system of technology or some exterior causes influence negatively both the process itself and the proper functioning of the machine's technology.

	Hardness in units HRB and HRC							
Hardness	HRB	HRB	HRB	HRC	HRB	HRC	HRB	HRB
No. sample	pr.3/01	pr.3/02	pr.3/03	pr.3/04	pr.3/05	pr.3/06	pr.3/07	pr.3/08
Initial hardness	56	97,33	97,33	51,3	84,66	55,83	108,66	88,83
Final hardness	91,4	109,8	111,1	53,3	110	57,1	112,5	88,9

Table 1

	Hardness in units HRB and HRC							
Hardness	HRB	HRB	HRB	HRB	HRB	HRC	HRC	HRC
No. sample	pr.3/09	pr.3/10	pr.3/11	pr.3/12	pr.3/14	pr.3/I	pr.3/1	pr.3/3
Initial hardness	95,33	80,66	76	77,16	78,83	49,3	54,5	52
Final hardness	99,5	81,3	80,1	78,9	80,9	61,1	62	62,6

Table 2

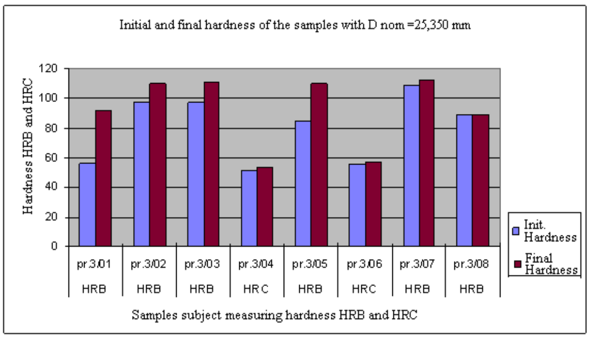


Figure 4

Thus, because of the thermal effect in the area, cutting abrasive blades undergo high temperatures of up to 800 - 1000 ^{0}C, and the parts to be processed, because the same heat effect, undergo, in turn, the negative effects of such high temperatures: changes in structure, expansion and addition of processing different from those originally considered, changes in surface, hardness and micro-hardness and in limited circumstances, when the schemes are too intense and the cooling is insufficient, even burning of the parts surface.

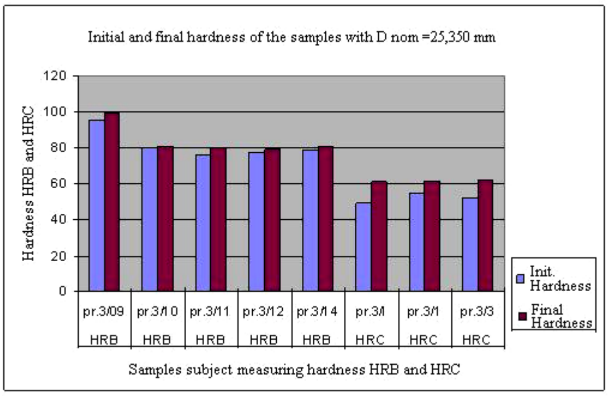


Figure 5

With heat transferred to the machine mass, if the command and control systems are affected, errors can occur even in the process of active and geometric control, with negative consequences on the dimensional accuracy and shape of the parts processed (e.g. to achieve in advance the order to withdraw due to expansions or changes added to the processing and expansion by additional loading of the elastic machine technology).

To solve the proposed problem, out of the range of samples subjected to processing model without finishing machine center, there was used to study the transmission of heat in a part with finite elements a material with the following geometrical, mechanical and thermal characteristics: OLC45, L = 19,8 mm; D = 25,15 mm E = $2,1 \cdot 10^{5}$ MPa, Young's modulus of elasticity; γ = 0,3 Poisson coefficient of contraction; K = 0,0445 W/mm ^{0}C thermal conductivity; $\alpha = 12,5 \cdot 10^{-6}$ 1/^{0}C coefficient of thermal expansion; b = $0,7 \cdot 10^{-3}$ convection coefficient (steel - coolant). Thermal loading of the structure of piece was examined, along the line of contact with the cutting abrasive blade, with a temperature T = 900 ^{0}C, and the remaining nodes on the exterior surfaces with a temperature T = 20 ^{0}C. Following the thermal analysis with the finite element program NISA II, there were obtained files showing the temperature at every node of the structure, according to figures 6 and 7.

Also, after the static analysis there result some main unknown issues such as: movements along the three axes of x, y, z coordinates of each node, thus determining the thermal expansion and the size of movements of the part structure. Thus, using the static analysis of the part structure by finite element, a static analysis was made owing to the thermal loads in all nodes of the part structure, resulting in graphical representations as shown in figures 8, 9 and 10.This is needed to determine the parameters of the technological process of centerless grinding cross with advance in order to introduce the necessary correction data in terms of dimensional accuracy of the parts rectified. From the figures one can observe that because of the temperature distribution in the processing of the part and considering that the maximum temperature of the contact part- cutting abrasive blade, figure 6 is 900 ^{0}C and the material of the parts is subject to significant expansion in size and direction (up the value of 0.6418197 mm, fig. 8). One can note that the expansions occur on the two perpendicular directions, x (0.6283 mm) and y (0.6316 mm), which involved the need to use the corrections of the active control and adaptive control of the machine, in the sense of compensating these deviations.

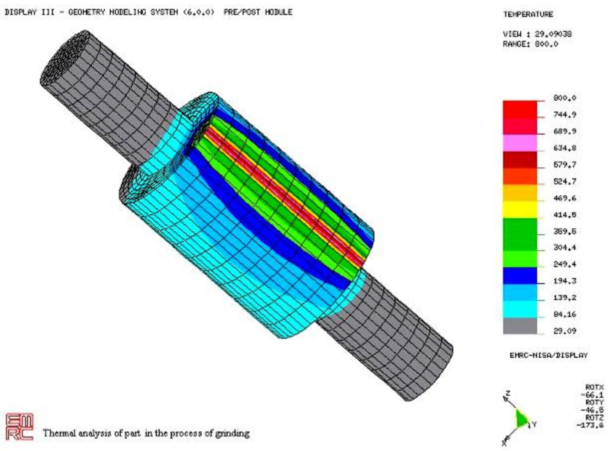


Figure 6

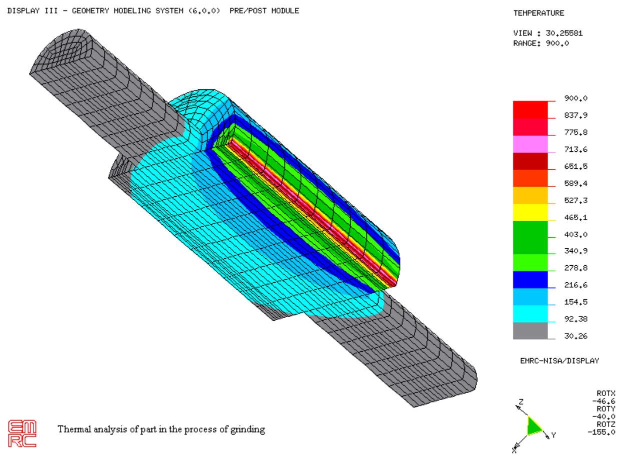


Figure 7

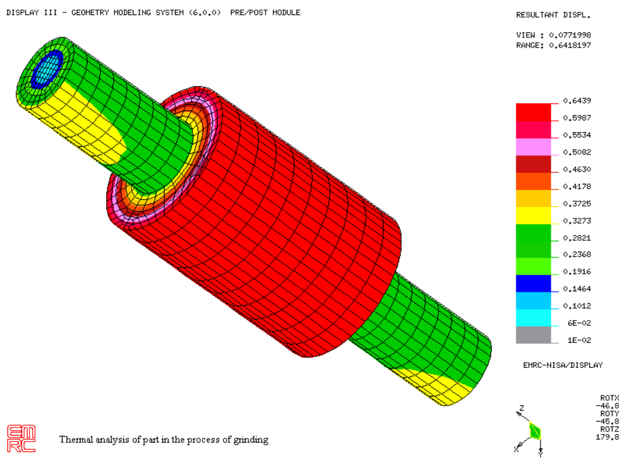


Figure 8

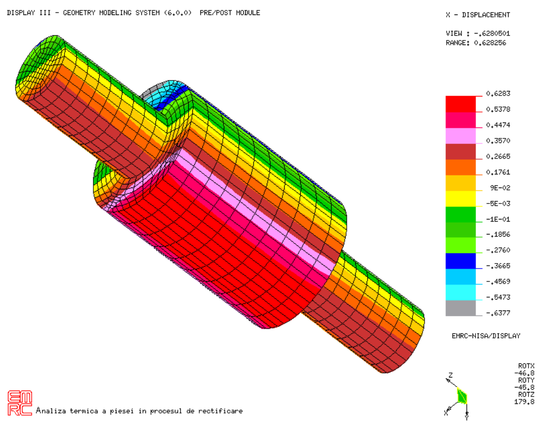


Figure 9

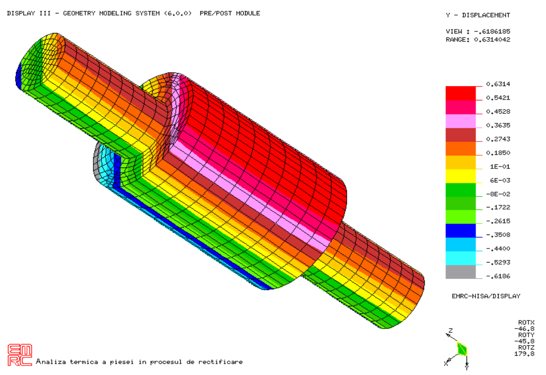


Figure 10

To confirm the theoretical assumptions that temperature dissipates during the processing into the part, the elements of the total processing technology that consist of the cutting abrasive blade, the disk setting and advance and the work rest blade, and that other sources of heat appear, measurements of temperature were performed with a measurement spot Laser Class A model RAY RPM, 2 EMLS, RAYTEC, Inc.., USA, which can be seen in figure 11.

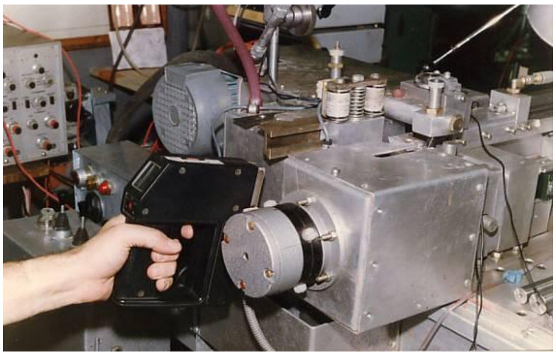


Figure 11

After measuring the temperatures in the processing and other elements of the model without finishing machine center, before and after correction with cooling or non-cooling of the processed parts the following data were systematized as presented in Table 3. One can note that the temperature varies relatively narrowly in the structure, with a tendency to stabilize after a period of processing and working of the machine, but the upward trend further, and as was expected, for the parts which were not cooled with coolant. The quality and accuracy of processed samples cooled with liquid cutting was better and the application elements, especially the abrasive blade, were lower, particularly in terms of time between two resharpening to increase it. To maintain constant temperature in the area and in the entire structure of the grinding machine without center in order to keep the parameters of the cutting constant one can control the working cycle by using the computer-assisted adaptive command, with which the grinding machine without center with transverse advance is equipped.

In this respect one used the method of controlling the technological cycle of processing, which instead of using the transverse advance continuously adjusted by the machine, used the processing power of the press and drive advance adjustment constant throughout the processing. The variation of the oscillograms of the velocity of advance and force in the transverse direction are presented in figures 12 and 13.

EXPERIMENTAL DATA																
Nr. crt.		**Cooling**		**TEMPERATURE ^{O}C**									**The technological scheme of processing**			
	Nr. piece	cooled in liquid		Piece	Abrasive blade	Disc advance and adjust.	Blade support	Hydraulic Motor	Central hydra-ulics	Liquid cooling	Abrasive disc to camp	Camp back abrasive disc	Speed abrasive disc	Speed track	Speed drive and adjustable advance	Time
		yes	no	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	[rot/min]	[rot/ min]	[rot/ min]	[sec]
1	2/18	-	no	28	22	22	22	22	24	19	27	29	2910	320	125	22"
2	2/18	yes	-	23	22	21	21	22	24	19	27	29	2908	330	125	12"
3	2/17	-	no	25	22	22	22	23	26	19	27	30	2948	380	125	12,5"
4	2/17	-	no	21	22	21	21	23	27	19	27	30	2926	340	125	10"
5	2/14	-	no	38	23	23	23	23	27	19	27	30	2880	290	125	17"
6	2/15	yes	-	22	22	21	22	23	27	19	27	30	2900	420	125	9"
7	2/17	-	no	27	23	22	22	23	27	21	27	30	2903	390	125	9"
8	2/13	yes	-	23	23	22	22	23	27	21	27	30	2875	380	125	7"
9	2/14	yes	-	22	22	22	22	23	25	21	27	29	2865	400	125	27"

Table 3

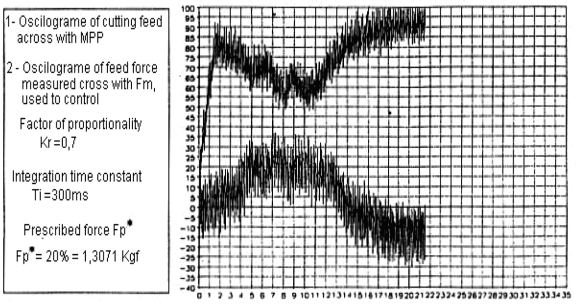


Figure 12

The factors listed above on which the temperature of the part processed through song without correction center depends, produce considerable thermal errors, which can be determined from the formula of size variation of the part, with great implications on the accuracy of measurement. The dimensional error of the part is given by the relationship:

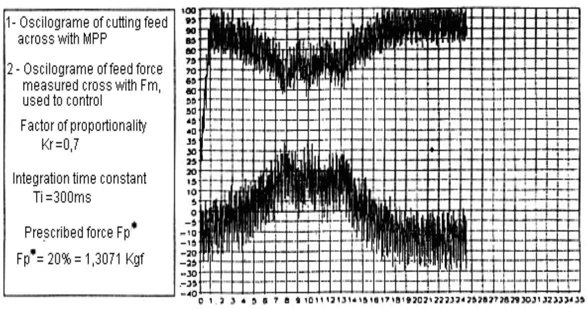


Figure 13

$$\Delta d = \mathrm{d} \cdot \left(\alpha_1 \Delta t_1^0 - \alpha_2 \Delta t_2^0\right) \quad (8)$$

or: $$\Delta d = \mathrm{d}\,[\alpha_{\mathrm{p}}\left(t_{fp}^0 - t_{0p}^0\right) - \alpha_d\left(t_{fd}^0 - t_{op}^0\right)] \quad (9)$$

where: Δd is size of the part variation (measurement error) in mm;

d - nominal value of the size measured in mm

α_p - coefficient of linear expansion of the part measured

t_{op}^0 - original temperature of part in Celsius degrees

t_{fp}^0 - final temperature of the part in the processing, in Celsius degrees;

α_d - coefficient of linear expansion measuring device in Celsius degrees,

t_{od}^0 - initial temperature of the measurement in Celsius degrees

t_{fd}^0 - final temperature of the measurement in Celsius degrees

When the temperature of the environment, of the measuring devices and of the part is equal to 20 ^{0}C, then formula (8) becomes:

$$\Delta d = d \cdot \alpha_p \left(t_{fp}^0 - t_{op}^0 \right) \quad (10)$$

During the experimental research temperature measurements on samples with nominal average dimensions were made: diameter medium d_{med} = 25.15 mm length subjected to processing B = 19.8 mm.

Following experimental determinations the initial and final temperatures were measured, where the processing included liquid cooling or without liquid, and the following values were found:

- t_{op} = 22 ^{0}C, initial temperature of the part

- t_{fp} = 38 ^{0}C, maximum final temperature of the part processed without coolant

The coefficient of linear expansion of the part, steel α_p is 10-6 = 13.6 and substituting the values specified in the formula (10), there results the error of measurement at the same temperature:

Δd_m=25,15 x 13,6 $\cdot 10^{-6}$ (38 - 22)= 0,00547 [mm]

To the maximum area of contact between the part to process and the abrasive blade of 911 ^{0}C, the maximum dilation processing value may be:

Δd_p=25,15 x 13,6 $\cdot 10^{-6}$ (911-22)= 0,30407 [mm]

The obtained value is high enough and has a negative influence on the regulation of the active control model of the machine and also on the accuracy of processing by a further expansion with the possibility of changing the rate of the final part.

4 SUMMARY

Following the experimental determinations and theoretical analysis using the classical analytic method and the modern one using the finite element one can draw some conclusions as follows:

- because of such high temperature in the processing zone, there were cold hardening and phase transformations in the superficial layer area, and due to thermal-mechanical processes these factors have resulted in an increase in micro-hardness and even in the general areas processed by grinding without center to advance cross;
- it was observed, as expected, that when using liquid cooling, the effects of the increase in temperature transferred from the cutting to the part obviously decreased, which dwindles the possibility of expansions and changing position in the scheme of the machine corrected without advance center with cross;
- maintaining the temperature in the working area and implicitly in the entire structure of the grinding machine without center constant in order to keep the parameters of the cutting constant can be done successfully by using the active cycle command electronically using the electronic calculator with which the model of the machine without center that has been used in the experiments is equipped;
- using the finite element method to obtain theoretical data which are almost the same in size and value with those obtained by the experiment, results in saying that the method can be used successfully to analyze the influence of temperature on the processing of parts by cutting.

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Resolving Open Innovation Contradictions

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Abstract

One of the foundation stones of TRIZ is the idea that 'someone somewhere has already solved your problem'. In this context, the emerging open innovation movement makes a lot of sense: present tough, unsolved problems to extremely large numbers of the world's most inventive minds and chances are someone, somewhere may either already have a solution or the wherewithal to deliver a solution. Look beyond a few well chosen 'low-hanging fruit' examples, however, and the distance between theory and practice begins to look like a rather large chasm. In fact, research conducted for this paper indicates that the chances of innovation success are no better if open innovation strategies are adopted or not. The paper discusses six issues common in open innovation, and in two cases suggests potential remedies through real case study examples taken from a range of different industry sectors.

Keywords

Open Innovation, Problem Definition, Trust Building

1 A BRIEF INTRODUCTION TO OPEN INNOVATION

Open innovation success stories from companies such as Proctor and Gamble have ensured that open innovation is now talked about as an exciting new way to generate breakthrough innovation at lower cost and fast time to market. Henry Chesborough, in his influential book Open Innovation [1] argues that because useful knowledge is no longer concentrated in a few large organisations, business leaders must adopt a new, "open" model of innovation. Using this model, companies should look outside their boundaries for ideas and intellectual property (IP) they can bring in, as well as licence out their own under-utilized home grown IP to other organisations.

In a typical open innovation activity, there are usually two parties and an intermediary, one party looking for a solution to a problem or searching for a technology to realise an opportunity, often referred to as the "Seeker" and one looking to provide a solution or technology, often referred to as the "Solver". In this paper we will use these terms when we refer to either party. At the start of an open innovation project, an innovation brief is prepared to communicate the requirements of the "Seeker" - this is often called a Request for Proposal or RFP for short. In this paper we will use this term to describe the innovation brief. Although traditionally the role of intermediary might have been performed by a technology broker, over the last few years a number of open innovation marketplaces have emerged, often making extensive use of on-line resources – these marketplaces are often described by the term "ideagora" or idea marketplace. Typical ideagoras include Nine Sigma, Innocentive, Idea Connection and yet2.com. The normal model operated by ideagoras is for an RFP to be prepared and posted to their wide networks of solvers with a submission deadline. A fee is usually charged to post the RFP and in some "success sharing" models, a success fee is payable based on a proportion of the value of any subsequent contract established between seeker and solver. Proposals received by the submission date are then reviewed internally before various screening reviews with the seeker. The most promising submissions are then followed up and direct contact between seeker and solver is established.

2 COMMON ISSUES IN OPEN INNOVATION

2.1 Issue 1: The initial problem posed to the open innovation community is the 'wrong problem'

A poorly defined initial brief can make a crucial difference between a successful open innovation project and abject failure to connect with potentially relevant partners or to generate innovation which is meaningful to the market. Surprisingly few open innovation briefs, as presented on Nine Sigma or Innocentive, highlight expected customer benefits or key consumer insights. Another aspect of poor definition in Open Innovation is requirement definitions which focus on pre-conceived solutions rather than focusing on functions and parameters to be delivered. For example, here is an excerpt from the introduction to a recent RFP outlined on Nine Sigma:

Nine Sigma, representing a global consumer products company, seeks processes or techniques to clean the glue doctor blade used in production of a paper consumer product. The object of this request is to identify process experts or partners with techniques or alternative methods to effectively clean the glue doctor or prevent lint/glue build-up. (Figure 1 shows the current doctor blade system).

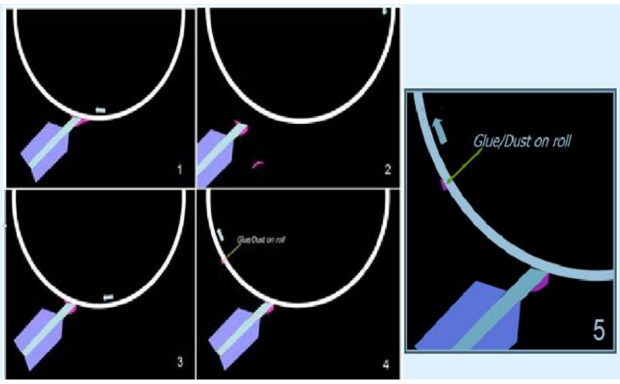

Figure 1: (1) glue doctor blade engaged with the rotating roll, collecting glue and lint, (2) disengaged, (3) reengaged, (4) glue/lint "blob" falls off the blade onto the roll, (5) close up of (4)

The first problem with this RFP is that it seems to narrows down the solution space at a point when the innovative problem solving process should be divergent and it will seriously obstruct cross-industry engagement – who says we even need a doctor blade in this system?

The second problem with the RFP is the lack of emphasis on the physical actions and associated parameters needed – i.e. what is the action which the doctor blade is performing and why is this action only required periodically? Perhaps the seeker is concerned about revealing too much proprietary information about their process, but this is just the sort of information a solver will need to put forwards a solution.

The last problem concerns the RFP format in general and relates to the “one-shot” nature of the traditional idea posting approach, in that the seeker doesn’t receive any real feedback about the quality of their brief until after the submission deadline. A telling statistic, according to Nine Sigma, is that fewer than 40% of all their RFPs are successful at present in identifying potentially suitable solutions. The success rate is similar at Innocentive.

2.2 Issue 2: Lack of objective means to determine whether a ‘new’ solution is better than existing solutions.

Once a solution is identified, how will the seeker decide if the solution is better than their existing solutions? Or more critically, how will seeker chose between competing solutions which are received from the open innovation network? Standard tools which are used to select between solutions often include weighting and rating against success criteria or for more sophisticated seekers, convergent design tools such as the Pugh Matrix [2]. Despite the reassurance of tools which attempt to introduce rationality into the selection process, often a solution is selected on the basis of little more than organised gut feel. That gut feel is typically built on the way we prioritise the various different success criteria. After potentially several years of optimizing the current design paradigm, any new solution almost inevitably looks ‘inferior’ against at least one of the traditional success criteria.

The problem here is the commonly observed (apparent) dip in the relative position of the S-curve for the current design solution versus that for the new solution – Figure 2. This is classic Innovator’s Dilemma territory – measured against the old criteria, the new solution often appears inferior, and hence is likely to be rejected. New solutions inevitably do not benefit from the optimization effort that the incumbent solution has received so this phenomenon is virtually inevitable. The problem is that, when measured against different criteria, the new solution becomes the better choice. Take the classic example of the recent disruptive jump from 35mm to digital photography. To the incumbent 35mm camera manufacturers measuring their world against things like quality and controllability of images, the first digital cameras were seen as little more than a joke. Digital cameras found a market not from photography aficionados but from what turned out to be millions of ‘non-photographers’ who measured their world in terms of the convenience of not having to get films developed, and the ability to avoid a host of waste by receiving immediate visual feedback that an image was either good or bad.

Once a solution has been identified, its implementation into the seeker’s organisation can be jeopardised when follow-on problems come to light. These issues often come to light at quite a late stage in the attempted implementation of the solution and can therefore appear very difficult to solve. Very few open innovation seekers employ proactive tools or processes to identify potential issues with the implementation of external solutions into their organisation.

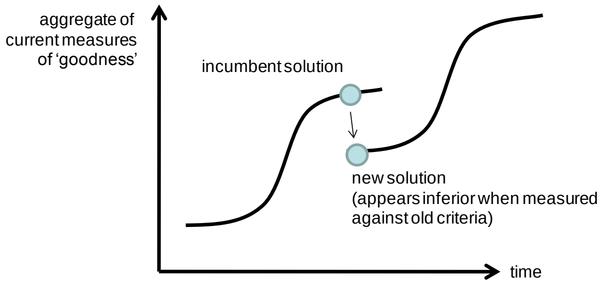

Figure 2

2.3 Issue 3 - Failure to adequately solve the inevitable ‘yes, but’ problems as an external solution is imported into the specific context of the organisation posting the challenge

By way of an example, a recent client was looking to import a coating technology from another industry. The coating featured all of the properties their particular application demanded and as a result allowed the company to overcome a costly and long-lived problem. The ‘yes, but’ problem that arose when the technology transfer discussions advanced towards implementation of the solution in the new role was that the coating application process in its current form had only ever been optimized for what were essentially flat surfaces. The new application required that the coating also be applied to substrates with potentially high degrees of curvature. This ‘yes, but’ was seen by the new production team as an insurmountable barrier, and indeed their initial attempts to engineer a fix that gave acceptable coating speeds were a dismal failure. Given that the production engineers were busy people, it was their strong desire to kill the project at this point – they had, in their eyes, given the new solution its ‘best shot’ and it had failed the test. The project could very easily have ground to a halt at this point. Fortunately, it did not, but only because someone from the technical team was familiar with TRIZ and immediately recognised that the insurmountable problem was merely a speed-versus-shape contradiction, and that many people in many places had already solved such problems. Unfortunately, this case is the exception rather than the rule. The ‘yes, buts’ are currently far more likely to kill open innovation projects than to be resolved. Until such times as seekers realise that the ‘yes, buts’ are an inevitable part of the open innovation equation, this will continue to be a significant source of failure in OI initiatives.

2.4 Issue 4: Failure to adequately transfer the surrounding tacit knowledge from domain to domain

When a technology or solution from a new industry sector is applied to a problem situation in the seekers industry, there is a risk that the supporting information relevant either to the new technology or the existing problem situation is not adequately transferred. This can result in sub-optimal implementation of the new technology or even complete failure of the solution. Specific strategies are needed to make sure that this does not happen. Many current open innovation models ignore this risk entirely.

The problem with tacit knowledge is that the people that hold it are fundamentally unable to elicit it to others because it has left their conscious and entered their unconscious. Open Innovation in effect doubles the problem by introducing two sets of people with two often very different sets of tacit knowledge. The seeker possesses tacit knowledge about their problem; the solver possesses tacit knowledge about their solution, and never the twain shall meet.

One of the authors found themselves in the middle of an argument between the two parties involved in a technology transfer initiative. The seeker was angry that the imported solution had failed after trials in a particular desert environment. 'But', said the confused solver, 'I thought sand was sand'. He had assumed that all sands were the same; the seeker assumed everyone knew that desert sand was very different from manufactured sand.

2.5 Issue 5: Failure to adequately account for the inevitable cultural and psychological conflicts that emerge as internal knowledge incumbents are 'displaced' by outside solutions

There are many way to kill a new idea and open innovation solutions, in the same way as any other new ideas, are not immune to the various innovation killers which will exist within the seeker organisation or psychology. To illustrate the negative influence of internal knowledge incumbents on innovation consider an example from an FMCG company. The company manufactured heat sealed packaged consumer products and was approaching the limit in terms of productivity improvement with the heat sealing technology. Many years previously, trials had been conducted with ultrasonic sealing systems without success. Later, when ultrasound was again identified as a potential next step in development of the manufacturing system, internal process experts strongly advised that this route was a dead-end; "we tried that before and it didn't work". Later still, examples from other industries started to appear demonstrating the potential of ultrasonic welding but the internal experts said "our process is different and our requirements are more demanding". It took a determined effort to ignore previous knowledge and start new ultrasonic trials which successfully demonstrated the potential impact and effectiveness of the new technology. Ultrasonic welding is now in routine use in this company and it has belatedly been shown to provide major benefits in terms of productivity and product performance.

The open innovation process should anticipate threats related to internal "psychological inertia" from an early stage and should introduce tactics to target and overcome potential stumbling blocks for innovation.

2.6 Issue 6: Failure to build trust between the solver and seeker

Open innovation seekers are often concerned about losing control of their IP and business intelligence as they "open up" their innovation to the outside world. At the same time, solvers often have exactly the same concern – if they are open with their own proprietary information or know how will they lose it? How can they trust the process to protect their rights and how can they gain and maintain confidence in the other side?

Feedback from a number of solvers who have engaged in open innovation highlighted the issue of trust as a major factor in their decision to discontinue their involvement with open innovation marketplaces such as Nine Sigma and Innocentive. Ex-solvers cited lack of feedback during the process, distrust with the motives of the seeker (i.e. "will they just take my idea and not pay me for it?" or "are they just using me to help them cheaply scope out a technology area?") and sudden demands for lots of extra information causing extra work and suspicion. The experience as solvers of both of the authors of this paper reinforces this feedback. In one example, after submitting a proposal to Nine Sigma in response to a medical device RFP, the seeker indicated that they were interested in the proposal. Over the following two weeks Nine Sigma sent a total of nine increasingly confusing and worrying e-mails demanding more information, suggesting that the proposal was not backed up by any IP and that the proposed concept was not unique. By the time Nine Sigma said that their client was no longer interested in the proposal, it was really quite a relief not to be working with such a suspicious and distrusting seeker.

3 ANALYSIS

It is clear that problems can start very early in the open innovation process, and that with poorly defined problems come poorly defined solutions. From the TRIZ standpoint there are a number of key contradictions evident in current open innovation practice. The following analysis seeks to highlight these contradictions and identify potential solutions to improve the situation. During the analysis we will map the problem from two perspectives, that of the seeker and that of the solver.

3.1 Open Innovation from the seeker perspective

In general, open innovation seekers are looking for ways to grow their business or increase profits through innovation. The focus of their open innovation activity is on solving a problem or realising an opportunity. In fact, to realise an opportunity, usually a problem must be solved. Clearly the seeker might chose to solve the problem themselves or internally within their own organisation but the attraction of open innovation is that a far broader range of solutions can be accessed, some of which may be almost ready to implement. Common concerns for seekers when considering the open innovation route include risk of loss of IP or other important business intelligence and the uncertainty related to finding a good solution. Figure 3 shows a typical needs hierarchy mapped from the seekers perspective.

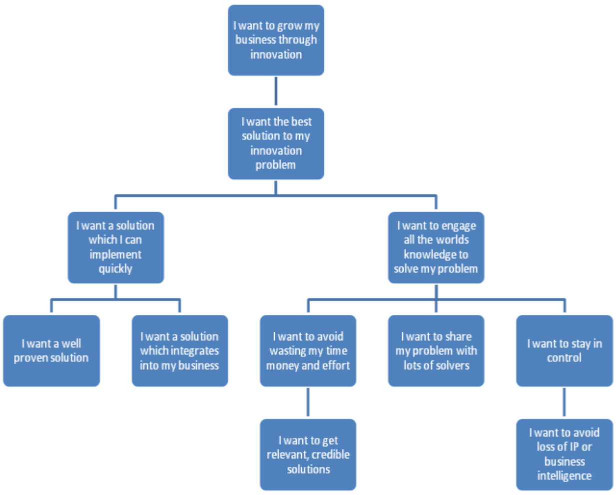

Figure 3: Open innovation seeker needs hierarchy.

3.2 Open Innovation from the solver perspective

As with seekers, solvers are looking for ways to grow their businesses, unlike seekers, however, solvers approach open innovation as a way to do this by finding new outlets for their knowledge or technologies. In other words they often see open innovation as a means to market their business. Solvers are looking for partners or clients who have a good fit with their business but as with seekers they are concerned that they may lose control of important aspects of their business either in terms of their IP or by becoming bound up in unfavourable contractual conditions. Potential solvers are often suspicious of the seekers motives and are put off if the open innovation process doesn't provide adequate feedback. Solvers are concerned that they may invest a large amount of effort trying to solve a seekers problem only for the seeker to say that the solution is inappropriate. The enthusiasm of solvers to engage in providing open innovation solutions can be very quickly eroded by lack of success or even lack of feedback. In our research we have encountered many ex-solvers who have become completely disenchanted by the open innovation model as it currently exists. Figure 4 shows a map of the main solver needs relating to open innovation.

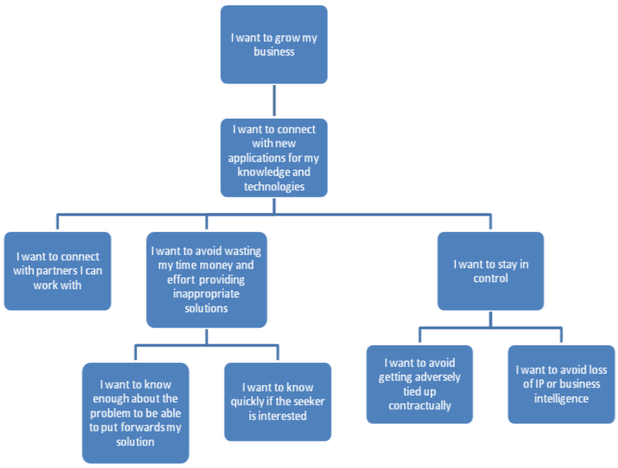

Figure 4: Open innovation solver needs hierarchy.

The issues identified in the previous section of this paper can be shown to relate to the needs hierarchy as follows:

Issue 1: The initial problem posed to the open innovation community is the 'wrong problem'.

Figure 5 shows the key conflict for the seeker in this issue. This conflict can be paraphrased as: *I want to engage all of the world's knowledge to solve my problem* ***but*** *I want to avoid wasting my time, energy and money chasing after irrelevant (sub-optimal) solutions.*

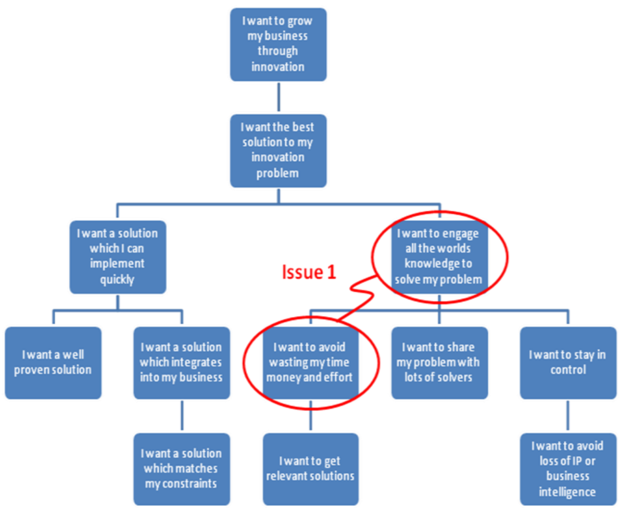

Figure 5: Illustration of issue 1.

Using the matrix developed for business and management [3], this analysis identifies the Improving parameter as: *amount of information* (parameter 22) and the worsening parameters as *Convenience* (parameter 26). The following inventive principles are particularly relevant:

- Principle 27 - Cheap Disposable
- Principle 13 - Other Way around
- Principle 3 – Asymmetry
- Principle 10 - Prior Action
- Principle 19 - Periodic Action

Solution Trigger	Ideas Generated
Principle 27 - Cheap Disposable	Use information which is already readily available in the public domain or through network contacts. With modern search engines and the ready availability of publications and patents, it is possible to exploit readily available information very easily.
Principle 13 - Other Way Around	Follow an open innovation approach which is not "open", i.e. not open to all to submit their ideas. Rather than try to access the world's knowledge based on an initial, literally written brief, use a more targeted approach and seek out contacts with relevant knowledge or technologies. Use a systematic process to define the problem in generic functional and physical terms rather just preparing an industry specific brief and identify ideal target statements for the key system resources (Ideal Final Result)
Principle 3 - Asymmetry	Go for specific sectors where the targeting applies. Look for extreme versions of the problem situation.
Principle 10 - Prior Action	Set up a basic network with nodes in strategic areas of interest. Insert an abstraction step into the open innovation process using a systematic approach
Principle 19 - Periodic Action	Adjust the frequency of communication and progression of information flow as appropriate for each stage of the open innovation process. Apply only the necessary contractual agreements at each stage to ensure appropriate progress can be made to complete that specific stage of the open innovation process

Table 1

Issue 6: Failure to build trust between the solver and seeker

The issue of trust in open innovation is a complex one, governed by the open innovation process, behaviours around the process and underlying beliefs. In an article by Luna-Reyes et al (2004), research into trust levels between suppliers and customers showed that it takes time to build trust and that there are potentially beneficial behaviours and attitudes which can help to grow trust levels over the longer term. The research showed that development of trust depends on:

- the expectations that the trustee will not behave opportunistically, especially when there are substantial incentives to do so,
- positive expectations or optimistic beliefs about the trustee are central.

In an experiment Luna-Reyes et al showed that "The highest interaction frequency patterns are the ones that show large fluctuations in the early time periods, then move upwards to high trust levels that remain high." …. "Paths with high frequency interactions, interpreted as faster learning, may be more volatile at first, since information that can change perceptions is flowing in at a higher rate. But other factors being equal, the more extensive knowledge base generated thereby leads ultimately to higher levels of trust." "The low frequency patterns show much smaller initial fluctuations and tend to lower levels of trust at the end point." This means that higher levels of interaction cause more havoc initially, but that exchange and exposure then ultimately leads to higher levels of trust (fig. 6).

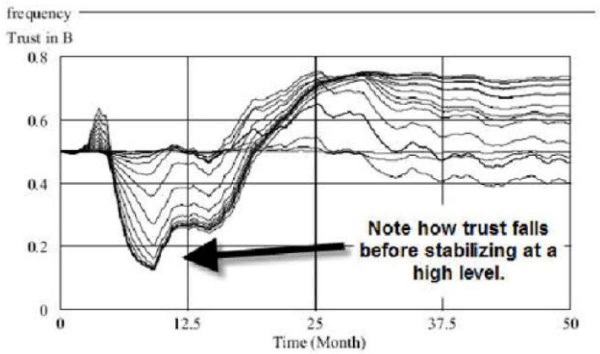

Figure 6: Curve showing development of trust between suppliers and customers.

A key issue for trust in open innovation relates to the question: how can the need to provide meaningful information to prospective solvers be reconciled with the seeker's need to protect their IP and avoid loss of valuable time? Figure 7 shows the conflict graphically, with the seeker's need for credibility plotted against the solver's level of commitment, both in terms of IP exposure and time. In the top left hand corner, the situation is biased towards the seeker need for credibility and puts the solver at risk of loss of IP and time investment (IP Give Away). In the bottom right hand corner, seeker risks being inundated by solutions of potentially little value from every crack-pot solver, regardless of their credibility. What is needed is an open innovation approach which targets the top right hand box, where highly credible solutions are provided with relatively low time investment or IP risk from the solver point of view.

Looking at the problem from the needs hierarchy perspective, figure 8 shows the conflict between the needs of the seeker and solver in relation to trust in open innovation. In this case, the seeker needs to get enough information about the proposed solution to be able to judge if the solution is appropriate and credible but the solver doesn't want to lose control of what could be a very important aspect of their business. This conflict can be paraphrased as: *The seeker wants to get relevant, credible solutions **but** the solver wants to avoid loss of control of their business.*

This analysis identifies the Improving parameter as: *R&D risk* and (parameters 4) and *Supply Risk* (parameter 14) and the worsening parameters as *Amount of Information* (parameter 22) and Tension/Stress (parameter 30).

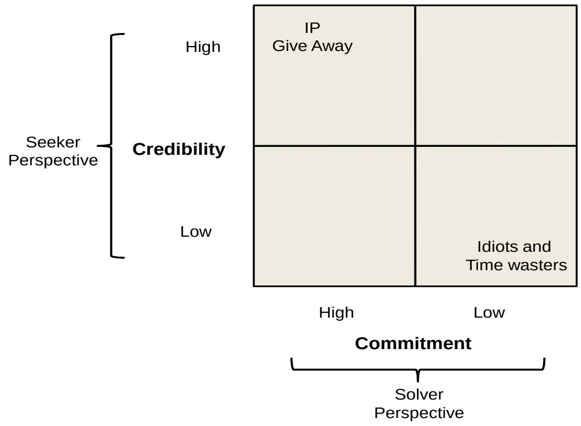

Figure 7: Conflict between seeker and solver nee

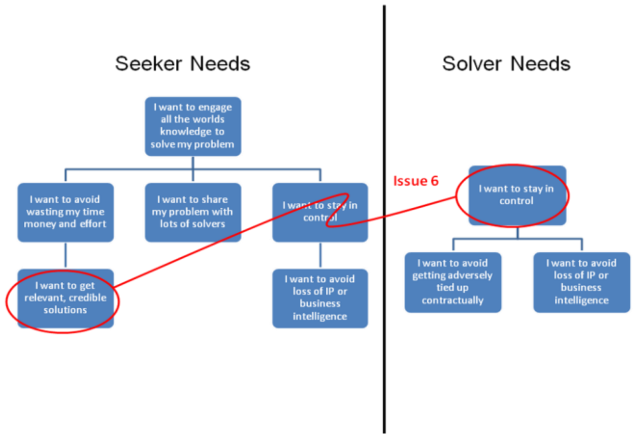

Figure 8: Needs hierarchy - Conflict between solver needs for relevant, credible solutions and solver need to stay in control.

The following inventive principles are particularly relevant:

- Principle 6 – Universality
- Principle 1 – Segmentation
- Principle 40 - Composite Structures
- Principle 39 - Calm Atmosphere

4 SUMMARY

It is clear from the initial issues identified for the current leading open innovation processes that the area of open innovation is still very much in its infancy. This paper outlines a number of improvements which, taken together, set the framework, perhaps, for a new, more principled and more targeted approach. In particular, the following steps could be particularly influential:

- Establish an open innovation charter which sets out expected behaviours from the very first stage of the open innovation process. This charter should form the basis for a more principled approach to open innovation;
- Use a systematic definition process to translate the initial problem into a generic (TRIZ world) problem to target research of areas where potentially strong solutions may exist and to indentify the necessary physical actions which any solution should deliver;
- Adopt a more targeted approach to identifying potentially strong innovation partners while making more use of readily available sources of information (e.g. internet, publications, well connected individuals or organisations);

Solution Trigger	Ideas Generated
Principle 6 - Universality	The open innovation intermediary sets up a charter which spells out expected behaviours and principles in the open innovation activity; this document seeks to clarify rights and responsibilities of all parties. Get intermediaries, seekers and solvers to sign up to this code so that everyone is clear of expected behaviours from an early stage
Principle 1 - Segmentation	Split the open innovation process into clear stages, each stage having clear contractual and confidentiality expectations. Avoid getting either party to share too much too soon – avoid need for “non-confidential disclosure”.
Principle 40 - Composite Structures	Some part of the intermediary needs to be configured to protect the needs of the solver as well as the seeker
Principle 39 - Calm Atmosphere	Introduce a neutral or safe zone into the open innovation process. This can be done through the concept of a “vault” where confidential information can be accessed only by intermediaries or through a contractual framework which helps to make the interaction safe for both parties.

Table 2

- Increase and adjust the frequency of communication within the open innovation process to support the need to build long standing high levels of trust between seeker, intermediary and solver;
- Provide a staged process for contractual engagement between seeker and solver which protects the rights of each party while providing sufficient information for the next step of the process to take place

If the issues identified in this paper can be overcome, open innovation still has the potential to yield major benefits for both seekers and solvers in the future. For open innovation to become a truly sustainable innovation methodology, we need to start by taking steps towards a more equitable framework for collaboration and engagement between complementary fields of expertise.

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Open Innovation Mapping: Linking Companies and Domains through Automated Patent Analysis

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Abstract

TRIZ suggests a level of abstraction to make knowledge structured and accessible across domains. In this paper we apply this notion of abstraction to generate a map of open innovation opportunities across companies and domains. In today's networked economy, having a helicopter view across domains can bring efficiency and sustainability to the process of finding technologies. Our domain maps are aimed at companies and individuals that want to explore the possibilities for knowledge transfer between several companies. This paper proposes a method to discover the most important domains in which a company applies for patents, a method for extracting the most significant companies in a domain and a visualization method for easy user interaction. This process encompasses the selection and analysis of patents from a structured database to extract the most significant companies per domain and the most significant domains per company respectively. Our strategy involves the application of several data mining techniques such as clustering methods and fuzzy searching algorithms. Additionally, this paper also proposes visualization for depicting the results. We explore several cases in which we build the domain maps for several companies and explain strategies to use these maps to make the open innovation process more efficient.

Keywords

Patent Analysis, Knowledge Transfer, Open Innovation

1 INTRODUCTION

The Open Innovation phenomenon has been a hot topic since the publication of the book with the same name by Henry W. Chesbrough in 2003 [1]. The core idea of this new paradigm is that companies can no longer solely rely on their own innovation efforts, but that organizations should also embrace external input. This can be achieved by licensing intellectual properties from other sources or by co-creation between an organisation and its customers or stakeholders. The concept of bringing in external knowledge has most successfully been applied in larger international organizations. A large scale application of this "Open Innovation" idea across all sizes of companies has been lagging, partly due to the lack of tools.

The aim of the authors is to create structured and automated approaches to discovering open innovation opportunities based on patent knowledge. This paper describes how to generate company domain maps by applying statistical analysis and data mining techniques.

2 APPLICATION

"Nobody is as smart as everybody" has been a motto of technology transfer methods. Open innovation is related to technology transfer, co-creation or co-development, though especially with knowledge going across different domains of technology. Companies are enlarging there pool of solutions, by not limiting themselves to their internal research, but seeing the competition, as well as less related domains as potential inspiration for new solutions. The importance to look outside your domain has been shown in numerous cases, where breakthrough innovation has occurred through importing technology from a completely different domain. The proposed the open innovation maps methodology enables to systematically search for other companies active in the same research, not necessary direct competitors. The maps furthermore identify areas where a companies' technology could be applied in a different domain.

3 METHODOLOGY

3.1 Patent data

The proposed methodology uses a relational database of patent documents which are described with full text fields (title, abstract, claims, description) and bibliographic fields (inventor, company, application date, publication date and one or more classification codes).

3.2 International Patent Classification

The proposed methodology uses the International Patent Classification (IPC) system, which is a broad set of subject classifications for patents. Its aim is to create a standardized categorization of patent documents to make searching easier for patent examiners and end users and to facilitate the monitoring of technological development in various areas.

Section:	H	ELECTRICITY	
Class:	H01	BASIC ELECTRIC ELEMENTS	
Subclass:	H01F	MAGNETS	
Main group:	H01F	1/00	Magnets or magnetic bodies characterised by the magnetic materials therefor
One-dot subgroup:		1/01	• of inorganic materials
Two-dot subgroup:		1/03	• • characterised by their coercivity
Three-dot subgroup:		1/032	• • • of hard magnetic materials
Four-dot subgroup:		1/04	• • • • Metals or alloys
Five-dot subgroup:		1/047	• • • • • Alloys characterised by their composition
Six-dot subgroup:		1/053	• • • • • • containing rare earth metals

Figure 1: Example of IPC classification.

As can seen from Figure 1, the classification system is hierarchically divided in 8 levels for which each lower level is a subdivision of the contents of a higher level. The patent documents are stored under one or more of the more than 60.000 classification codes. If needed the proposed method can also be applied using the finer detailed ECLA classification system.

3.3 Implementation steps

The first phase of the process, indicated by the dotted area on the left in figure 2, is to identify the core domains of a given company.

1. In a first step we use a user selected company name to query the database for all documents of that applicant. Optionally, we can perform additional cleaning to exclude duplicate patent documents (e.g. one document per patent family).
2. In the second step we select only the IPC codes that have a significant representation in the total data. Codes that occur too few times in the collection or classifications that are on the deepest IPC level and are too specific can be omitted.
3. In this step we use a form of unsupervised classification so that documents with similar IPC codes are in the same class and dissimilar ones are in other classes. For this we devised a simple similarity metric based on Minimum Spanning Tree [2] with weighted vertexes. This uses distances in the IPC tree to calculate how similar 2 codes are. Various clustering methods, like BIRCH (hierarchical) [3] or K-Means (partioning) [4] exist to achieve this. At the end of this step we label each cluster with one or more of its most promising descriptors.

The second phase of the process, indicated by the dotted area on the right in Figure 2, consists of the following steps for each of the selected domains:

4. Once we have the cluster representing a single domain for a certain company, we use the cluster medoid [4] or several documents close to the cluster centre to find the most relevant IPC codes.
5. Using these IPC codes we can query the database again to obtain all patent documents filed under these codes ranking each document with how much of the codes matched.
6. Finally, we can discover which companies are the top applicants in the subset of documents.
7.

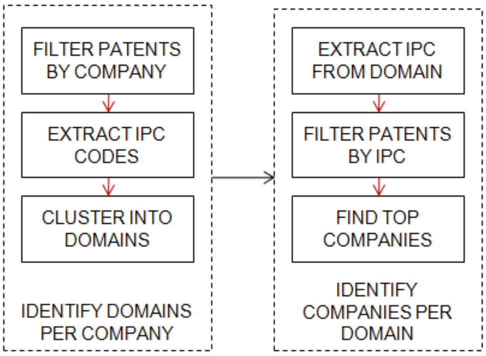

Figure 2: Data flow.

4 VISUZALIZATIONS

A popular visualization of this type of node/link data is the use of directed or undirected graphs. This type of visualization gives a clear indication of the structure of the data; e.g. which companies are linked in several domains. Depending on the size of the input, graph visualizations can be rather complex because of the many vertex crossings. Creating a graph based visualization which is aesthetically appealing and easy to read is not always possible. An alternative is to use tree-based visualizations which reveal less of the actual graph structure but offer increased readability.

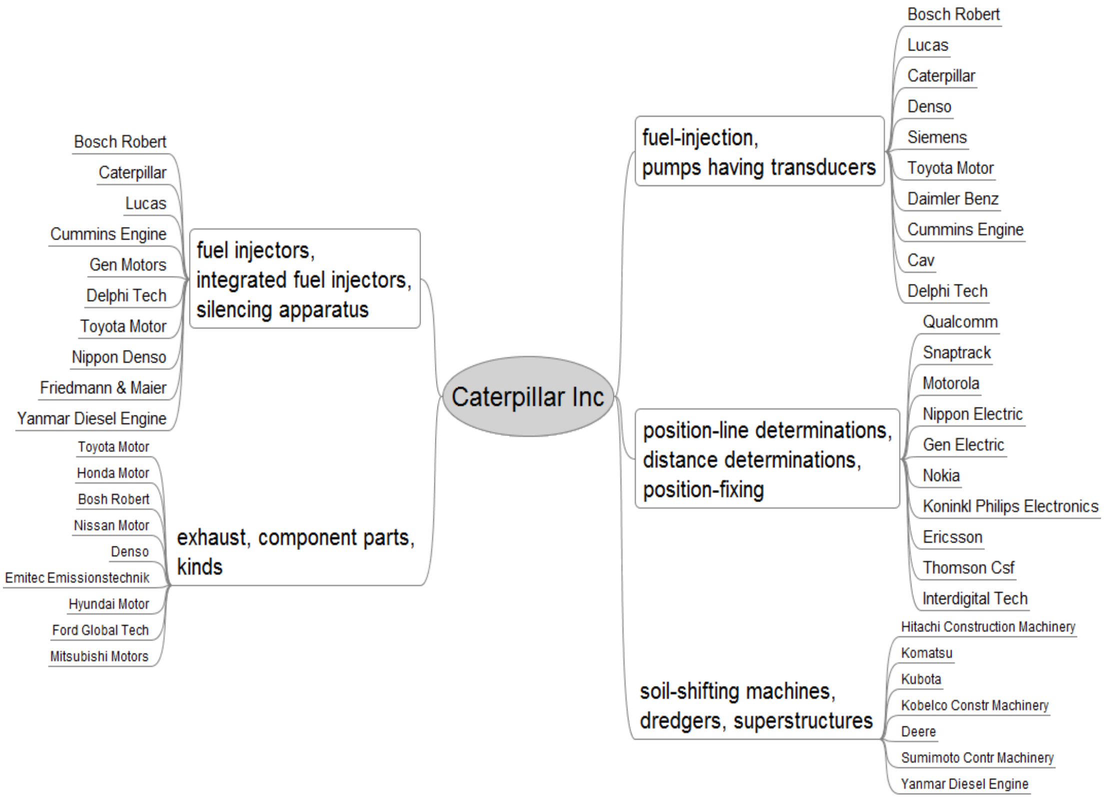

Figure 3: Tree-based visualization of patent domain analysis of Caterpillar Inc.

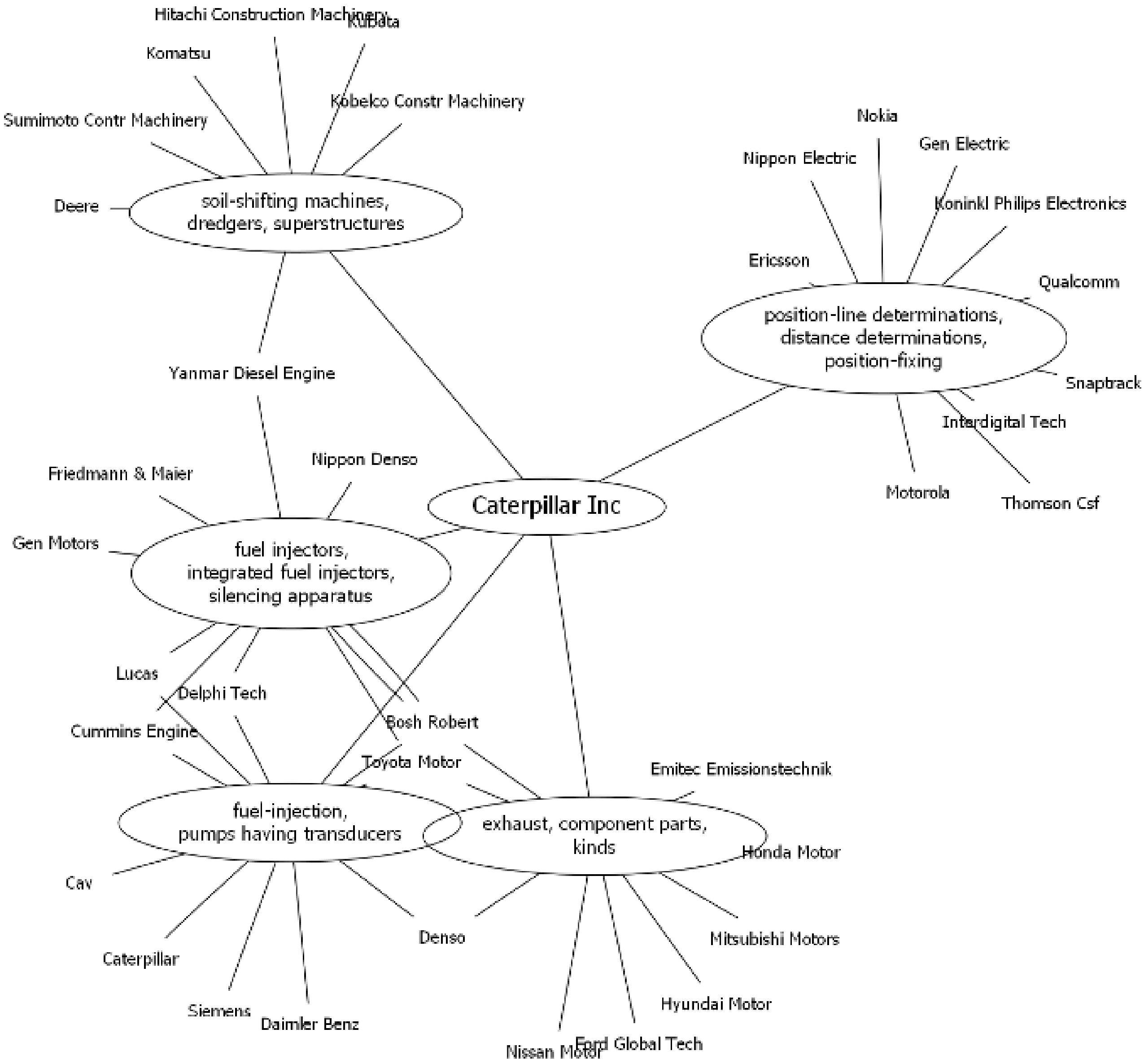

Figure 4: Undirected graph visualization of patent domain analysis of Caterpillar Inc.

5 INTERPRETATIONS

The proposed method combined with its visualization(s) gives the user easy access to areas where other companies have similar interests and expertise. These areas are the first candidates to explore when looking for Open Innovation opportunities.

In this case, Caterpillar can identify that in the area of fuel-injection Delphi systems has competing knowledge. This means a listing of these relevant patents emerges, and Caterpillar can be inspired, interested in acquiring or even interested in licensing their own technology to Delphi, if that appears opportune.

6 REMARKS

A prerequisite of our method is that the map is limited to companies that have applied for patents and that they are available in our relational database with one or more classifications attached.

7 SUMMARY

Using existing knowledge for solving contemporary problems is a must for developing towards a sustainable society. In order to ‘recycle’ existing solutions then to‘re-search’ from scratch; open innovation mapping can be a good first step. The technique automatically visualises, which areas of research are related, as those relations are in the patent database structure.

This paper has shown maps linking companies that have IP on similar research topics, though any form of analogy can be the basis for a map. One can create a map on ‘solving the same problem’ or achieving the same function. Examples of the diversity patent data generated Open Innovation Maps will be presented at the conference.

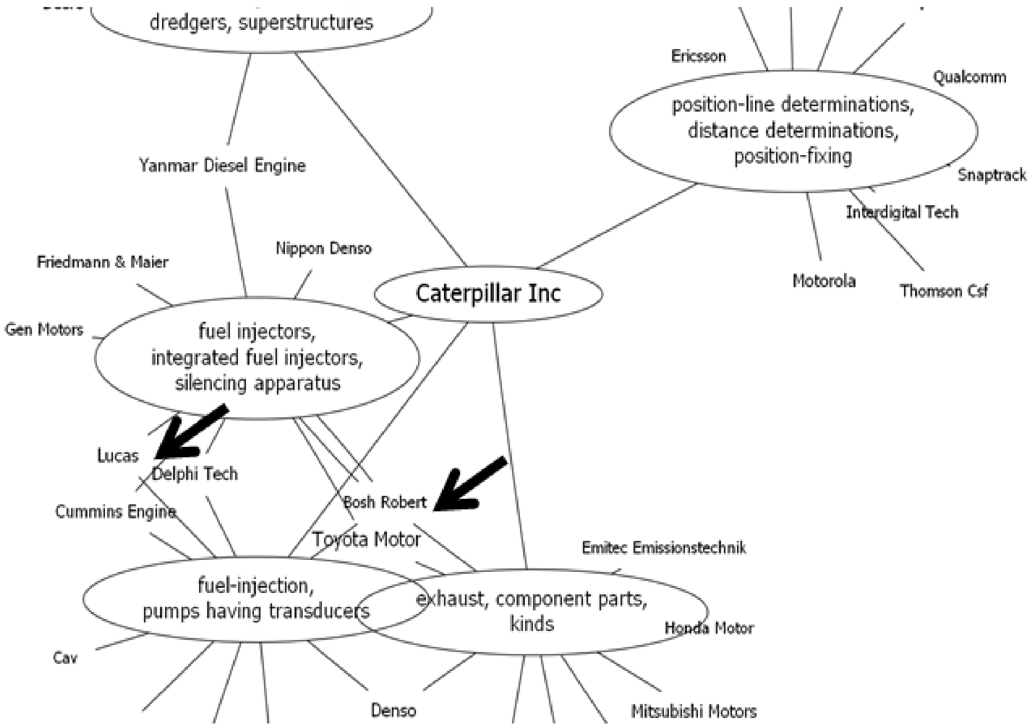

Figure 5: Detecting candidates for Open Innovation opportunities in graph visualization.

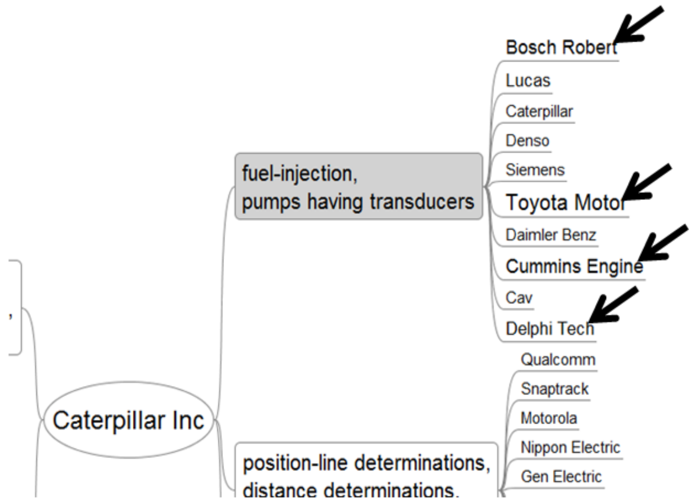

Figure 6: Detecting candidates for Open Innovation opportunities in graph visualisation.

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Best Practices in Applying TRIZ at Philips Royal Electronics

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Abstract

In the past seven years we, at Philips Applied Technologies have consistently used TRIZ in our innovation process for various businesses at Philips as well as for external parties, and particularly in workshop settings, in which the participants are not generally trained in the use of TRIZ. Initially we have tried to use elements of TRIZ directly in the definition and ideation phases, but have met with some difficulties. We have subsequently developed a different way of integrating the systematics of TRIZ within the structure of our project settings, and based on our experience we will show how we integrate TRIZ in our innovation process, present our learnings and links to other innovation tools.

Keywords

TRIZ, Workshop

1 INTRODUCTION

As part of Philips Corporate Technologies, Philips Applied Technologies is a contract R&D organization that supports the development of products, applications and technical solutions. Our customers are market leaders, fast growing companies and start-ups. For every phase of the innovation process, we offer integral solutions, consultancy and specialist services. With over 1000 in-house experts, we can draw on a wide range of competences. These competencies are used by the Philips businesses, Healthcare and Lifestyle as well as customers outside Philips.

Industry consulting, the group we work for, is concerned with the provision of consulting services to support our clients in making their processes more efficient and effective and therewith gain money, time or both. This includes processes such as technology roadmapping, product architecture, portfolio management, change management, product creation processes, “Lean Manufacturing”, integral cost calculations, and, of course, hands-on support in the area of ideation.

Considering this background, TRIZ with its structured and targeted way of working on one hand lends itself to be used; on the other hand the projects show characteristics that do not always support a classic TRIZ approach:

- the projects last from a few days to a few months,
- the participants are called upon from a wide range of backgrounds and may be involved only at certain points in time,
- the projects reside with our clients, Philips operating businesses, Philips Applied Technologies, Start-up companies or with external companies,
- our role is typically that of a consultant or facilitator supporting a project leader.

With this in mind we are using a specific approach based around ideation workshops that is designed to reach the clients objective in the most cost and time effective way.

2 OUR APPROACH

Our approach consists of three basic steps that are quite generic to creative processes:

- definition phase,
- ideation phase,
- decision phase.

The basic guideline is the use of analytical, diverging and converging processes, analytical for definition and focus purposes, diverging for creative purposes, and converging for decision making purposes.

Furthermore we define a team structure to bring forward the project through the different phases. A core team of two to four members is formed that contains participants from the client side as well as from Philips Applied Technologies. The purpose of the core team is to keep the project leadership and also close alignment between the different parties involved throughout the process.

The core team is strengthened by the contribution of specialist participants as well as stakeholders at defined moments throughout the project.

In addition to the above phases and dependent on the objective of the project enrichment sessions may be conducted, for example to fill knowledge gaps that may be identified at any point during the project.

In the past we have tried to use elements of TRIZ directly in the definition and ideation phases, but have met with some difficulties:

- TRIZ has a unique vocabulary that is difficult to learn within a few minutes and thus makes communication quite difficult.
- While the principles of most TRIZ tools are logical and simple, it takes some time to learn, to apply to the best advantage, and to be convinced of the benefits of using such a tool. This time is not available considering our tight time schedules. Some other TRIZ tools (ARIZ) are too complex to use with the unacquainted in any case.
- The group dynamics and expectations of the participants are targeted at solving the problem at hand, not at learning new problem solving techniques.

We have subsequently developed a different way of integrating the systematics of TRIZ within the structure of our project settings.

2.1 Definition phase

In this phase the objective of the project is defined. Being used as a guide throughout the projects it has to be formulated to be:

- concise – to make it easily understandable to the workshop participants,
- clear – to keep the creative effort focused,
- shared within the organisation – to ensure the results are taken forward.

Typically the core team as well as selected stakeholders are involved to define the exact focus and objective of the project.

Two kinds of tools are used here. Firstly, to sharpen the focus and objective of the project, tools such as the Ideal Final Result (IFR), 9 windows model or root-cause-analysis are used.

Secondly, once the objective is defined, a number of creative tools are selected to be used in the creative session or sessions. For us this is an important preparatory step, as the participants in those sessions are typically not trained in the use of idea creation tools such as TRIZ, and may also be not intimately acquainted with the background of a project. They may find themselves thus unable to support any necessary ad-hoc decision about the way forward in a problem solving project. To ensure a high level of confidence in achieving the project result, we therefore map out the most likely matches between creative tools and project questions in advance.

Following this selection process specific information concerning the project is collected, and presentation material around the tools is compiled. The aim is here to provide all the relevant information to the participants in the ideation phase so as to focus as much as possible on the ideation and not on the understanding of any tool used.

2.2 Ideation phase

In this phase the solution space described in the Definition phase is explored. The ideation phase or phases, in the majority of the cases, are taking place within a workshop setting. Critical elements here are:

- good preparation,
- looking at the solution space from many different angles,
- involving different disciplines and specialists.

Such a workshop setting has some typical characteristics, the number of participants is limited to about eight or ten, participants may be briefed in advanced and are chosen for the specific knowledge they can contribute, and the workshop normally lasts a maximum of eight hours. Furthermore we utilise guided creativity techniques, where trained facilitators are used to keep the focus throughout the workshop.

How TRIZ tools are used in such a setting is best described by example, and the use of Contradictions / Inventive principles, Trends and Trimming are described in the following:

Contradictions / inventive principles

During the preparation for the creative session the objective and questions arising from the project are discussed with the core team, and the main contradictions identified. We then use these contradictions to identify a set of relevant inventive principles. Rather than identifying a single contradiction we find it useful to define a set of possibly relevant contradictions and to derive ten to fifteen inventive principles from that.

In the creative workshop the core team as well as a number of specialists are involved. The participants have been briefed about the objective of the project, as well as some general background, specific problems, characteristics and requirements. They are introduced to the selected inventive principles, one at a time; the contradictions may or may not be provided as background information. In our experience the use of inventive principles can easily be explained, particularly when using examples such as are easily available from literature [1]. After ideas are created on a first principle the team moves on to the next, until all pre-defined inventive principles have been explored. It is not unusual to find that 50 to 100 relevant ideas are created from using contradictions and inventive principles in this way.

Trends

Again it is during the preparation for the creative session that the objective and questions arising from the project are discussed with the core team, here with the aim to identify trends that may be relevant. A function analysis is sometimes performed in advance to get a better understanding of the functions involved. Depending on the complexity of the project different numbers of trends may be identified.

During the creative workshop the participants are introduced to the selected trends – one at a time. The trends are introduced by the facilitator, and explained using examples. To speed up the process we aim at providing carefully chosen examples that have some relevancy for the project and / or field of expertise. TRIZ software can successfully be used for this part. Based on a trend ideas are generated. We then move on to the next trend. In our experience the number of ideas generated using trends is typically lower than those generated using contradictions.

Trimming

During the preparation for the creative session the main components and functions of the project need to be carefully charted. Here the core team might involve relevant specialists to gain additional insights. We also like to visualise this using, for example, function analysis diagrams. These visualisations are ideal to identify possible areas of interest that could be targeted for trimming exercises. A word of warning is warranted here, complex arrangements can be confusing. There is an art in finding the right level of segmentation, sufficiently complex to understand the issues, simple enough not to confuse.

The visualisations are also an excellent communication tool we use in the creative workshop. With the workshop team we walk through the possible areas of interest one by one, exploring the possibilities for trimming or substitution and jotting ideas down on the way. Changes can easily be made on the overview, and ideas that are created may be added creating a visual diary of possibilities.

Other tools

In addition to TRIZ based tools we also use a large number of other creative techniques. It is our experience there is a nice balance and also at times similarities between these different tools. We find that TRIZ is excellently suited to tackle problems that can be well-defined, and where the elements or components are known. In other cases different tools or processes such as lateral thinking or InnoGame™ seem more suitable. Very often, however, we combine the structured thinking of TRIZ with more ludic ideation tools within a single workshop setting. This gives the facilitator the possibility to adjust the pace of working throughout the day and to adapt to the energy level of the participants.

The choice of the “right” creative tools remains a key question for us. Ultimately it is dependent not only on the problem at hand, but also on the resources available and the human factor – the participants. Over the years, and based on the many workshops that we facilitate, a pattern has emerged in our use of different creative tools. Table 1 shows a brief overview that may serve as a guideline for the use of a variety of creative tools based on objectives we are typically confronted with. Typical TRIZ related tools are underlined.

Objective	**Creative tools that, based on our experience, provide good opportunities to achieve the objective**
Creation of user insights, concepts or features based on these insights	• Co-creation tools • Lateral thinking tools [2] • Industry scouting [3] • Mind map • Inno-Game™ [4] • *Trends*
Creation options for concepts based on specific requirements, (technical) problem solving	• *Contradictions* • *Trends* • *Knowledge / Effects* • *SIT*
Improvement projects including Cost-down activities for products and processes	• *Trimming* • *Contradictions* • Lateral thinking tools
Designing around a patent	• *Trimming* • *Contradictions* • *Knowledge / Effects*
Search for applications based on a specific technology	• Lateral thinking tools • Inno-Game™ • *Knowledge / Effects* • *Trends*

Table 1: Overview for the use of a variety of creative tools based on typical project objectives

2.3 Decision phase

The decision phase is the moment in time where, from a number of possible solutions one or more solutions are chosen. Key elements in this phase are:

- clear description of decision criteria,
- decision criteria covering the responsibilities of the stakeholders,
- use of specialists,
- involvement of key stakeholders.

This is a convergent process and we do not use typical TRIZ tools here. Depending on the complexity and scale of the project quick ranking procedures such as paired ranking may be used, moving up the scale to much more formalised and involved ranking schemes.

3 LEARNINGS

TRIZ, with its idiosyncratic language and bewildering amount of different tools can be daunting to the uninitiated and be difficult to use with a team of untrained participants in a workshop setting.

Our solution is to split up the use of TRIZ tools in such a way that a small core-tem prepares a roadmap of tools to use in advance to a creative session. In the creative session the creative power of a larger group of specialists can fully be explored using TRIZ tools and other creative techniques to achieve the project objective.

In general we observe that there is a correlation between the use of TRIZ related creativity tools and the level of definition of the problem at hand. The more specific and function related the objective is described, the more likely TRIZ related creativity tools are yielding good results. If the objective is described fuzzier or more marketing / user related, other creative tools such as InnoGame™ or lateral thinking promise to deliver better results.

4 SUMMARY

This paper has discussed some of the difficulties encountered when using TRIZ tools in workshop settings where the participants have no or little knowledge of using TRIZ.

Based on experience we have outlined a way of working with TRIZ tools in those circumstances. By way of example this has been further explored. Furthermore, a table has been presented that may serve as a guideline to decide in which situations specific creative tools may be preferably used to achieve the project objectives.

ACKNOWLEDGMENTS

I like to extend my sincere thanks to all who directly or indirectly contributed to preparing this paper, particularly my colleagues Ad Vermeulen and Jose Loeffen at Philips, but also to all those participants of our creative workshops. Ultimately it is their work, reactions and feedback that helped us to come this far and make these workshops successful add value-adding events.

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For further information see, for example:

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[2] For further information see, for example: Edward de Bono, 1990, “Lateral Thinking For Management”, Penguin Books, ISBN 0-14-013780-7.

[3] Industry scouting is a tool that helps to create new user insights as well as product ideas based on industry research. For further information please contact the author.

[4] InnoGame™ is a tool that has been developed at Philips Applied Technologies. It is a role-playing game that helps you to gain insights into your competitors, their products, market choices and product features. For further information please contact the author.

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Using TRIZ to Find Innovative Redesign Solutions for a Jigsaw

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Abstract

This paper's aim is to present a set of solutions for redesigning the jigsaw. The paper covers the divergent creation phase, and it presents an abstract of technical contradictions and a solution using Su-Field analysis. The contradiction matrix and TRIZ inventive principles were employed to established the possible technical solutions for the jigsaw. Once convergent creation phase is reached, the solutions generated in the divergent phase are analyzed and axiomatic design is then used to choose the solution with the highest probability of success.

Keywords

TRIZ, divergent creation phase, convergent creation phase, axiomatic design.

1 INTRODUCTION

Because the designers are faced with increasing requests from customers to create new and improved products, it is important that the customers' requirements be rigorously established and understood by the team that will design the product.

The designers need to permanently improve the quality of products in order for these to be sold on the market. That can be done only by continuous innovation.

It can be a partial innovation, by improving the old products or total innovation when the old product is replaced with a new one.

After gathering the customer's requirements in order to improve the old products, or create new ones that will satisfy these requirements, the next phase is the product creation process. This process is composed from two very important phases.

The divergent creation phase is when the team transforms the customer's requirements into an abstract creation. An extraction of all the essential elements is required, and using a divergent type of reasoning, the team comes up with a solution that takes into account the customer's requirements. This is the phase when all the psychological barriers of designers should be overcome and when deep, creative thinking should lead to the elaboration of bold product solutions. It is the phase when all design methods that contribute to the development of creative thinking are welcome. TRIZ plays a very important role in this phase. It is in this phase of creation, through breaking down the psychological barriers and imaginative thinking, that new products that cannot be obtained with the present technologies could be designed. Sometimes these bold products are not fully understood by people, and therefore they are not considered to be technological designs. It has been proven by the history that these "lonely wolves" of the human imaginative thinking have revolutionized technology and science.

The convergent creation phase is the phase when the team tries to select from the numerous solutions obtained in the divergent thinking phase those solutions that can be put into practice using existing technologies. Other choice criteria include maximizing the performance and efficiency of the solution and minimizing the product's cost.

Taking into account these aspects our paper's aim is to present a set of solutions for redesigning the jigsaw. To reach this goal we tried in the divergent creation phase to solve technical contradictions and finding a solution using Su-Field analysis. The contradiction matrix and TRIZ inventive principles were employed to established the possible technical solutions for the jigsaw. Regarding the convergent phase we think that using the axiomatic design that is governed by the two axioms it can be choose the best solution. This convergent phase regarding the jigsaw will be deployed in our future work.

We started to analyze the existent product, the jigsaw, (fig. 1). We know that the main functionality for our product is to be able to cut materials. The effective cutting of materials is materialized through a blade movement. This movement requires an energy source. Using logic to make a FAST diagram, we imagined a possible product decomposition, which is presented in figure 2.

A FAST (Functional Analysis System Technique) Diagram [1] represents a translation of each working function into technical functions and materializes these technical functions in constructive solutions. This kind of diagram is built from left to right and is governed by logic: Why? How?

Figure1: The Jigsaw.

2 META-ALGORITHM FOR INVENTION

As is stated in [2] that TRIZ is a qualitative model that can provide recommendations, rules, instructions, suggestions, and examples. These types of qualitative models are all instruments for thinking – the achievement of practical results based on systematic and generalized experiences – and they correspond closely to the concepts of constructive mathematics. An algorithm is the entire set of rules that determine the development of the objects to be constructed. A generalized scheme of a meta-algorithm for invention is presented in figure 3 [2]. It comprises four stages:

8. Diagnosis (statement of the problem),
9. Reduction (reference to known models),
10. Transformation (identification of ideas based on controllable rules of transformation), and
11. Verification (check of the potential attainability of goals).

The diagnosis and reduction stages are in essence procedures for the analysis of the problem, while the transformations and verification stages synthesize the solution. This meta-algorithm for invention is the primary navigation system for solutions to any problem in inventing. The procedures from this scheme are supported by database shown clearly in the form of drawings whose basis is the A-navigators [2].

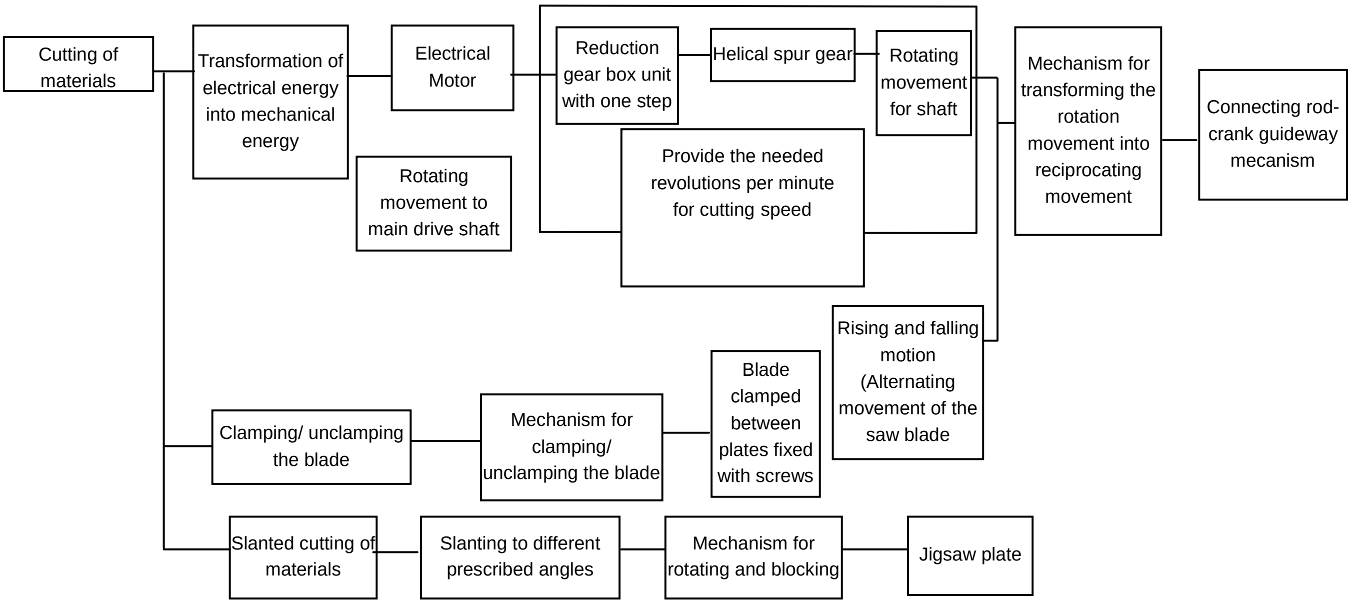

Figure 2: Product decomposition.

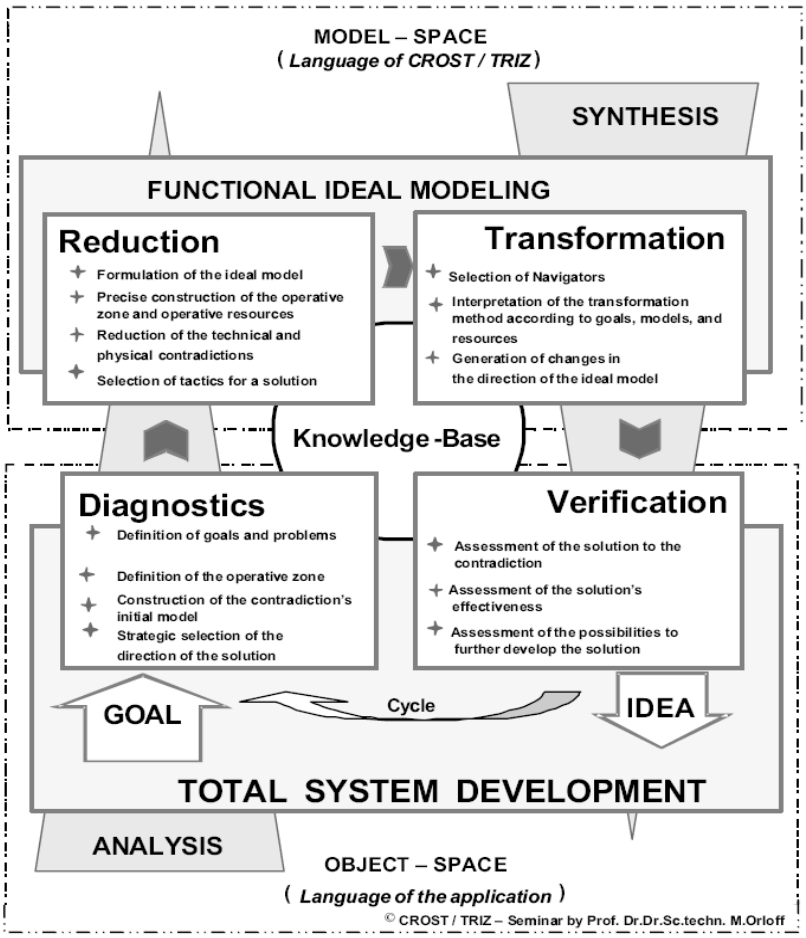

Figure 3: Generalized Scheme of a Meta-Algorithm of Inventing [2].

3 DIVERGENT CREATION PHASE

During the divergent creation phase, an important step is to diagnose the problem [2]. In this step, the following measures have to be taken:

- Define goals and problems,
- Define the operative zone,
- Construct the initial model of contradiction, and
- Identify a strategic selection of the direction of the solutions.

3.1 Defining goals and problems

The goal for the jigsaw is to cut a material in a very short time and make a cutout using small curvature radius.

3.2 Defining the operative zone and its elements

The operative zone (OZ) is the entire set of components of a system and its environment that are directly related to a contradiction.

Actors are the primary elements of the OZ that interact in the OZ and give rise to contradiction.

Inductor is an actor that influences another actor (receptor) with a transfer of energy, information, or material that then initiates a change or action in the receptor.

Receptor is an actor that receives the influence of the inductor and then changes itself or starts an action due to this influence.

The jigsaw can be abstracted, as presented in figure 4. The cutting tool is the inductor and the cutting material is the receptor. The inductor will receive the energy needed to realize the cutting from an energy source and by acting upon the receptor will realize the cut.

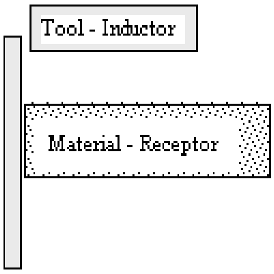

Figure 4: Tool's abstraction.

3.3 Constructing the initial model of contradiction

Useful functions (positive) include:

- obtaining a cutout using small curvature radius, and
- removing rapidly the material which is in the front of the tool

Negative functions include:

- wearing down of tool, followed by its failure,
- creating increased vibrations generated by cutting, which decreases the quality of the cut, and
- productiveness of the cutting's work out

Operative zone is represented by the contact (connection) between inductor and receptor. A Su-Field analysis, according to [4] and [5], is presented in figure 5.

It can be observed that a mechanical field, a pressure that acts upon the cutting tool (S1) will help to transform the material ahead of it – the material is then removed, thus realizing the cutting of the material. In turn, the material to be cut (S2) acts upon the tool and wears it down.

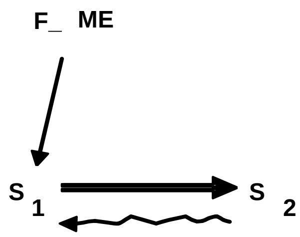

Figure 5: Operative Zone Su-Field Model.

The following directions to solve the problem are noted:

- -intensifying the inductor's motive power upon the receptor,
- -Intensifying the inductor cutting speed, and
- -designing a cutting tool with increased wear resistance.

The greater the inductor's motive power, the greater the yield from cutting; however, the tool is also worn down more so and it loses from its ability to provide a quality cut, hence giving rise to vibrations. To cut along small curvature radii, it is important to have a tool that creates a narrow cut. The contradictions that arise are presented in figure 6.

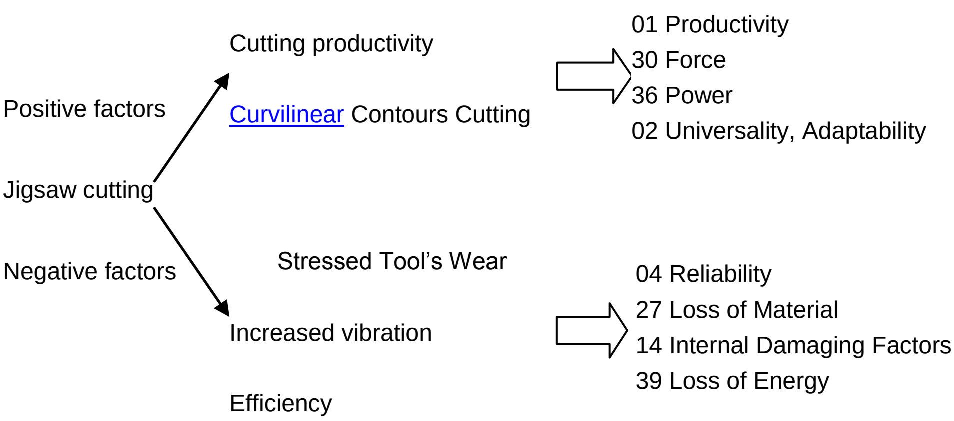

Figure 6: Technical contradictions.

3.4 Identifying a strategic selection of the direction of the solutions

Using contraction matrix [3] specialized solution directions can be identified, such as:

1. Employing the mechanical oscillation

According to this solution direction, the cutting tool will undergo an oscillating movement in order to discard parts from the material to be processed to prepare it for cutting. The cutting blade (see fig. 7) has an oscillating movement with an active stroke. This solution exists and the blade teeth are oriented upwards so that the cutting force is taken over by the portable saw (as seen in fig. 7).

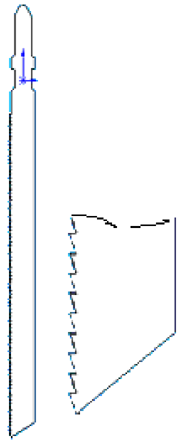

Figure 7: Cutting blade.

In the present solution, presented before, the following transformation of certain used fields is included. One can see how the electrical field is transformed in a magnetic field that spins the rotor of an electric motor S1, rotor, obtaining a high rotation motion. This in turn is transformed in another slower rotation motion, through a gear reduction unit S2, and the crank and connecting-rod assembly S3 transform the rotation motion into an oscillating parallel displacement motion. The cutting blade (S4) forms a unit with S3, and through its upward stoke produces the cut (see figure 8).

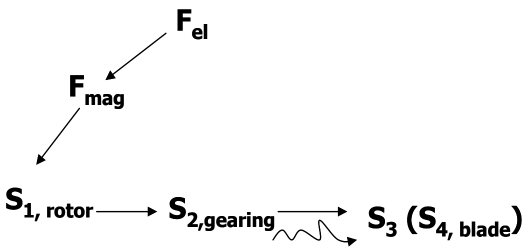

Figure 8: Fields transforming in oscillatory movement.

This transformation implies the existence of a revolution reduction unit, which with a relatively high revolution transfer rate can lead to vibrations that are not desirable.

Thus, a new operative zone appears, corresponding to the transformation of the electric field into an oscillating parallel displacement motion through a shorter chain, as shown in figure 9. According to this scheme, the electric field is transformed into a magnetic field, which operates on S3, with which the cutting blade S4 is forming a unit, the oscillating parallel displacement motion needed for cutting is thus created. A viable solution that creates the needed motion is based on Tutelea's research [6] and is presented in figures 10 and 11. The linear permanent magnet oscillatory machines have gained momentum in the last decade and could play an important role in the direct driving of piston pumps, compressors, etc. A flat surface mover allows for permanent magnet flux concentration, and the machine core is easy to manufacture from laminations.

The sketch of the permanent oscillatory machine with buried permanent magnet flux concentration is show in figure 10:

- the mover is sliding on linear bearings,
- the kinetic energy is recovered by two mechanical springs, and
- the blade will be joint with mover.

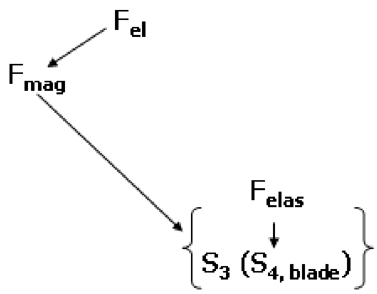

Figure 9: Decreasing the transformation chain.

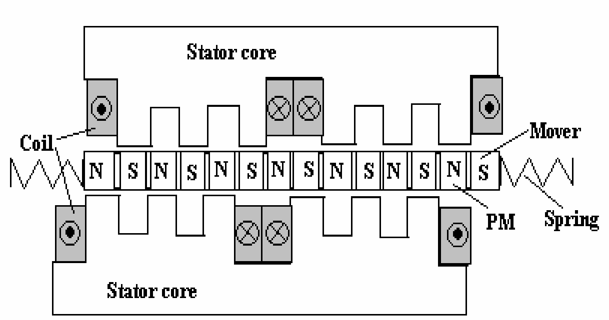

Figure 10: Solution with buried permanent magnet.

The sketch of the permanent oscillatory machine with surface permanent magnets is present in figure 11.

The disadvantages of this solution are: the frequency of the mover has to be equal with the resonance frequency of the mechanical spring, the cutting speed has to be constant, and the maximum stroke is 30-40 mm.

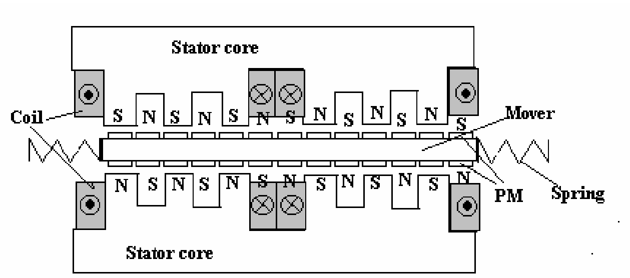

Figure11: Solution with surface permanent magnets.

2. Replacement of mechanical matter

Replacement of mechanical matter- according to this direction, the replacement of the solid body of the cutting blade with other materials leads to other types of material cutting.

If the solid body of the cutting blade is replaced with a liquid under pressure, which engages abrasive particles, then we have fluid cutting. This type of cutting requires a high-pressure liquid that engages the abrasive particles, which will in turn cut the processed material. The solution has the advantage of curvilinear cutting, following small curvature radii, due to the fluid's reduced intensity resulting in a very high quality of the cutting. It is difficult to apply this solution to a manual saw because the transfer of the fluid at a high pressure from the fixed part of the saw to its mobile part would create some problems and also the protection of the operator and environment would be difficult to achieve.

The use of air under pressure, which would engage abrasive particles to cut materials, raises even bigger problems regarding operator and environment protection.

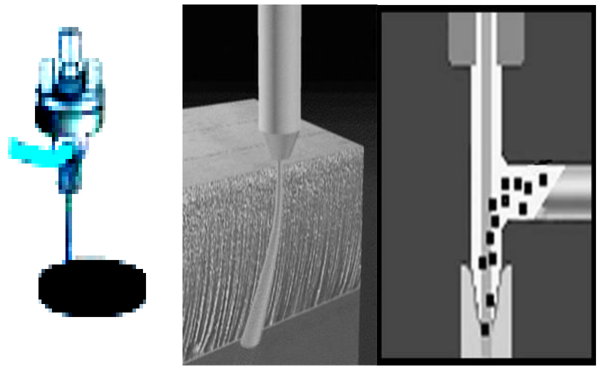

Figure 9: Cutting with liquid jet.

3. *Inverse action*

According to this solution direction, the following solution can be developed: In mechanical cutting, due to the interaction between the cutting blade and the material to be processed, apart from the abrasive wear, heat results, which contributes to the tool damaging. Solutions which make use of heat in cutting materials are:

Laser beam cutting. In this case the heat from the laser beam is used to evaporate the material touched by the beam and thus the materials are cut. Using the laser beam with a manual saw creates other problems, thus making it a solution not likely to be used.

Another solution is the use of the heat emitted by electrical energy, which melts the material and cuts it. It is the case of the wire electro erosion processing. This solution is difficult to implement with a manual saw because the material to be cut has to be immersed in a dielectric.

In order to use the abrasion as a proper solution, a cutting using the electrical contact was developed in [7] and [8]. In this method the tool interacts electrically with the material to be processed. The heat resulting from the electric contact melts the material in front of the tool, which is then removed by the movement of the tool. Notice that by adjusting the electrical and mechanical parameters of the cutting equipment, there is little to no wear of the tool. This depends in a large part on the characteristics of the material to be processed and on the working parameters of the cutting equipment. In addition, the cutting tool needs to be properly cooled.

Although the electrical cutting would be tempting when making a portable saw, presently there are some technical problems which would be difficult to surmount. The small dimensions of the tool (which is intend to be a line) makes the proper cooling of the tool difficult to achieve), and moreover, the portable saw is used when cutting a wide range of materials with different mechanical characteristics, case in which the tool wear would be greater, so the tool would damage rapidly. Perhaps the future technologies would solve this debate and this solution could be adapted to a portable saw.

4. *Dynamization, segmentation*

According to this solution direction applied to jigsaw, the tool constructive design should be changed so that continuous rotating movement can be used at high speed (rpm). The disadvantages of constructive solutions that use straight reciprocating motion are: the existence of a return stroke that leads to the decrease of the cutting efficiency, inertia forces that are generated when the tool's movement sense of direction is changed (because of the oscillatory movement), and the insertion of a supplementary device that will interrupt the tool's contact with the working material in the return stroke. These disadvantages can be removed using a continuous tool movement, but it has to ensure that the tool's return stroke will be through the previously made cut.

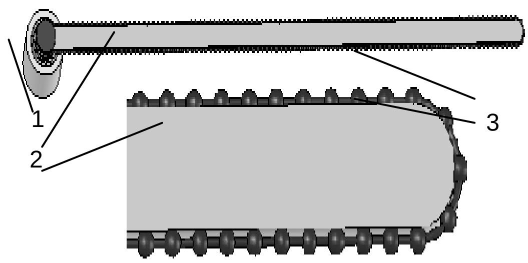

Figure 13: The tool with continuous movement.

The cutting tool with continuous movement is made from a resistant and flexible wire, 3, that has attached spheres. The upper side of these spheres is made from abrasive material - diamond milling- and the inferior side of the spheres is used to drive the cutting wire, meaning to guide this on a guiding plate, 2. This wire meant for abrasion cutting is driven into the rotation movement by a driving roller, 1. Also, in this case, the wire's rotating sense of direction is chosen so that the jigsaw will take over the cutting force. This design can be easily transformed by using arc cutting, case where the wire will be without spheres; however, the problems of excessive wear and cooling would have to be solved.

4 THE CONVERGENT CREATION PHASE

In the divergent creation phase multiple solutions for a stated problem are created. In this phase, there is little convergent thinking related identifying whether the solutions can be applied in practice.

The divergent creation phase is followed by the convergent creation phase. In this second phase, the generated solutions are analyzed having in mind the customer's requests. In this sense, it is useful to see which are the solutions with the highest probability to be realized, and for this the axiomatic design developed by [9] and [10] can be employed.

The key of a successful design is to abide by the following axioms

- A1. The Independence Axiom – Maintain the independence of functional requirements.
- A2. The Information Axiom – Minimize the information content.

The first axiom, the independence Axiom, requests that each of the functional requirements be accomplished independently, in no connection with one another. There has to be a minimum set of imposed functions (functional requirements) that characterize the product or the process. They have to remain independent during the whole product lifecycle.

The second axiom, the Information Axiom, allows the selection from the design solutions of the solution that abides by the first axiom and that has the least information content. If the information content is greater than 0, then we need supplementary information to satisfy the functional requirements. By information we mean the probability of providing the functional requirement.

The customer's functional requirements for the jigsaw are presented in figure 14, and the according design parameters are presented in figure 15.

Functional requirements are: F – Cutting of materials, F_1– Rotational movement of the cutting tools, F_2 – Feed motion, F_3 – Angled cutting, F_4 – Chipping removal, F_5 – Assurance of straight-line cutting, F_6 – Mounting of the cutting tools, F_7 – Operator's security, F_{11} – Ensuring the needed cutting speed, F_{12} – Assurance of cutting with small radius of curvature, F_{21} – Variable feed, F_{22} – Applying a feed force on cutting tools, F_{31} – Slanting to prescribed angles, F_{32} – Slanting to any desired angle.

The corresponding design parameters are: DP – Jigsaw, DP1 – Electrical motor, DP2 – Variable feed mechanism, DP3 – Swinging base plate, DP4 – Vacuum device, DP5 – Light projected on material for guidance, DP6 – Mechanism for mounting the cutting tool, DP7 – Protection screen, DP11 – Electronically speed variation, DP12 – Guidance plate, DP21 – Electronically feed variation, DP22 – Feed roll, DP31 – Blocking and labeling (indexing) mechanism, DP32 – Blocking and rotation mechanism.

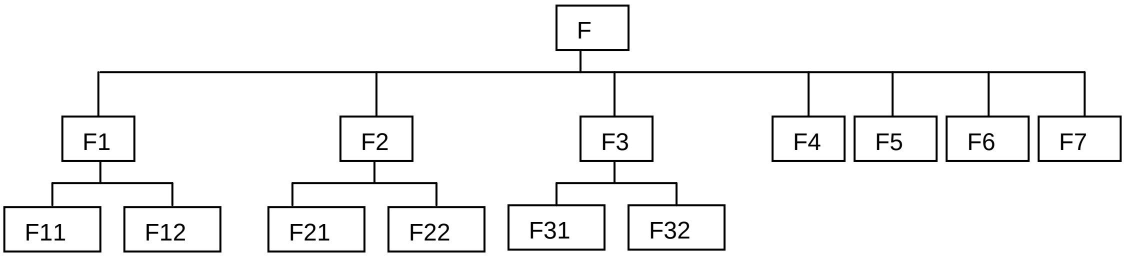

Figure 14: Functional requirements.

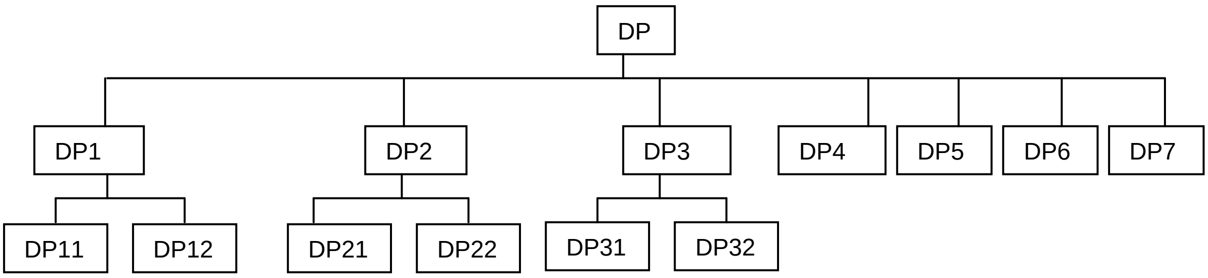

Figure 15: Design parameters.

The design matrix shows the correlation between functional requirements and design parameters. For our case it is presented below [11]:

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \\ DP_7 \end{Bmatrix}$$

$$\begin{Bmatrix} F_{11} \\ F_{12} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP_{11} \\ DP_{12} \end{Bmatrix}$$

$$\begin{Bmatrix} F_{21} \\ F_{22} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP_{21} \\ DP_{22} \end{Bmatrix}$$

$$\begin{Bmatrix} F_{31} \\ F_{32} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \cdot \begin{Bmatrix} DP_{31} \\ DP_{32} \end{Bmatrix}$$

It can be observed that the design matrix is not diagonal, is triangular. This one assures the functional independence so it is respected the first axiom-the independence axiom.

The flow chart (fig. 16) and module junction diagram (fig. 17) are a better way of representing the system architecture. The relationship between modules (Ms) are represented using circled symbols. A module represents a row in design matrix. The following circled symbols have been used:

S = simple summation of FRs (uncoupled design)

C = control junction (DPs and Ms must be controlled in a sequence (decoupled design)

F = requires feedback and violates the Independence Axiom (coupled design)

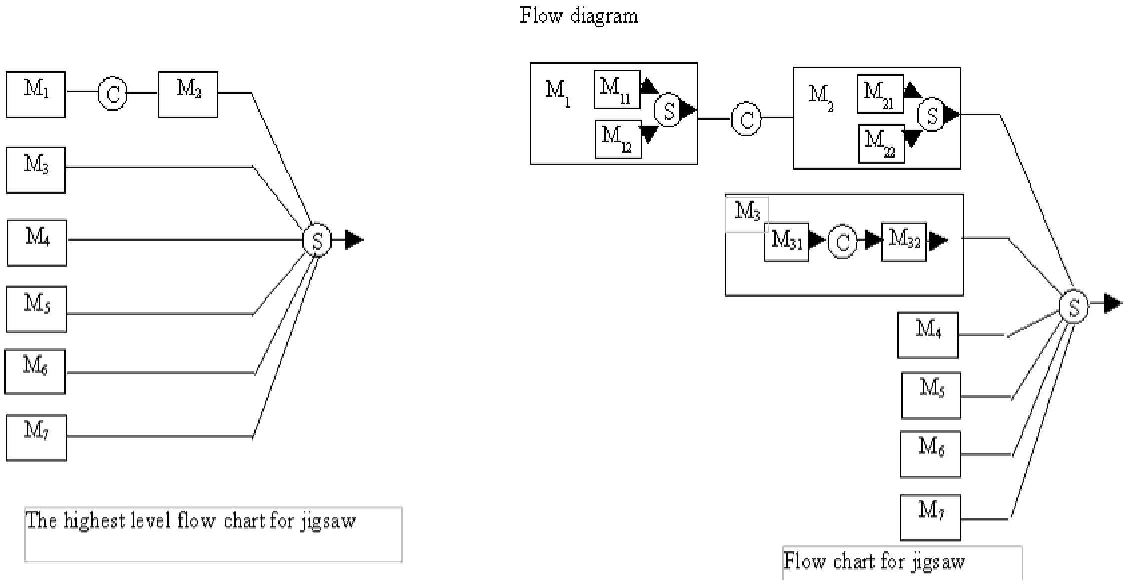

Figure16: Flow diagram for jigsaw.

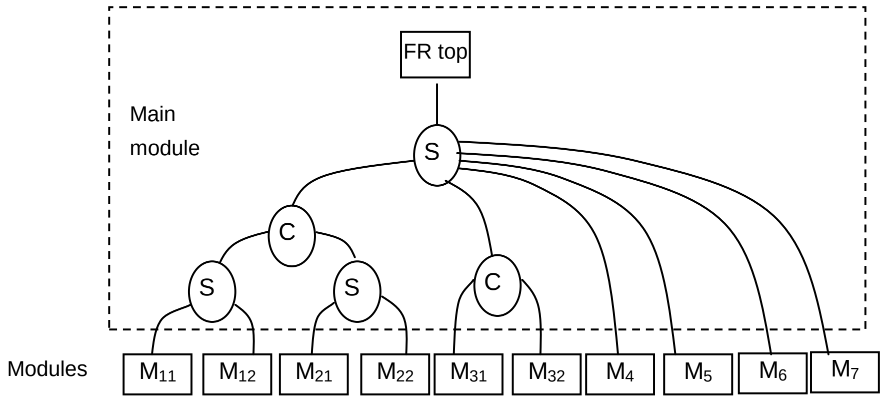

Figure 17: The module-junction diagram for jigsaw.

5 CONCLUSIONS

The design activity is a very important one and has been contribution to the society's development for a long time. Therefore, research that contributes to the improvement of design methods is crucial to advancement.

To improve the existent products, and especially to design new ones, it is important to present in specialized literature analytical models that can help designers to overcome psychological barriers and think outside the box.

The functions of new products are increasingly complex. This complexity creates the need to employ TRIZ creative thinking methods and to work in teams with experts from different fields. In this way, all expertise is pooled, thus leading to the creation of products with new, exciting functions and features.

This paper's aim was to present a set of solutions for redesigning the jigsaw. The used method to generate solutions is TRIZ and provides us with good results. It was used the Su-Field analysis to abstract and solve the technical contradictions. Using the TRIZ contradiction matrix and TRIZ inventive principles it was established the possible technical solutions for the jigsaw. Once convergent creation phase is reached, the solutions generated in the divergent phase are analyzed. An axiomatic design is then used to choose the solution with the highest probability of success.

Regarding the convergent phase we think that using the axiomatic design that is governed by the two axioms, the solution with the highest probability of success will be identified and this will be further developed in our future work.

ACKNOWLEDGMENTS

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Complex Model of Telescopic Cover

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Abstract

The aim is to develop a fast development process with variable input to provide quality and cost efficient solution for high speed machines. Complex model of telescopic cover has been created as a tool to optimize this process. Trying to find a solution of a particular problem is not the right approach in this case, because it leads to discovery of much more complex problem.

The first step is to create a knowledge base of mechanical and material properties of separate items. This way it is possible to understand the nature of problems the item could be responsible for and to avoid them straight away. The second step is to solve interaction of these items in the assembly.

Keywords

Complex Model, Telescopic Cover

1 INTRODUCTION

Covering of motion axes is one of design factors that has significant impact on the reliability and long life of a machine tool. That is the reason, why cover problematic deserves adequate attention. Rising dynamic parameters of machine tool axes is common trend of the last years. Along with this trend, new challenges in the branch of covering emerged.

Nowadays design of machine tool telescopic covers is usually based on empiric knowledge and usage of simple means only. Functional covers can be created this way, but several useful information, e.g. possible dimension (weight) reduction, passive resistance of covers and so on, remain unknown. Moreover the design and calculation process is time consuming.

It is necessary to solve or improve problematic items or processes and to add more value to the product (e.g. better customer support) to take an advantage over competition. The aim is to develop a fast process with variable input to provide quality and cost efficient solution for high speed machines.

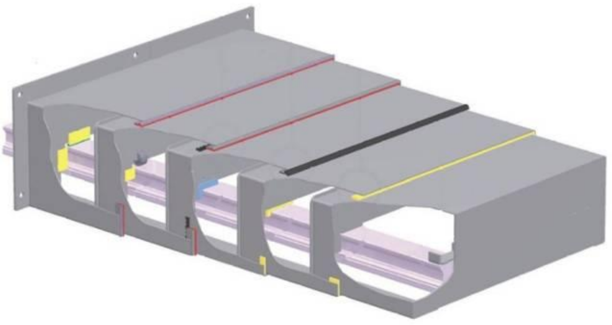

Figure 1: Telescopic cover.

2 A REASON FOR INNOVATION

As mentioned in the introduction, in order to raise productivity and precision of machine tool, manufacturers began to focus on raising performance of particular components formerly considered as less important. The focus changes the aim from drive speed, control precision and tool performance to main structure design and other mechanical parts properties that suddenly began to limit the improvement progress.

Telescopic cover of machine tool axis represents this type of limit for following improvement approaches:

- Axis travel speed increase.
- Higher precision of axis positioning.
- Protection of sensitive drive and control components for higher reliability.

Basically, it limits the improvement of performance, quality and function of a machine tool. And it is necessary to deal with the same limits of covers.

3 RESTRAINS AND REQUIREMENTS

Covers must seal protected (drive) area from impurities generated by machining process, such as chips and cutting liquids.

Low passive resistance and mass is required to reduce the influence of cover to dynamic properties of axis drive and precision of axis positioning.

Cover and its parts must have small dimensions to fit into limited space given by machine dimensions.

Quiet operation, high reliability and long service life as well as low price and short delivery time are also automatically expected properties of telescopic cover.

Unfortunately, some of these requirements are contradictive, e.g. good sealing function and low friction of sealant. That is common phenomenon of solution process of technical problems.

4 PROBLEM IDENTIFICATION

Along with all restrains and requirements there is a lot of problems to be solved in order to improve and raise limits of covers.

- Time consuming design process.
- Time consuming price evaluation.
- Unknown parameters of final cover (mass, resistance against movement).
- Dimension optimization to reduce overall cover dimension to fit the machine.
- Dimensioning for high movement speeds.
- Minimizing the amount of cover segments to reduce movable mass.
- Deformation of cover segments caused by preload of sealing wiper leading to sealing dysfunction.
- Slip-stick effect of sealing wiper causing vibrations.
- Segments getting stuck during movement.
- Compliance of guiding mechanism.
- Shock caused by impact of unguided segments.

- Vibration of machine structure caused by impact shocks.
- Reliability during cover lifetime.

5 FOCUS APPROACH

In case we tried to analyze and solve only one problem of the system, we would most likely find another one or more possible causes that could be the results of other phenomena and so on.

For example: Vibration caused by slip-stick effect of sealing wiper. This effect can be caused by cover compliance, wiper geometry, wiper material, wiper condition, value of operational preload, imperfection of assembly, contact conditions (dry, water, oil), operational parameters of cover (speed, acceleration)… One problem has multiplied into many factors and conditions than need to be examined. And that is only the first level.

Contact condition may differ during machine operation, e.g. cooling liquid can flood the cover, can be spilled non-homogenously or can dry out on the cover segment leaving greasy or even more frictional film.

If we succeeded and solved the whole slip-stick problem, the solution could collide with different requirements or cause other problem.

Decision to use material with lower friction coefficient or geometry modification to create lower preload can reduce the sealing function.

With so many problems to be solved it is more effective to choose different approach.

6 COMPLEX APPROACH

To deal with such an amount of problems, it is impossible to focus on all listed problems of the system individually.

The decision was to study all elements present on cover from its very bases and to find out what properties they have.

The knowledge of properties allows determining problems this part can be responsible for.

This approach can be used for problem solving as well as for product improvement.

Figure 2: Wiper sealing gap between cover segments.

For example: Polyurethane sealing wiper. Its material is viscoelastic. That means it is strain characteristic is not only load and temperature dependent. It also depends on time and load history (simplified explanation). These properties are responsible for degradation of its elasticity and preload, limiting the ability to adapt to imperfection of sealed surface. That reduces its sealing capabilities, but it also reduces friction causing resistance against movement.

It is also necessary to determine wiper stiffness dependent on geometry, wiper clamping, operational deformation and other aspects, that could have any effect to the surrounding components and the whole system.

7 TASKS AND KNOWLEDGE BASE

At the beginning, it is necessary to make a list of tasks – areas of interests that need to be aimed at.

In case of telescopic cover, the decision is to concentrate on following topics.

- Sealing wipers.
- Guiding parts.
- Shock absorbing systems.
- Segment motion mechanisms.
- Low reactions transferred into machine body.
- Lightweight design.

It is highly recommended to create a knowledge base of all topics. That means to make a research of all possible existing patents and papers and to discuss which solutions are useful or which solutions and ideas have to be avoided. When all advantages and drawbacks are known, the next step is to decide whether it is possible to use existing solution, to derive solution out of existing one or whether it is necessary to spend time to create an original solution.

8 INTERACTION RESEARCH EFFECTIVITY

Everyone can imagine that research and development of all aimed areas of interests is very time consuming. It takes time to design new components and to describe all needed properties and conditions for its behaviour prediction.

Saving time in the phase of interaction research is the initiation of complex model development. This model gives fast overview of expected behaviour of the whole system.

Investing time into complex model development has a reason not only for the development phase but it is also useful for later modifications.

In case of telescopic cover, the model usability is even higher. The system has similar structure for every application. Several parts must be selected according to specified restrains, but it the rest is usually only shape and dimension adjustment of a template.

This product range allows the model to be used during first production phase of every new cover.

This phase is an offer calculation according to customer specification. The complex model calculates specific dimensions so sales manager can estimate the price according to material consumption.

If the model is used in everyday production process, it is up to consideration whether it is possible to use the model for more purposes.

This purpose can be added value offered to a customer which gives manufacturer an advantage over competition. This value can even help the innovation department to put the idea of model development through a company management.

The nature of added value will be disclosed in the description of complex model.

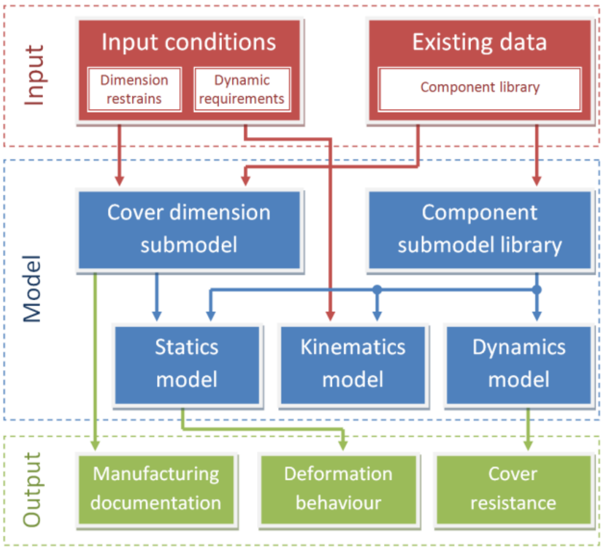

Figure 3: The complex model scheme.

9 COMPLEX MODEL

Circumstances mentioned in previous chapter imply the motivation for development of complex model of telescopic covers.

The complex model consists of three basic layers: input data layer, model layer and output data layer.

9.1 Input data

Input data layer acts as database of model settings. It consists of two main elements – input conditions and existing data.

Input conditions are information containing dimensional and dynamic restrains specified by the customer in the inquiry form. The existing data is a database of cover components – its physical properties and capabilities.

9.2 Model layer

The model layer contains mathematical models calculating physical behaviour and interactions of parts according to specified input parameters and component properties.

This layer is consists of several models and submodels.

The cover dimension submodel suggests all dimensions of cover optimized for required travel. Optimization is based on dimensional restrains of customer machine tool and dimensional parameters of used components. This assures minimal reasonable proportions for reduction of material consumption, inertial forces and costs.

The component submodel contains mathematical description of components behaviour based on its specific properties (mass, stiffness). These characteristics are used in superior interaction models.

The statics model calculates strain and deformation of particular components. It is possible to predict behaviour of operational covers when function and life is concerned. This prevents unacceptable deformations and excessive loads of components.

The kinematics model describes motion of movable parts and mechanisms dependent on axes movement to reveal necessary space and possible collisions. It is also a data source for dynamics model of covers.

The dynamics model determines actual accelerations and dynamic effect on particular parts of a cover. Along with resistance forces (inertial and friction), these effects represent overall resistance against movement. Resistance is an error value important for axis drive dimensioning.

9.3 Output data

Output data layer contains information crucial for actual production and successful implementation of covers into machine tool. This information sets are the basis for automatically generated manufacturing documentation.

It also allows checking the behaviour of operational covers – load, wear and deformation of components. That is important for designers to verify the sufficiency of their solution.

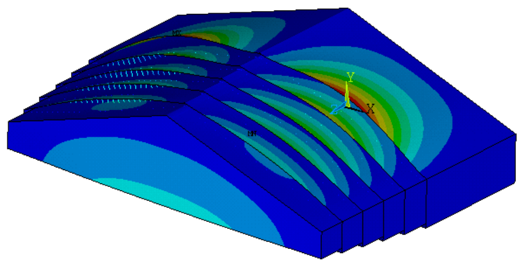

Figure 4: Cover deflection.

The last output is overall cover resistance. This data are important for determination of drive axis load caused by covers. That is the very important information for customer.

Cover is usually one of the last parts mounted to the machine because it is requested when all parts of the machine (including drives) are specified for order or designed and ready for production.

Problem could happen if the cover was not taken into account during drive dimensioning. There is a significant difference in machine drive dynamics when cover is mounted to the machine. Drive positioning is less responsive and power consumption is 10-30 % higher [1].

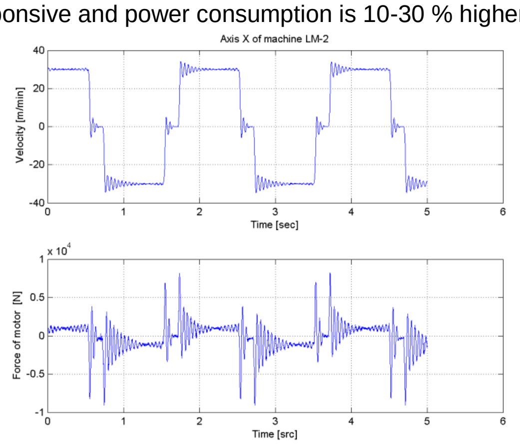

Figure 5: Impact of frictional and inertial forces to drive performance.

Producer is usually unable to provide such an information, definitely not before the cover is produced. This model can estimate cover resistance during the price offer process before the cover is designed.

That is the added value of the complex model.

10 SUMMARY

This paper introduces the complex development approach and it explains the circumstances and reasons for this approach.

Its philosophy is to analyze all elements present in the system and their properties to estimate future interaction of all system components.

Analysis of the element allows easier mathematical modelling and experimental verification. This may contribute to fast recovery of any possible analysis error.

This approach is applicable when the structure of final system is established so it is possible to create mathematical models of component interactions.

A tool of this approach is a complex model describing component interactions. This model is synthesis of analyzed elements. It allows estimating the final behaviour of the whole system according to selected presets and component properties.

An added value of this model in case of telescopic covers is a fast development process of a new cover and overview of its final physical properties in stage of price evaluation before actual production.

ACKNOWLEDGMENTS

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The TRIZ Approach Applied o Vehicle System Design – Variable Valve Timing

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Abstract

The aim of this paper was to carry out the process of applying TRIZ in the vehicle system design by using its tools and techniques. Variable Valve Timing system was chosen as the field in which TRIZ has been approached. The TRIZ method was introduced and its unique capability to solve problems was contrasted with others inventive methods. Its technical aspects were also presented. To adopt TRIZ methodology and to achieve the objective the deep understanding of the system as well as the identification of the problem were needed. Therefore, this paper presents variable valve timing and compares it with the conventional valve train. Many TRIZ tools were used to overcome psychological inertia and negative influence encountered especially at the beginning of the work. Finally, the undertaken techniques enabled the feasible and novel Variable Valve Train mechanisms to be designed. The technical solution was implemented with the use of CAD [2, 6], and to be based on the 3D model the FEM [9] analysis was also conducted.

Keywords

TRIZ, CAD, Valve Train System, Combustion Engine

1 INTRODUCTION

The term “Teoriya Resheniya Izobretatelskikh Zadatch” comes from Russia and means “theory of inventive problem solving” [1]. TRIZ solutions have been taking out since the sixties, from the worldwide patent into small set of rules and methods that can seriously improve problem solving skills in almost any technological application and at any level. According to the research of K. Rantanen and E. Domb [8] the beauty of TRIZ is that, it is a style of reasoning as well as a set of methods and that the essential TRIZ knowledge is available free of cost for everybody who is at least interested in it. Brain storming, lateral thinking or divergent thinking can still bring up some results or ideas but, comparing to TRIZ, they are time and energy consuming. That is why process of systematic study and analysis, started by G. Altshuller (1926-98) in Russia continues to gather momentum worldwide.

TRIZ consists of various tools and techniques which can be applied to a problem. Some people call TRIZ as a compass that enables the user to be guided or rather navigated to get to the solution, some call it a map. No matter how TRIZ is entitled, everything starts from a clarification of the problem by narrowing the focus from the large systems level, through the sub-system to the component, then to the function and finally to the parameter level.

In the second stage TRIZ methods such as 40 inventive principles or 76 standard solutions are used - both obtained from worldwide, mentioned above, patent analysis - to generate a number of feasible solutions matching best of class patents in various fields.

In the third stage, the most promising solution is transformed from a basic concept and detailed back into a usable form. This last stage is very important. It has significant influence on how well a solution is converted into a new product, process or invention which the “user” of TRIZ is interested in.

2 IN PURSUIT OF ENGINE POWER

From the past times of motorization, the constructors have been pursuing to get as much power as possible from combustion engines. The oldest receipt for the success was to increase the number of cylinders and capacity of the motor. The peak of the absurd was reached in 70’s when Americans commonly put engines suitable for lorries into ordinary cars.

The golden age of motorization was ended then - the fuel crisis had been approaching - the era of saving was begun. For car constructors the saving meant optimization. The panel of experts was looking for the compromise between the size of the body of a car and its safety or weight and between engines performance and their economical feature.

As far as the supply system is concerned, the significant progress was made. Initially, engineers improved the star-up devices in the engine and economical aspects of the carburettors. However, after some years the carburettor was displaced by the more efficient fuel injection. The future brought up new solutions and a multipoint fuel injection was invented. Moreover, many cars on the streets have direct petrol injection to the combustion chamber. Since engineers started working on the engine performance, its effectiveness has been gradually going up. Nevertheless, the timing gear system was the thing which caused problems while trying to modify or improve it. Obviously, tappet clearance could be reduced by hydraulic implementation and this solution was put into effect in 50’s.

Nevertheless, the valve timing was the element of the engine which could not be control undependably - the time of filling the cylinder with the mixture of the fuel with air and the time of emptying it from exhaust gases was constant, regardless of the revolutions and engine load. The major goal regarding the valve time was to create the system, which would smoothly change the valve time (the time when valves are open and the period of opening - in other words lift and timing) fully or partially and would depend on the engine performance at the exact moment [4].

Unfortunately, the valve time is strictly mechanical system and the moment as well as period of opening (which is related to the crankshaft) is controlled by cams - more precisely by cams profile. In the car engine, the profile of the camshaft is the result of compromise [4]. Therefore, many of tuning companies often replace camshafts to these specials, which put up the engine performance. Regrettably, while the power increases the efficiency at the low and average RPM goes down. It appears there is no solution - valve timing seems to be the impregnable fortress.

3 WHY THE VARIABLE VALVE TIMING IS SO ESSENTIAL?

In an ordinary engine the same camshaft controls both the inlet and exhaust valves and the opening phase is determined by the cams which are situated on the different angle. It is possible to accelerate or delay only both types of valves and, even worst, only simultaneously. In this case engine uses relatively rich air-fuel mixture. However, in the new generation engines there are two different camshafts for the inlet and exhaust valves. It enables design engineers to create system to open inlet valves for long or short period – in other words for different time than the outlet valves.

For instance, when one is driving the new Honda Accord VTEC on the flat road with the constant velocity, the inlet valves open only for a split second. When the rapid acceleration is needed or the way of driving is more dynamic (e.g. in a city), the inlet valves switch the opening and closing phase automatically. The engines sucks in the rich in fuel mixture hence we can get more power from the car. Generally, in the whole range of rotational speed, engine gets the optimum amount of fuel. Consequently, it enables the driver to save the petrol while limiting pollution of exhaust gases.

4 CONVENTIONAL VALVE TRAIN DESIGN - (D)OHC ENGINE

The valve train presented in this paper bases on (Double) Over Head valve and Camshaft (fig. 1) [7]. This limitation is the result of its common use of this kind of engine in today’s cars. Moreover, majority of the engines which employ VVT are constructed in the (D)OHC versions. That is why they have been gradually supplanting the previous type OHV (Over Head Valve) engine.

OHC (Over Head valve and Camshaft) is a valve combination that both inlet and exhaust valves and also camshafts are on the top of the engine block. This type of an engine has a high compression ratio and gives out more power than OHV (Over Head Valve), therefore this valve combination is commonly used in most engines today. It is because there is no push rod so the valves are directly driven by the camshafts. This feature prevents the loss of energy due to complexity of the OHV mechanism (push rods must transmit the movement of camshaft to a valve).

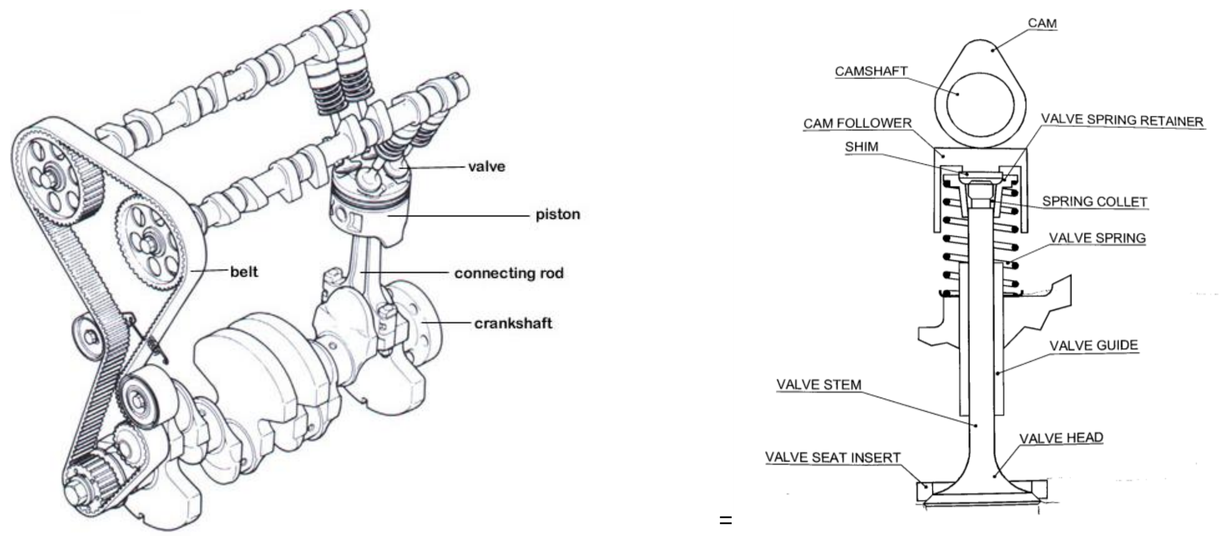

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Figure 1: Transmission of camshafts and valves of the four-valve engine.

5 RESEARCH

The TRIZ team came into being at the Wroclaw University of Technology in 2008. The beginning of the collaboration amid the authors of the paper was triggered by the problem related to valve timing in a combustion engine. It is worth to notice, the team was neither specialized in engines nor the TRIZ methodology was known at the University then. The knowledge about the Theory of Inventive Problem Solving was derived from the UK where one of the authors took part in a TRIZ course. Having returned to the mother University in Wroclaw it became lucid that the valve timing problem – earlier challenged by Faculty of Mechanical Engineering – should be solved by the use of TRIZ. The method fascinated the second author of this paper who is a quality expert, notably in fields of Six Sigma and Total Quality Management. This was a time when the TRIZ team was established on Faculty of Mechanical Engineering in Wroclaw. Once the processes which take place in an internal combustion engine were understood and the team followed some logic operations in terms of TRIZ there was time to solve the technical problem. Obviously, while improving the system, some contradictions occurred – getting better one feature worsted others. To produce an invention means to resolve these contractions. The first concept was born after the approximately 2.5 months of extensive work on TRIZ and researches concerning not only valve train system but also the whole Spark Ignition (SI) engines.

The concept, what can seem strange but agrees with TRIZ theory, was created without spending excessively time on possible solution analyses. What is more, the psychological inertia was overcome. TRIZ allows its user to get into other areas, which usually scare away inventors because they may think they do not have sufficient knowledge in a particularly field of study [3, 5, 8, 11].

5.1 Initial understanding of the problem

The research is focus on finding a reliable mechanism to make significant benefits in improving SI engine's performance, safe fuel and decrease the exhaust gases in terms of ecological aspects. Thus, a new variable valve actuation system that could vary valve lift and timing events in continuously would be desirable.

Valves must be open and closed at precise moment and for the right altitude to achieve maximum fuel economy or, when needed, maximum acceleration. Besides that, research of the innovative solution requires full boundary condition of the system (Table 1) [8, 10, 11].

Must have	Nice to have
80.000 kilometres of reliability. Ability to move up to 36g. 29 mm against 6 bar cylinder's pressure. 2.5 mm reaction time. Operating temperatures 40÷150ºC. Valve's head must resist 400ºC. 12V/24V power supply is preferred. Low seat landing: no more than 240 mm/s i.e. 0.01 mm/cam degree. Great corrosion resistance (especially exhaust valve). Low weight to decrease the force of inertia.	Low cost. Work quiet. Easy to assembly and manufacture. Infinitely valve time.

Table 1: Requirements of the valve train system

Figure 2 and table 2 depict the inputs and outputs associated with a four-stroke engine. It helps to understand better some key issues, which have direct influence not only on the engine parameters but also on performance and general efficiency. The engine, with the in/out- arrows, shown above also enables the user to notice the system entirely. In other words, having understood the function of each component - mainly focusing on the valve train - it is possible to imagine the whole system working. It is great advantage of TRIZ because its user does not need to see the whole system working in reality.

Inputs	Outputs
Camshaft exhaust position CEP Camshaft intake position CIP Carbon monoxide CO Differential pressure DPS Engine speed ES Hydrocarbon HC Ignition angle IA Injection timing IT Engine temperature TE Throttle position TP Valve lift VL	Torque T Carbon dioxide CO2 Nitrogen oxide NOx Bottom dead centre BDC Top dead centre TDC

Table 2: Inputs and outputs of the spark ignition engine

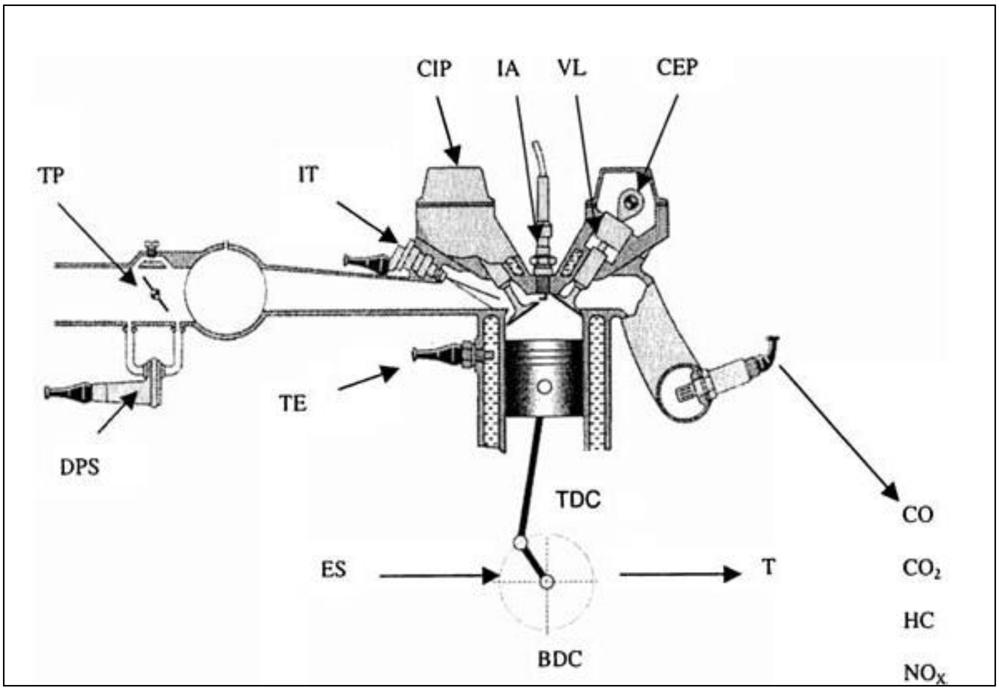

Figure 2: Spark ignition engine - inputs and outputs.

5.2 Nine boxes

Now it is time to see the system more widely, thanks to great TRIZ tool called "nine boxes" (figure 3). The location of the problem on the system level can be presented by a chart, which contains nine boxes. Once the chart was created, it is easier to see and notice problems more clearly. What is more, it is possible to look on the system more broadly and consider not only the present but also the past and future on all the three levels including sub- and supersystem. In other words, thinking in terms of Time and Space is possible.

While moving throughout TRIZ it is advisable to keep in mind these boxes - especially system and supersystem play key roles in this paper's research. The chart allows getting into the problem and permits the user to imagine that one is on the same plane as the box. Naturally creative people think in time & space. However, it is said that very bright person can always solve a problem. Unfortunately, only a small part of the population belongs to this exceptional group. TRIZ tries to enhance the problem-solving capabilities of the majority.

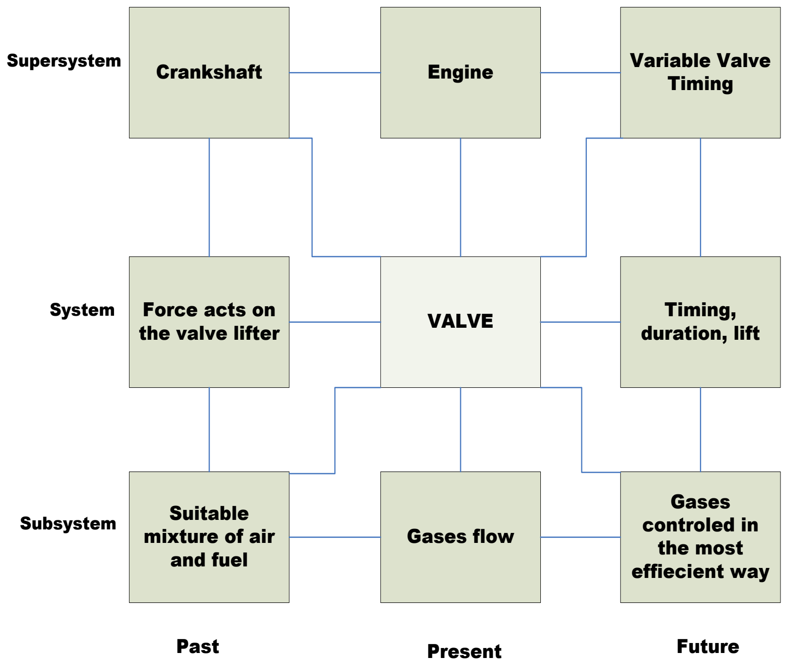

Figure 3: Nine boxes.

5.3 Contradiction matrix

Contradiction matrix (figure 4) helps to find a highly inventive solution and eliminate “tradeoffs” in a quick and often surprisingly accurate way. The rows of the matrix are labelled with typical features, which should be improved, and the columns with the features that give undesired result, get the feature worse. The cell where the column and the row intersect has the number of principles that were historically used most frequently to solve the particularly problem. First, the principle that needed to be changed was found:

- 35 adaptability or versatility[1] of valve timing

Then the principle with an undesirable secondary effect was located

- 36 device complexity[2]

The technical conflict was stated:

The more adaptability or versatility the valve timing is, the more complex it becomes.

The proposed solutions were used to create ideas for solving the problem. All of them have some hints how the variable valve timing mechanism should be constructed. Especially two first principles i.e. “Dynamic” and “Pneumatics and hydraulic” have been directly implemented into concepts. Thermal expansion, even though the temperature in the engine changes significantly, it cannot be used at this level because very rapid adjustment is needed as far as valve train is concerned.

6 VARIABLE VALVE TIMING SYSTEM - A CONCEPT

The construction and the principle of operation are presented for the variable lift and valve timing idea developed. The mechanism consists of the new following components:

- Self-locking screw right-hand threaded up to 2/3 of its high.
- Threaded plain bush with small vanes.
- Follower’s circular plate with a feather key.
- Piston with integral key and a chamber for oil.
- Oil lines.

The described mechanism presents another way to obtain variable valve timing. In summary, it conveners the linear motion of the oil to a rotary output transmitted to a nut mating with a special screw. The idea can be characterized as a simple, compact device, which can be applied to many types of cylinder heads just by making minimal modifications for oil lines.

For this concept, four oil lines are expected through which the oil from an oil pump will be provided under high pressure to the piston’s chamber. The oil exerts the pressure on the vanes from the one side of the threaded plain bush.

The reaction of the vanes causes their rotation and due to their soldering to the threaded bush, this component is also rotated about a given angle. Once the bush is put into motion, it starts acting on the screw similar as in an ordinary screw joint. However, it must be mentioned that the type of the thread should be both very precise and quick so a revolution of the bush causes relative long lift of the screw.

As it was written above, the oil can act on the two sides of the plain bush. It causes clockwise or anticlockwise rotation. Therefore, the screw vertical movement is strictly connected with the plain bush. That is why the suitable amount of oil pushed through the oil lines on the right side (namely, the pressure on the vanes) makes the screw go up or down. Finally, the top part of screw is connected with the follower’s circular plate. Any possible rotations of the plate are constrained by its feather key mating with the integral key on the piston. Since the circular plate is in constant mating with the cam (thanks to the valve spring reaction) the thread on the screw must be self-locking at

[1] The extent to which a system or object responds positively to external changes. A system that can be used in multiply ways in a variety of circumstances.

[2] Number and diversity of elements and components interrelationship within the system.

any possible value of the force for the mechanism. This feature prevents self-unscrewing of the bolt.

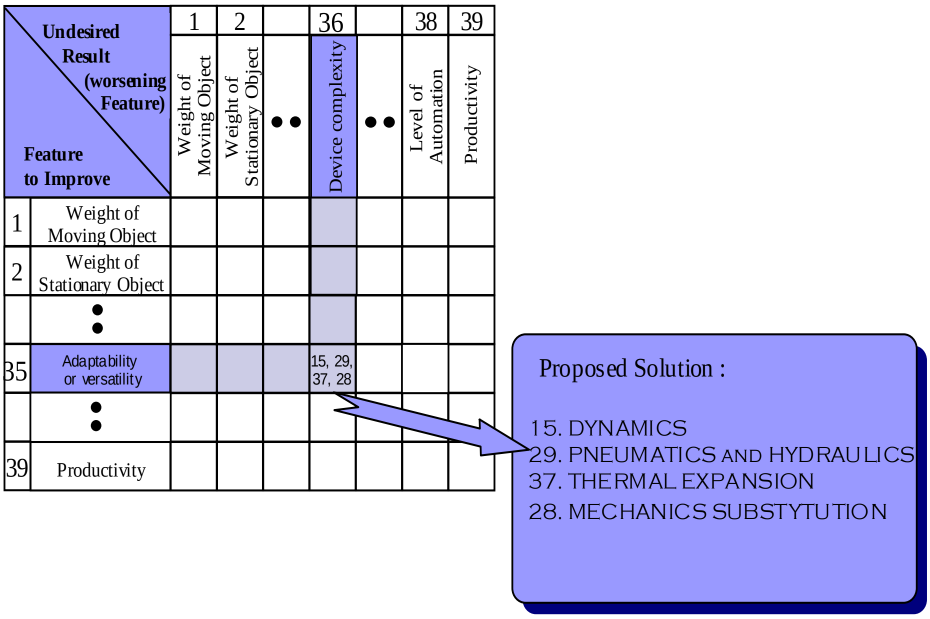

Figure 4: Contradiction matrix.

7 THE PRINCIPLE OF OPERATION FOR THE MECHANISM AT DIFFERENT RPM

7.1 Low Revolutions Per Minute (Fig. 6)

At the low RPM the sensor gives the oil pump a signal to increase the pressure in the oil line which cause clockwise rotation (a view from the camshaft position) of the bush so its begin screwing in of the bolt. This movement of the screw effects on the follower's plate altitude relative to the chamber. The action lasts until the time when the pressure in the oil lines is even.

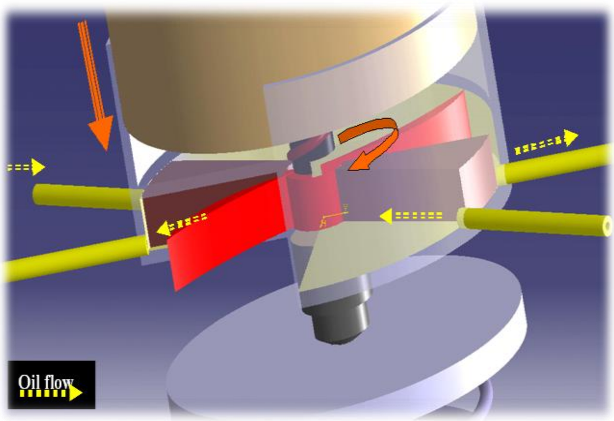

Figure 6: The oil movement causes clockwise rotation of vanes; the follower goes down, as there is the screwing in.

7.2 High Revolutions Per Minute (Fig. 7)

When the engine reaches revolutions (approx. 3500RPM) the oil starts rotating the bush in the anticlockwise direction causes the screwing out. The value of the lift must be precise to adjust the valve lift and opening time exactly to the current performance of the engine. As it was mentioned above, it is essential - especially in this phase - that the thread is self-locking because the force acting on the screw via the plate is increased (again the reaction of the spring must be considered).

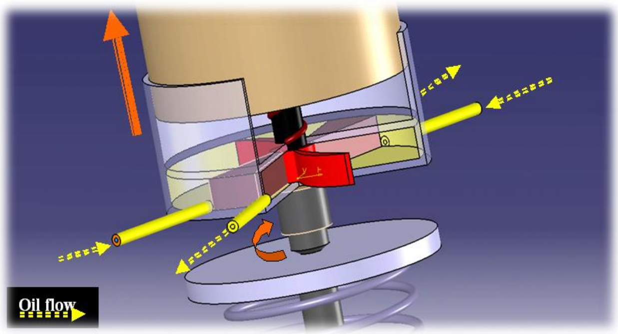

Figure 7: The oil movement causes anticlockwise rotation of vanes; the follower goes up, as there is unscrewing.

The big advantage of the proposed concept is it can adjust valve lift and simultaneously the valve time in a simple, continuous and accurate way at the same time.

8 CONCLUSION

This paper presents the essential steps, which have been considered as milestones to understand, immerse in the TRIZ tools and, finally, put the theory of inventive problem solving into effect - simultaneously working on the technical aspects of the valve train.

Studies were carried out to gain as much credible information from the most reliable and accurate sources as it was possible. As the result of these studies the knowledge and the understating of the problem was gained ensuring that the requirements are met.

It has been proved, that even after a century of developments the internal combustion engines continue to evolve. This great evolution was shown on the example of variable valve timing which high potential heralds a bright future in the fuel economy, overall engine efficiency, driving pleasure and environmental issues.

However, what differs this work from others is the fact that the novel concept was introduced. It is a result of deep studies in the field of TRIZ. Many from its tools were undertaken to develop the concept from which the contradiction matrix, functional analysis, nine boxes and the trends were found the most helpful in terms of solving the technical problem i.e. make the timing, duration and the lift of the valve variable. The proposed concept employs the engine oil as the resource.

The concept, which is called: “the mechanism with the vanes” does not employ any additional motors, though. The ability to vary the valve lift was obtained by the controlled oil flow supplied by the use of four oil lines. The oil pressure rotates the vanes in a desired direction. The rotation of the vanes causes, through the screw joint, the change of the of valve lift. Further development enabled the concept to obtain some unique features such as pores and lightweight materials. The above characteristic of the mechanism enabled it to be evaluated as the most suitable technology.

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Elaboration of the Value Equation to Express Laws of System Evolution

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Abstract

With the exception of Ideality, the Laws of system evolution are formed using words only. Mathematics as a universal language can serve better in expressing the laws and make them more understandable and usable. It is possible to partially achieve this by integrating two steps - dividing the equation to human related and non human related components and separating Supersystem from Systems components. The result is an elaborate equation which expresses more of the laws.

Keywords

Laws of System Evolution, Equation, Ideality, Human, Supersystem, System, Functionality, Amplifying

1 INTRODUCTION

At the fundamentals of TRIZ are the "Laws of system evolution". With the exception of Ideality, the laws are formulated in words only.

Throughout the history of mankind mathematics has served as an international language, clearly expressing ideas regardless of the local spoken language. Therefore formulation of mathematical notation of the laws can improve understanding and usability of the Laws worldwide.

In this article I will propose a potential direction, how to describe more laws mathematically.

Not all the laws are presented by the proposed equation and there is no proposed resolution to coefficients.

2 VALUE EQUATION AND IDEALITY

2.1 Standard equation

The Value equation and Ideality can be found in different forms [1], [3]. I will use the most basic one as a starting point:

Value equals the Sum of all *Functionalities* of a system over the sum of all *Costs:*

$$V = \frac{\sum_i F_i}{\sum_j C_j} \qquad (1)$$

V = Value

F = Functionality

C = Cost

If *Functionality (F)* approaches infinity or *Cost (C)* approaches zero, then *Value (V)* approaches infinity and therefore approaches *"Ideality" (I)*

$$V = \frac{\sum_i F_i \to \infty}{\sum_j C_j \to 0} \to I \qquad (2)$$

But what forms *F* and *C*? Are they measurable?

A common definition of *C* is:

Cost equals the sum of all *Resources* used plus the sum of all *Harmful effects:*

$$\sum_j C_j = \sum_z R_z + \sum_q H_q \Rightarrow V = \frac{\sum_i F_i}{\sum_z R_z + \sum_q H_q} \qquad (3)$$

What about Functionality?

I would like to propose the following insight:

It is possible to *"split in relation"* the equation, so that the numerator of the equation will describe *Human related activities*, while the denominator describes all other system components.

2.2 Argument

All Manmade systems were designed to amplify Human capabilities.

(As technology evolves – a system may be developed in order to amplify another system's capability, but this in turn was designed for amplifying a human capability).

It is possible to explain *Functionality* based on this argument, by dividing *Functionality* by two basic parts, the *amplifying of Human capabilities* and actual *Human involvement*:

Functionality** equals the **sum of all of Human capabilities** minus the **sum of all Human actions multiplied by the duration of the action

$$\sum_i F_i = \sum_l aMc_l - \sum_t (Ma_t * T_t) \qquad (4)$$

Where:

a – Amplifying coefficient

Mc – Standard Human Capability

Ma – Human Activity

T – Duration of Activity

The elaborated Value equation:

$$V = \frac{\sum_i F_i}{\sum_j C_j} = \frac{\sum_l aMc_l - \sum_t (Ma_t * T_t)}{\sum_z R_z + \sum_q H_q} \qquad (5)$$

Example:

- A car amplifies human's capability of moving in plane. Comparing a car traveling at 100-120 k/hr and a Marathon athlete running at a speed of 15-20 km/h, then the *Coefficient* of "Speed" will be at an order of 10.

2.3 Elaborating Resources

It is possible to split *"Resources"* and *"Harmful effects"* as well by dividing these terms to *"System"* and *"Supersystem"* elements:

$$V = \frac{\sum_i F_i}{\sum_j C_j} = \frac{\sum_l aMc_l - \sum_t (Ma_t * T_t)}{(\sum_y R_y + \sum_q H_q)^{Sys} + (\sum_z R_z + \sum_b H_b)^{Sup}} \qquad (6)$$

Where:

$(R+H)^{Sys}$ - System Resources and System Harm

$(R+H)^{Sup}$ - Supersystem Resources and Supersystem Harm

3 THE ELABORATED EQUATION AND THE LAWS OF SYSTEM EVOLUTION[2]

3.1 "Law of transition into the Supersystem or Subsystem"

The *"law of transition into the Supersystem or Subsystem"* is captured in the denominator:
R^{Sys} represent *System* opportunities and R^{Sup} represent *Supersystem* opportunities.

Transition to the Supersystem means utilizing *Supersystem Resources* while reducing the utilization of the *System Resources*.

Assuming $\Delta F=0$ and $\Delta H = 0$
(ΔF can be negative, if $\Delta(R+H)$ is of higher magnitude)

Given $R_1^{Sup} > R_0^{Sup}$

$V_1>V_0$ only if $|\Delta R^{Sys}| > |\Delta R^{Sup}|$

3.2 *The law of "increasing Complexity follows by Simplification"*

"Increasing Complexity follows by Simplification" is mainly represented by the *Index* number of R^{Sys}. Raising the Index number presents complexity growth as larger varieties of internal resources are being utilized, while lower *index*, presents simplification.

$\Sigma_v R_v^{Sys}$; When $v_1>v_0$ complexity growth

3.3 *The law of "Evolution toward decreased human involvement"*

"Evolution toward decreased human involvement" is expressed by (Ma*T):

If $(Ma*T)_1<(Ma*T)_0$ then potentially $V_1>V_0$

Interesting though, as the term Ma*T is placed at the numerator, even if there is no human involvement in the system, as of the other numerator's elements, the system will not approach towards infinity.

3.4 *Other Laws*

The rest of the laws:

- *Non-uniform development of system elements*
- *Evolution towards increased dynamism and controllability*
- *Evolution with matching and mismatching elements*
- *Evolution towards micro-levels and the increased use of fields*

are not well expressed by the new elaborated equation and probably call for more developments.

On the other hand, the proposed equation improves the visibility of other calculations, for example:

Environmental impact can be directly expressed and weighted by the term $(R+H)^{Sup}$.

3.5 Units and Coefficients

Like Energy and Work, Value should be a scalar. The value equation describes value as Functionality over Cost.

- Cost is measured by $
- Functionality units are specified per specific function

There has to be a coefficient which has units of $/F

$$V = c_{\frac{\$}{F}} \cdot \frac{\sum_i F_{fi}}{\sum_j c_{\$j}} \qquad (7)$$

For the elaborate equation elements:

Mc - Mc stands for Human capability and its unit change based on the measured attribute and its coefficient must change accordingly:

$C_{i\ \$/Mci}$

Ma - Ma has units of Scalar/Time. Multiplying it by Time will provide a Scalar number

R&H - Would typically stand for Mass, therefore it can be measured in Dollar/Mass, and this should be multiplied by Mass/Time and duration of action to give Dollars:

$$\frac{\$}{Kg} * \frac{Kg}{Hr} * Hr = \$$$

The duration multiplier should be added to the equation; by choosing a standard duration it is possible to integrate it with the Coefficient c.

3.6 *Further potential Segregation*

A group of humans can act like a Herd or a Swarm. This is a special case of a Supersystem which is directly related to humans. It is possible to express it by continuing the segregation of the numerator's element ***"Amplifying"*** to *"Amplifying individual capabilities"* and "*Amplifying group capabilities"*.

Example:
If one person or a group is traveling by a car, the car's functionality does not change; therefore the car is amplifying individual capabilities.
A market on the other hand has no functionality without a group. Markets amplify the capabilities of a group to trade goods.

Putting it into the Value Equation:

$$V = \frac{\sum_i F_i}{\sum_j C_j} = \frac{\sum_l aMc_l^{In} + \sum_m aMc_m^{Gr} - \sum_r (Ma_r * T_r)}{\sum_y R_y + \sum_z H_z} \qquad (8)$$

Where:

aMc^{In} - Amplifying capabilities of an Individual

aMc^{Gr} - Amplifying capabilities of a Group

4 SUMMARY

Segregating the numerator and denominator of the Value equation by category, although increasing the complexity of the equation, provides a more detailed articulation of "Ideality" and expresses more of the "laws of systems evolution" in mathematical terminology. The elaborate equation highlights the consideration to be made, when aiming towards a more ideal system and the next potential evolutionary steps.

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TRIZ Approach to Solve the Hot Rolling Process of the Seamless Steel Problem

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Abstract

During hot rolling process of the seamless steels, they have to undergo the high temperature of about 1200 ^{o}C. The desired shape can be obtained through the high temperature process but it leads to the bad effect on the properties on steel. The oxidation of steel can occur over 800 ^{o}C. The related researchers have tried to solve this problem to find the optimum conditions. Their efforts somewhat improve the properties but cannot be the complete solution. Thus the TRIZ approach to solve this rolling process of steel plate problem completely was required. This specific situation can be converted into physical contradiction. “hot (1200 ^{o}C) and cold (< 800 ^{o}C).” We used “separation of space” principle and solved this problem.

Keywords

TRIZ, Seamless Pipe, Hot Rolling Process, Physical Contradiction, Inductive Heating, Separation in Space

1 INTRODUCTION

Hot rolling seamless steel pipe process mainly consists of heating, piercing, and elongating steel. During the process, the steels are manipulated to form the shape and geometry with a set of work rolls which revolve at the same speed but in opposite directions.

The processing temperature is generally above recrystallization temperature [1,2]. Hot rolling can reduce the process time as oppose to cold rolling process. The process performed at high temperature, the steel has less residual stress and excellent dimensional stability.

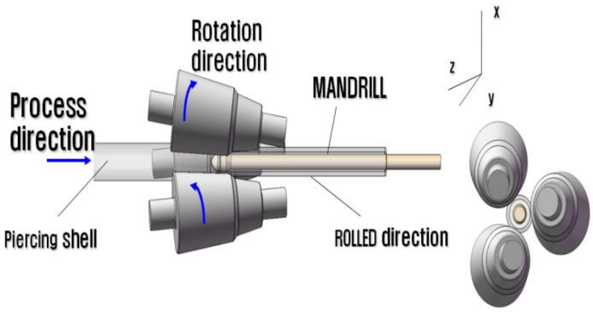

Figure 1: Example of a picture.

However, the process is generally performed at the high temperature process and it leads to the bad effect on the properties on steel. One of them is the oxidation of steel which occurs at the temperature of over 800 ^{o}C.

The related researchers have tried to solve this problem to find the optimum conditions. Their efforts somewhat improve the properties but cannot be the complete solution. Thus the TRIZ approach to solve this rolling process of steel plate problem completely was required.

2 PROBLEM DESCRIPTION

In this work, we focused on only the problem of temperature in the course of hot rolling seamless steel pipe process. Thus, the main limitation is to keep the temperature of over 1200 ^{o}C to obtain the desired properties. The reformulation of this problem is excluded such as finding below 800 ^{o}C process. The given problem is: Keep the process temperature and remove the oxidation of steel. Set the page margins at 20 mm for the top margin and 18 mm for bottom. The first page and all uneven pages should have a right hand layout: right margin 12 mm and left margin 22 mm. The even pages should have a left hand layout: left margin 12 mm and right margin 22 mm. Centring of text sections refers to those margins.

3 TECHNICAL CONTRADICTION

The problem can be reformulated with technical contradiction [3-5].

If we select “high temperature process”, the “quality of steel” is good but cause “oxidation” on the steel. To remove the technical contradiction, we keep the “quality of steel” and remove the bad effect of “oxidation”. 40 principles is typically used to remove the bad effects[6]:

<u>16. Partial or Excessive Action</u>: The processed steel has bigger dimension than the desired. After process, it is machined to the desired size. But, it has a disadvantage of the material loss.

<u>39. Inert Environment</u>: Hot rolling seamless steel pipe process is performed under inert environment and the oxidation of steel does not occur. But, the isolated room is needed and should consider the space and costs.

<u>11. Cushion in Advance</u>: The steel surface was slightly oxidized then removes it when the process is done. It worked but it is very difficult to control the oxidized thickness.

<u>24. Mediator</u>: The substance can be covered the steel surface. The coating technology can be used but the cost is high. In addition, the removal of coated material needs high cost and efforts.

4 PHYSICAL CONTRADICTION

Before physical contradiction are described, operation time (OT), operation (OZ), ideal final result (IFR) should be defined [5,7,8]:

<u>Operation time (OT)</u>: During hot rolling seamless steel pipe process

<u>Operation zone (OZ)</u>:

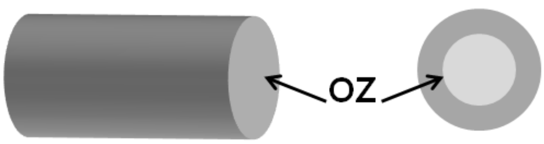

Figure 2: Operation zone (OZ).

Ideal final result (IFR): Hot rolling seamless steel pipe process without oxidation

Technical contradiction could be intrinsically controlled by one parameter. Sometime it is implicitly exists and is hard to find and the problem have to be reformulated. Fortunately, the parameter seems to appear explicitly in this problem in the course of definition of technical contradiction. It is temperature.

For hot rolling seamless steel pipe process, the temperature is high (1200 ^{o}C)

For removing oxidation during process, the temperature is low (800 ^{o}C)

Thus, physical contradiction can be defined: the temperature has to be high and low.

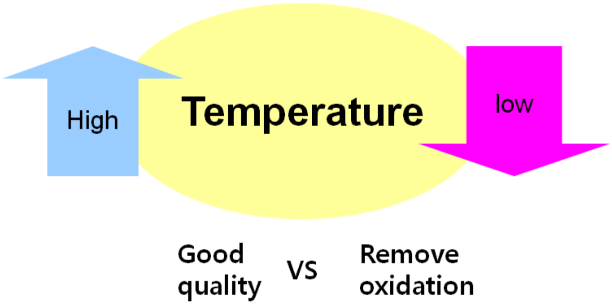

Figure 3: Physical contradiction for the problem.

The physical contradiction can be removed by the separation principles. The "separation of time" cannot be available to this problem. The hot rolling seamless steel pipe process is continuous and 2 temperature conditions cannot work. The "separation of the part and the whole" is not proper to apply, either because the steel is one-body.

The "separation of space" can apply to this problem. The operation zone is investigated carefully. The high temperature is required at "A" area to obtain good quality. While, the low temperature is required at "B" area to avoid oxidation.

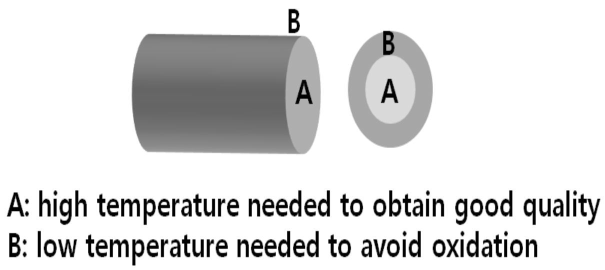

Figure 4: Separation of space for solving physical contradiction.

The next step is to find how to achieve the high temperature at "A". Using searching engine such as "Google" and "NAVER in Korea". The induction heating was found to be a good method to obtain partially high temperature at "A" [9,10]. This solution removes clearly the physical contradiction and satisfies the IFR which was defined as the above. Now, hot rolling seamless steel pipe process is carried out with this method and has been tried to find the optimum conditions.

5 CONCLUSION

During hot rolling process of the seamless steels, the oxidation on the surface of steel occurs and main problem to resolve. TRIZ approach is introduced to solve the problem.

In this case, technical contradiction and physical contradiction were used to solve the problem. Through those methods, several ideas are generated. Among them, the solution using "inducting heating" is the most effective as one conceptual solution and applied to the hot rolling seamless steel pipe process.

As one similar research, Hongyul Yoon et al. in Korea, also reports an industrial case study at POSCO (POhang Steel COmpany), "Cooling problem of wire rod in the manufacturing process" at TRIZCON2004 [11].

In the manufacturing process, the wire rod is extended to make thinner in a few steps. In the process improvement project, there was a problem of how to control the rod cooling rate. In general, if the rod is cooled slowly we get thicker rod with lower tensile strength, whereas if it is cooled rapidly we get thinner rod with higher tensile strength. But the new requirement of the problem is to manufacture thin rod with low tensile strength. The authors derived a physical contradiction and applied the Separation Principle in Space. The concept found for the solution was to heat the rod in the cooling process only near the surface so as to reduce the temperature difference between the surface and the body. The Induction heating was applied to perform this function, too.

This conceptual solutions by TRIZ, are being applied specially at one of small and medium size steel company as R & D project supported by Korea government with one item of high value and new business for blue ocean of conventional steel pipe manufacturing with low profit.

Korea is the most active country on TRIZ applications in the world. These days the TRIZ results are being made at small and medium size companies in Korea besides big companies such as Samsung, LS cable, LG, POSCO, Hynix semiconductor and Hyundai Automobile, too [12].

ACKNOWLEDGMENTS

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How to Prevent Cords and Cables from Getting Entangled: A Study of Systematic Classification of Various Solutions

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Abstract

Cords and cables often cause troubles by getting complex and entangled, around appliances at home, around PCs at offices, around equipments in labs, etc. The present study started to think of methods of preventing cords and cables from getting entangled. Since the problem lasts so long and spreads so widely, there must be a lot of different solutions known and used in the world, we thought. Hence, as an educational case study, we set our goal to collect different solutions and build up a hierarchical system of solutions to this common problem. Classifying/categorizing solutions has fundamental significance in systematically understanding the whole solution space.

We first searched for various methods, tools, devices, equipments, etc. which are used for such a purpose, at home, at offices, at hardware stores, at PC shops, etc. Then we classified all these cases, in a bottom-up manner into a hierarchical system of methods. Recognizing the need of a more systematic approach, we introduced the scope of the target system and expanded it stepwise. As the result of reorganization, we have built up a system of solutions to this problem, namely: (A) As for a cord or cable, to adjust its length so as not to get entangled. (B) As for multiple cords or cables, to bundle them, to combine and unite them. (C) As for the connecting parts between devices and cords/cables, to standardize them for easy connection and disconnection and to use simple connection modules. (D) As for the system containing devices and cords and cables, to reorganize the devices in their functions, structures, methods, and arrangements, and to set and store cords and cables in appropriate places.

Keywords

Cords, cables, entangled, connectors, modular, system of solutions, classification

1 INTRODUCTION

It is often seen that cords and cables get messy and entangled around PCs, TV and audio sets. To think of some methods for preventing such messy, entangled situations is the motive of the present study.

This topic was proposed by Tomoyuki Itoh in early summer in 2006 as a subject for his thesis work [1] at Osaka Gakuin University. In Nakagawa's seminar class in the Faculty of Informatics, we choose "Thinking Methods for Creative Problem Solving" as the main, common subject and give training of TRIZ (Theory of Inventive Problem Solving) [2, 3] and USIT (Unified Structured Inventive Thinking) [4, 5]. Students are advised to find some concrete problems to solve and are requested to write a thesis individually after the group work of trying to solve the problems in the class.

On this topic, it could be an approach, of course, to try to solve the concrete case of problem, i.e. the cords and cables getting entangled around his own desktop PC at home, and to find some concrete solutions or to make new devices. But we did not choose this approach.

Since we know that the problems caused by cords and cables getting messy and entangled can be seen everywhere, we have chosen in the present study an approach to think over this universally spread problem and to try to find solutions in a much wider scope.

The problematic situations of cords and cables getting messy and entangled can be seen everywhere in the kitchen, in the offices, in the labs, in the factories, inside equipments, etc. The problem has occurred for many decades and everywhere in the world. Thus, people must have tried various methods and made quite different devices. So if we look around closely, we will be able to find a variety of solutions. Hence it must be more useful to survey in a wide scope and to think generally of the whole space of solutions than to try to find individual specific solutions.

Thus the task of the present study is to collect as many methods, devices, materials, and products as possible used in the world for the purpose of preventing cords and cables from getting messy and entangled and to organize them by category into a system of solutions.

In which way to organize those solutions is the focus of the present study. We have decided to organize those different solutions from the viewpoint of intended functional methods.

Classification or categorization is a basic means for systematization. Clarifying the viewpoints of classification is a way to reveal the solution system. Viewpoints of classification need to be hierarchical and multi-dimensional, in the sense that the detailed level of classification requires another new viewpoint. Thus the viewpoints of classification and the items obtained in the classification reveal the new viewpoints of solution methods and new further specific ideas.

Building a system of (known) solutions to the common problem has been chosen as an educational goal in the present study. However, such a task is almost always required in real problem solving. Surveying known/ conventional solutions and systematizing them are the task necessary at the early stage of problem solving for the purpose of understanding the current state of the art and focusing the areas to tackle with. Building a system of new and old solutions together is also an important step at the nearly-final stage of problem solving for the purpose of generating further new ideas and exhausting the possible solution space. Thus the present study may be regarded as a case study demonstrating such steps.

We describe below that TRIZ and USIT have enabled the introduction of new viewpoints into the classification and resulted in deeper understanding in building the system of solutions.

2 COLLECTING EXAMPLES OF SOLUTIONS

In the present study we started to observe and collect various methods applied for the purpose of preventing the cords and cables from getting messy and entangled, and to collect their concrete items, such as devices, materials, and products.

The survey is found effective at the following places:

- at home, in the living room, study room, kitchen, etc.
- at offices
- PC rooms, laboratories,
- shops of electric and IT products,
- do-it-yourself store, hardware store,
- in the factories,
- inside the rack housing and chassis

'Cords and cables' in the present paper mostly mean some kind of wires having metal cords (inside) and transferring electricity and signals. Since the words of cords and cables are used in various items in the interchangeable way, we use them here without distinction.

As the survey went on, we understood that we should better think of the target objects wider than the original restriction of 'cords and cables'.

For example, wires, ropes, strings, threads, tubes, hoses, and pipes have similar problems of getting complex and entangled, even though they have different features from cords and cables due to differences in materials, shapes, and sizes. Thus various practices of using these similar things are of some help for reference. For example, fishermen release the ropes of fishing nets rapidly without getting them entangled, and fire fighters handle the water hoses in a compact manner.

Similarly, gardeners support the stems of flowers and also bundle many of them; their tasks have features common to the present one. Hence, not only the electric and communication fields which we can easily associate with cords and cables but also many other fields can provide us examples of solution ideas and solution items for our problem.

For each case of examples, we have collected the real item, its photo, photos in use and recorded the observation. We tried to accumulate them in cards and in files.

Next we tried to observe each case closely and discussed: In which situation and for which target objects the method or the item is used; how the item/device/material works; what kind of structure, shape, and material does it have; what merits, restrictions, and demerits does it have; how is it improved further; etc.

3 PRELIMINARY CONSIDERATION FOR THE CLASSIFICATION AND SYSTEMATIZATION

The collection and classification of these cases of examples were carried out in the following way, where some backtracking processes are omitted.

3.1 What Is the Problem?

According to the USIT process of problem solving, we have to clarify first what is really the problem, or undesirable effects. We may list up the followings:

"Cords and cables get messy and entangled around devices"

- Difficult to recognize the connecting relationships among the devices
- Difficult to manage, maintenance, replace, etc.
- Using unnecessarily-long cords and cables
- Causing leakage of electricity, and burning
- Taking space unnecessarily and wastefully
- Looking messy, untidy, unclean

The problem situation may be sketched as illustrated in figure 1.

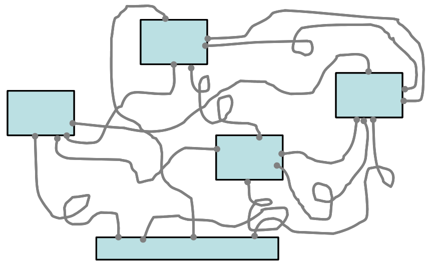

Figure 1: Problem situation of entangled cords and cables.

Thus the task we need to solve is represented in general terms as 'to prevent cords and cables getting messy and entangled around devices', and it contains a number of sub-tasks as mentioned above,

3.2 What Are the Causes of the Problem?

The causes of the problem described above are multi-folded in the following way:

- There are many devices involved.
- They need to be connected with many cords and cables.
- It is necessary to remove, add, and replace the devices from time to time.
- It is necessary to move the devices from time to time.
- There are a variety of devices and different sorts of cords and cables.
- It is necessary to be prepared for the future change in the system.
- Cords and cables must not be disconnected or unlinked.
- Cords and cables are longer than they are needed.
- Cords and cables gather at some places.
- Cords and cables get entangled in a complex way.

3.3 Organizing Various Solution Methods in a Bottom-up Manner

Obtaining a number of cases of solutions, we first tried to organize them in a bottom-up manner with the functional expression of Action-Object. At the stage of the thesis written by Tomoyuki Itoh [1], the solutions at the first hierarchical level were:

- Eliminate the property of cords and cables getting entangled easily.
- Make the length of cords and cables adjustable.
- Wind up the cords and cables.
- Fold up the cords and cables.
- Bundle several cords and cables together.
- Unite several cords and cables together.
- Set and fix the cords and cables after setting positions of the devices.
- Rearrange the cords and cables.
- Connect the devices and cords/cables in modules.
- Hide the cords and cables from sight.
- Remove the cords and cables.
- Use different shapes.

Below these first-level categories, we have many lower-level categories.

Since these are categorized empirically in the bottom-up manner, the classified system has as many as 12 items at the first level of hierarchy and leaves some doubts in their quality of systematic and comprehensive coverage of solutions.

3.4 Introduction of Basic Viewpoints by Simplifying the System

Thus, for making the results more persuasive, we have found the need of introducing some basic viewpoints in the classification of solutions. So we introduced the system thinking, i.e. to build up the system with simple base elements. We have introduced the four-stage scopes to understand the system, in the following way.

- Scope A. A single cord or cable (connecting two devices)
- Scope B. Multiple cords or cables (connecting several devices)
- Scope C. Connection parts between devices and cords or cables (in the system of multiple devices and multiple cords and cables)
- Scope D. A system of multiple devices connected with multiple cords and cables.

In the above descriptions of A to C, it is important that we do not pay attention to the items written in ( ). Namely, in the Scope A, we do not pay attention to the devices at the end of a cord/cable, but we consider only a single cord or cable and try to find some solutions on it, for the purpose of preventing the cords and cables from getting messy and entangled in complex systems.

Let us demonstrate the step-wise thinking in the followings:

Scope A. A single cord or cable

Figure 2 illustrates the Scope A, the first stage, of the problem situation and schematically shows the directions of solutions. The devices are shown with broken lines because we pay no attention to them.

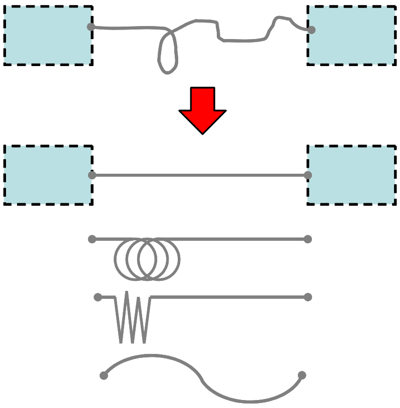

Figure 2: Scope A: A single cord or cable, together with directions of solutions.

The solution directions on a single cord or cable are to make it adjustable in the length, eliminate its extraneous part, and prevent it from getting entangled. For achieving the goal, we may make the cord/cable expandable and shrinkable, wind it up, and fold it up, etc. It is another solution to eliminate the property of easily getting entangled. There is still another solution to replace a long cord/cable with a shorter one; however, this solution implies the easy connection/disconnection of cord/cable with the devices, and hence is considered in the Scope C.

Scope B: Multiple cords and cables

The second scope regards multiple cords and cables as the target objects in the system containing multiple devices. The problem situation and the solution directions in the scope are illustrated in figure 3.

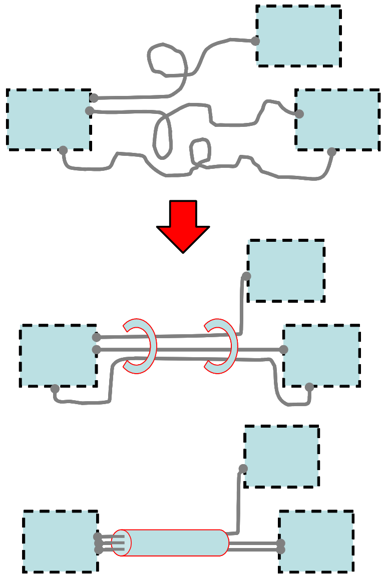

Figure 3: Scope B: Multiple cords and cables, together with solution directions.

The main solution direction in Scope B is to bundle multiple cords and cables running near and in parallel (or anti-parallel). This basic solution is applicable at a place, at multiple places of the cords/cables, and for a certain distance along the cords/cables, and further in the form of combining multiple cords and cables into a multiplex cord/cable.

Here we may also have other solutions, such as to fix the bundled cords/cables at a place, and to rearrange the positions of cords and cables. These solutions, however, are categorized in Scope D, because rearranging the positions of all the devices and cords/cables in the system is the scope more appropriate for it.

Scope C. Connection parts between devices and cords/cables

The third scope is focused at the connection parts between a device and a cord/cable. By achieving the easiness of connection and disconnection in these parts, we may try to solve the problems. Figure 4 illustrates the scope and the corresponding solution directions.

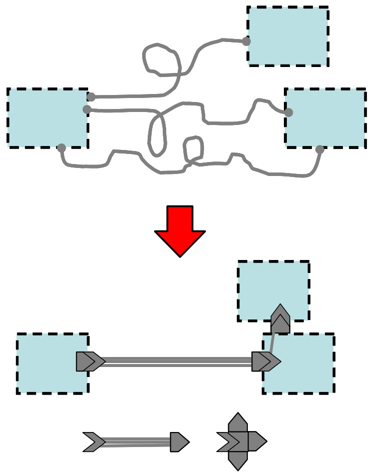

Figure 4: Scope C: Connection parts between devices and cords/cables, together with the solution directions.

The basic solution concept in this scope is to make the connection parts between devices and cords/cables standardized, easy to connect and disconnect, and easy to replace the devices and cords/cables on any request. The connection parts are commonly known as connectors, and have been standardized and improved for many years. It is a general solution direction to compose the system in a modular manner by using such standardized connectors so as to make the system flexible and extensible. In this scheme, it is also widely known to use small devices specialized for connecting functions and supplemented with some additional functions such as switching and multi-branching.

Scope D: A system composed of multiple devices and multiple cords/cables

So far we have focused our attention to a single or multiple cords/cables and to the connection parts; they are parts of a system. The fourth scope handles the whole system of the problem. The problem situation and the solution directions in this scope are illustrated in Fig. 5.

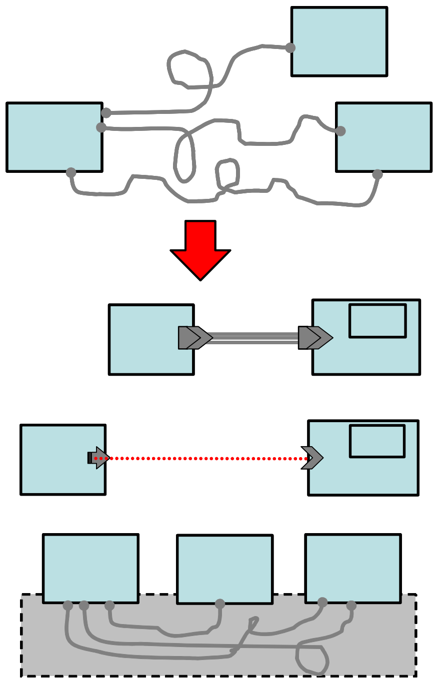

Figure 5: Scope D: A system with multiple devices and multiple cords/cables, together with the solution directions.

Either after trying to solve the problem in the scopes A to C or prior to but assuming the afterward trials of problem solving in the scopes A to C, we try to solve the problem in this scope D. We examine the devices in their functions, structures, spatial arrangements, etc. and accordingly we decide/modify the overall arrangements of cords and cables.

The general solution direction in this scope is first to re-examine the devices of the system in the problem from the aspects of their functions, structures, and spatial arrangements, etc. Sometimes it is recommended to merge or unite a device with another, and some other times to divide a device into multiple ones and to take out a part of a device. There are other cases that the whole system of multiple devices is reorganized and recomposed into a new one and that the whole system is made into a movable unit.

Another important viewpoint in this scope is to change the scheme of connection with cords and cables. A focus in the current technology is the wireless connection using radio waves, infrared rays, etc. and thus eliminating the objects in the form of cords and cables. Eliminating power cables by use of batteries may be a case of merging devices.

Another typical solution direction is to set and fix the indispensable and complex cords and cables at appropriate places inside or around the system, especially at the places besides/outside the human activities, in such a way that they are non-disturbing, hidden, unseen, and hence as if absent of existence. This solution principle is widely used by setting the cords/cables inside the devices, under or back of the desks, under the floor, over the ceiling, inside the cable/pipe ducts, etc.

4 A SYSTEM OF SOLUTIONS FOR PREVENTING THE CORDS AND CABLES FROM GETTING ENTANGLED

On the basis of the discussion in the previous section, we have reorganized the cases collected so far and added newly and have built a system of solutions for preventing the cords and cables from getting entangled. The result is shown in Table 1, at the end of this paper.

As the results of the step-wise consideration of the scope of the problem, the solution system shown in the table has much clear positioning of various solution ideas and is more systematic and comprehensive than the previous bottom-up study. Even though all these solution directions are already known and widely used, the present study has its significance in the understanding of such solutions in the general scheme of preventing the cords and cables from getting entangled. We will point out a number of significant solution directions in the followings.

4.1 (A) A single cord or cable: To adjust the length and prevent from getting entangled

'To expand and shrink' (A1) is realized in the form of spiral telephone code, imitating the rubber structure in a macro scale, but with not so large expansion ratio. To use longer and shorter cords/cables in the interchangeable way is categorized in (C1), because the solution assumes smooth connection and disconnection with standardized connectors.

It is more practical to store the extra portion of cord/cable in a compact manner. Winding-up (A2) and folding-up (A3) are the solutions used commonly. Since cords and cables containing thin metal wires can not be bent sharply, folding-up the cords/cables does not give a neat structure. Thus winding-up is used more often. However, when the cords/cables are coiled like a snake, they are twisted and this causes a trouble in handling long cords/cables. Thus, it is a normal method for thin cords/cables to catch one at the middle of the length and wind it up towards both ends simultaneously in a flat manner.

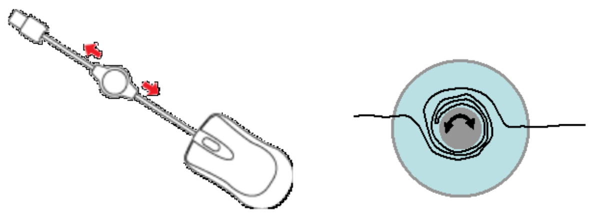

Figure 6: Winding-up the cord/cable. An example and its inner structure.

Another good method is to wind up the cord/cable in the form of character '8'. This method is used in storing the fishing-net ropes and applicable to even thick cords/cables which do not bend nor twist so much. This method is used manually, but I have not seen any compact automatic device applying this method.

4.2 (B) Multiple cords and cables: To bundle, to combine, and to unite

The most common way to handle multiple cords and cables is to bundle them and keep them together (B1). Since this method is easy and useful, various types of devices (mostly in some form of belts) are produced and used. Not only bundling the multiple cords/cables at a place or at several places, but also bundling them along a certain distance (B2) is often useful.

An interesting tool in this category is a spiral belt made of plastic with elasticity (See Fig. 7). Since the spiral is not closed, it can be installed at the middle of multiple cords/cables, and the size of the bundle and the length of bundling can be adjusted as desired.

Figure 7: Examples of bundling cords and cables.

It is also important to combine multiple cords and cables into a single united cord/cable (B3). Two wires for power supply are usually attached side by side, and are handled as a single (composite) cord/cable. Several tens of signal cables are attached side by side forming a belt, which is used in the PC cabinet, etc. Furthermore, there are many cases of composite cords/cables containing a number of inner cords/cables and sometimes a number of inner layers of different functions. The case of USB cable is suggestive in the point that it contains not only signal cables but also power supply cables.

4.3 (C) Connection parts between devices and cords/cables: To use standardized connectors and connection modules

To use standardized connectors at the connecting parts between the devices and cords/cables (C1) is of course a widely used solution. To attach connectors to the devices and to the both ends of cords/cables (C2) is the solution at the next step. According to this solution, it becomes easy to replace devices and to use cords/cables of appropriate lengths so that the cords/cables can be arranged neatly.

On the basis of these connectors, different kinds of modules specialized for connecting functions and further incorporated with various additional functions (C2) have been made and used. For example, the power strips may have the functions of multi-branching, switching (On/Off), surge protection, etc.

Figure 8: An example of multi-branching connection module

These modules should have varieties and flexibilities in their spatial arrangement of structure (C3) for their practical use.

4.4 (D) System: To reorganize the devices and to store the cords/cables in and around the system

This is the fourth step approach where we examine the whole system containing multiple devices and many cords and cables. Instead of the simple approach to preventing the cords and cables from getting entangled, one may take an approach of improving the system in its basic principle, and then the problems of cords and cables may be solved at their root causes.

The multiplexing telecommunication, where multiple channels are transmitted through a single cable, is an example of this category (D1). It is recommended to set and fix the principal devices in the system and then to optimize the arrangement of cords and cables (D2). After deciding the arrangement of cords and cables in the system, one may fix the cords and cables at some critical positions (D3).

Introducing wireless communications and eliminating the needs of cords and cables (D4) is the current trend of technological evolution.

After applying various means described so far to solve the problem, we often meet the situations where we still have many cords and cables arranged in a complex/confusing manner. In such situations, it a common practice to rearrange and store the cords and cables in the places such as inside the chassis/racks, under or behind the desks, under the (free-access) floor, etc., so that they are hidden without giving disturbances (D5).

5 DISCUSSION

5.1 Significance of Systematic Classification

As we have described so far, the present study has addressed the task 'how to prevent cords and cables from getting messy and entangled' and clarified a system of solutions to the initially vague problem. We have adopted the processes, i.e., collecting various examples of solutions, classifying them in a bottom-up manner, introducing the problem-solving approach, clarifying the scopes of analysis, expanding the analysis scope step by step, and constructed a hierarchical system of solutions in the top-down manner.

One of the benefits of having built such a system of solutions is the possibility of understanding the directions of various relevant technological evolutions in a systematic way. On the basis of such understanding, when we meet new interesting products we will be able to see their essence better. And such understanding will give us strong support for us to think of new solutions to our problems.

For example, a power strip is a device for transmitting the power from a power source, e.g. on the wall, through a cable and providing multiple power sources by branching. If we used multiple cables from the original power source to individual devices, such cables could get messy and entangled. Thus we use only one cable to a common place near the devices, and then make multiple branches of cables. This is a well understood solution idea. We can now understand that the different devices shown in figure 9 have the same simple idea in their essence.

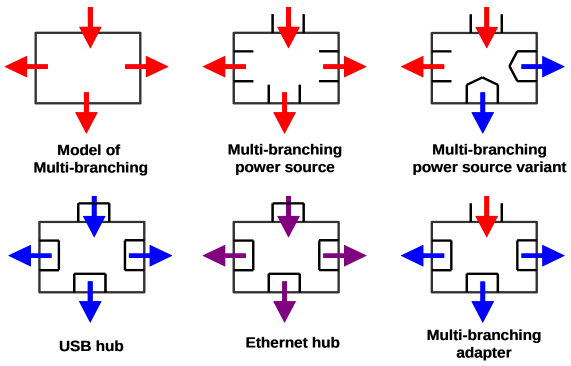

Figure 9: A connection module with multiple branching: a model and its different examples

5.2 The Root Causes of the Problem

You may notice that various solutions listed up as 'the methods for preventing cords and cables from getting messy and entangled' in the present study are rather well known as a common sense. For example, the basic solution directions at the second level (A1, B2, etc.) in Table 1 are well known. And in the markets we can find a large number of concrete products mentioned here. Nevertheless, we see everywhere the problematic situations of cords and cables got entangled. Why not solved?

For example, one of the most basic solution directions (C1 and C2) tells us that we should better use shorter (i.e. not unnecessarily long) power cord and extend it whenever necessary by use of standardized connectors and extension cords.

On the connectors we pose many contradictory requirements: The fundamental requirement is the easy connection. Electricity or signals must be transmitted surely through the connectors and without risks of erroneous connection. However, at the same time, connectors must be easy to disconnect. Nevertheless, connectors must not get disconnected without intended operation. Connectors must be concrete products, fulfilling all these contradictory requirements in the compact body with inexpensive cost.

Connectors for ordinary power cords are designed with various considerations and improvements, and yet have some defects of not fulfilling some points of requirements. Thus it is the common sense that one should not use the connectors in the middle of cords/cables without absolute necessity.

Most of devices provide the power cords of 2 to 3 m in length. Under the situations of ordinary setting up, most of the cords have the slack of 1 to 2 m; this extraneous length is the main cause of getting entangled. To move the device for maintenance, we need the slack. To rearrange the positions of devices, we need the slack. For the cases of being far from the power source on the wall, we need the slack. Considering different situations of customers, we need the slack.

Under these considerations, the power cords of various devices are sold having the length of 2 to 3 m. We seldom see shorter cords having usually-sufficient length of 1 to 2 m. For the shorter cords, we need some extension cords from time to time; however, we cannot have any guarantee that the extension cord is available (either being provided or carrying around) whenever necessary. This causes a serious problem in such an unfortunate occasion.

After all, people have chosen to use the cords/cables somewhat longer than the usually-sufficient length, for the consideration of future, though not so large, possibility of needs. Such choices result in the extraneous lengths of cords and cables, which provide the root causes of many cords and cables getting entangled everywhere.

5.3 Usage of TRIZ/USIT Way of Thinking

The present paper is not a case study of using concrete tools in TRIZ and USIT, but is a case study of using the ways of thinking in TRIZ and USIT. You may see such ways of thinking in the followings:

- Collecting a large number of examples of solutions first, extracting essence of solution ideas of them, and further systematizing the solution principles. -- This is the fundamental approach in TRIZ.
- What is the problem? and what are the root causes of it? -- These questions are the usual starting points of TRIZ and USIT.
- Various solution ideas are searched for and considered with abstract thinking with emphasis on the functions. -- This is a characteristic approach in TRIZ and USIT.
- The scope of analysis is extended step by step as: (A) a single cord/cable, (B) multiple cords/cables, (C) connection parts, and (D) a system with multiple devices and multiple cords/cables (and further the system's environment). -- This stems from the system's thinking in TRIZ and USIT.
- Various solution ideas are backed up by the Inventive Principles in TRIZ.
- At the lower hierarchical levels of the solution system, considerations on attributes of solution items, such as shapes and material properties, are fully used. -- Thinking in terms of attributes is also typical in TRIZ and USIT.

At the end of this paper, we would like to mention the insufficiency of our study in the point that we did not carry out the surveys of references, patents, and know-how even though there must be abundant knowledge in the world and some portions of them must be documented already. However, not the individual solutions to the present problem but the way of revealing the solution space in a systematic way is the target of this study.

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Table 1. A System of Solutions for Preventing Cords/Cables from Getting Messy & Entangled

A. A single cord or cable: To adjust the length and prevent from getting entangled

A1. To expand and to shrink for adjusting the length

like a telescope, like a rubber, like a spiral telephone cord

A2. To wind up for adjusting the length

in a spiral, in a winding-up carton, around something, in the form of character 8

A3. To fold up for adjusting the length

folding and binding, in an accordion style

A4. To eliminate the property of cord/cable being easy to get entangled

no local bending, no twisting

B. Multiple cords and cables: To bundle, to combine, and to unite,

B1. To bundle multiple cords and cables at a place

The bundle held with twisting, with tying, with hooking, with fixing in a hole, with adhesion, within a frame,

The bundle held with elastic closure, with an elastic spiral belt, with a winding tape

B2. To bundle multiple cords and cables along a certain distance

Within a fame, with an elastic spiral belt, with a winding tape

B3. To combine multiple cords and cables into a single united cord/cable

By braiding, by winding each other, by attaching side by side,

By forming a new united cord/cable, such as a composite cable, a multiplex cable

C. Connection parts between devices and cords/cables:

To use standardized connectors for easier connection/disconnection, and to use specialized connection modules

C1. To use standardized connection parts between devices and cords/cables for easier connection/disconnection

At the connection parts of the devices

At the ends of cords and cables

C2. To use modules specialized for connecting function and containing some additional functions

Additional with on/off, with route switching, with multiple branching, with an adaptor, with a filter, with twist elimination

C3. To use different shapes and spatial arrangements in the connection parts and the connection modules

With vertical or horizontal shape, with straight or bent shape, with flexible shape

D. A system of multiple devices and multiple cords/cables:

To examine the devices in their functions, structures, schemes, and to store cords/cables in or around the system

D1. To examine the functions and structures and to consider merging, uniting, dividing, taking out, etc. of the devices

Uniting the devices into a new device using fewer cords and cables (e.g. multiplex communication)

D2. To reorganize and optimize the arrangements of devices and cords/cables

D3. To reorganize the arrangements and fix the cords and cables at their places

By reorganizing according to their paths, by setting the devices and paths in the 3D space

By fixing inside the devices, in the system, in the environment (desk, floor, wall, ceiling, etc.)

D4. To eliminate the cords and cables

By embedding the cords/cables in the base, by combining multiple devices into one, by using batteries

By using wireless communication between the devices

D5. To hide the complex cords and cables at some appropriate places

Inside the chassis, in a box, under or behind the desk, over the head

Under the (free-access) floor, over the ceiling board, inside the ducts, inside the piping trench

A Study of Decision-Making Model to Evaluate "Index of Ideality"

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Abstract

My presented paper at ETRIA2007 referred to "Four patterns of Innovation". This time, I would like to introduce "Decision-Making Model (D-MM)" for "Innovation pattern 3 & 4" focusing on "High-End Customer (HEC)". In my opinion, "HEC" basically chases "Ideal Final Result (IFR)" from the point of view in TRIZ thinking. Therefore, in this paper, I want to define "chasing IFR of product" as "chasing highly-valued product".

As I mentioned in my previous paper at ETRIA2007, chasing "IFR" is one of big features about "Innovation 3 & 4". Consequently, proposed "D-MM" to be built here is to search "the Idealized Conceptual Designs (ICD)" to realize highly-valued product rationally from the standpoint of "chasing IFR".

To be concrete, based on TRIZ thinking, the concept of "IFR" is connected with "Evolution Towards Increased Ideality (ETII)". Because "Increasing Ideality" indicates that products (technical systems) are developed according to the "Direction" that "Useful Functions (UFs)" are increased and "Harmful Effects (HEs) "are reduced in time axis. As a result of "ETII" of an object product, it approaches "IFR".

In this article, as a beginning, I describe the relationship between "Innovation pattern 3 & 4" and "Proposed D-MM". Then, I refer to the features of proposal "D-MM" based on the concept of "IFR". The basis of the proposal "D-MM" is "Analytic Hierarchy Process (AHP)". To put it concretely, it is devised to evaluate "Ideality" from various aspects corresponding to not only "UFs (such as product design parameters)" but also "HEs (such as side effects with useful functions)". Based on "the Hierarchy Diagrams (it's called AHP hierarchy)", which focus on a series of "UFs" and "HEs" in an object product, the proposal "D-MM" is able to measure its "Index of Ideality". Finally, through one case example, I want to consider the effectiveness of proposed "D-M M".

Keywords

Ideal Final Result (IFR), Evolution Towards Increased Ideality (ETII), Decision-Making Model

1 THE PURPOSE OF THE STUDY

The purpose of this study is to propose the " Decision-Making Model(D-MM)"to evaluate the highly-valued product for customers in product development activities form the standpoint of "Evolution Towards Increased Ideality (ETII)".To be concrete, according to the "ETII", "Useful Functions (UFs)", for example, "performance of main parameters" will be improved and "Harmful Effects (HEs)", for instance, "weight, space, noise, cost and so on" will be decreased in the technical systems. It means that through time, the technical systems usually advance toward increased ideality.

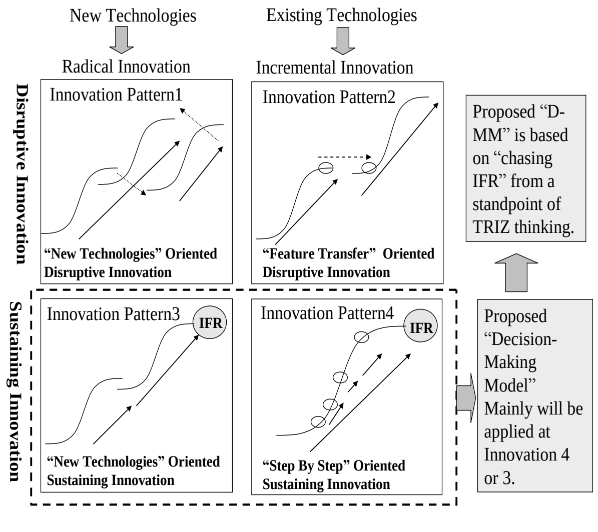

Figure1: Four Innovation patterns based on the S-curve concept.

Therefore, I'd like to introduce the rational and unique techniques to search for the highly- valued "Design Proposals (DPs)" by utilizing "Analytic Hierarchy Process (AHP)" from a standpoint of "the improvement of Ideality in TRIZ thinking". By the way, customers who chase highly-valued product at any time are usually called "High-End Customer (HEC)". Therefore, Proposed "D-MM" mainly will be applied on the field of "Innovation pattern 3 or 4". Because both Innovation pattern 3 and 4 focus on "HEC".

Although I already referred "Four patterns of Innovation [1]" at ETRIA2007, I want to show "Four patterns of Innovation" including Innovation pattern 3 and 4 in order to confirm the features of each Innovation pattern.

Understanding the features of each Innovation makes easier to use "D-MM". Four patterns of Innovation based on the S-curve concept" as show below (see fig.1).

2 OUTLINE OF PROPOSED MODEL

In order to measure ""Ideality Index (II)" for "DPs"(alternatives) from the viewpoint of "ETII", I suggest drawing up two types of "Hierarchy Structure Diagrams(HSD)". This is because the proposed "D-MM" is based on AHP. One is for "UFs" and the other is for "HEs". On the basis of two types of diagrams, it's expected to measure the coefficient showing "degree of Ideality (it means "II")"rationally for "DPs" to be considered through TRIZ activities.

To be concrete, firstly, "Decision-Maker Unit (DMU)" has to estimate "the weight (Level of Importance)" for each DP by utilizing AHP including "Desiring Level (DL)". After that, "DMU" has to calculate "the weight (degree of incident)" for each DP based on "Acceptable Level (AL)". Finally, it has to be calculated "II" for each DP by dividing sum total of weight for each "UF "into them for each "HE" for each "DP".

"AL" is the minimum level to be acceptable for customers. In other words, "AL" is the criterion in the opposite direction of "DL". Therefore, the more "II" for each "DP" is bigger (especially more than 1), the more it will be valuable for customers (especially, high-end customers).

3 IMPLEMENTATION PROCEDURES OF PROPOSED MODEL

The flowchart regarding implementation procedures of the proposed "D-MM" is as shown below (see fig.2).

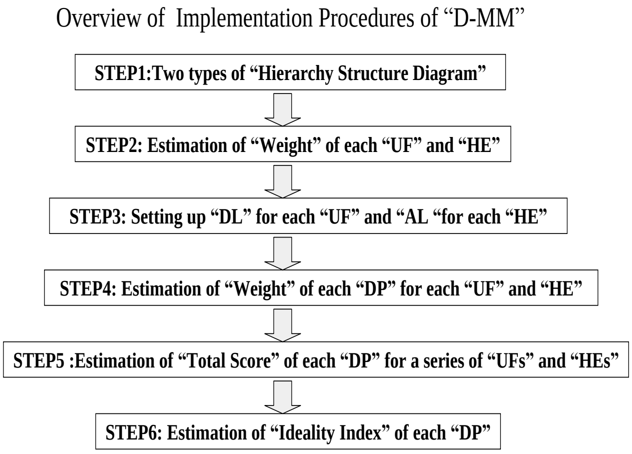

Figure 2: Overview of Implementation Procedures of "D-MM".

STEP1: Making two types of "Hierarchy Structure Diagram (HSD)" from the point of view in "Evolution Towards Increased Ideality (ETII)"

We draw up the two types of "HSD" based on the purpose of improvement for "required useful functions" and reduction for "harmful effects to be avoided".

STEP2: Estimation of "Weight (Level of Importance)" of each "Useful Function (UF)" and "Harmful Effect (HE)"

We estimate relative weight for each "UF" and "HE" by utilizing usual AHP (Type of Relative Measurement Approach).

UWi: *Weight of UFi* (It means "level of importance for customers".)

HWj: *Weight of HEj* (It means "degree of incidence" against customers.)

Note, however, that $\sum_{i=1}^{n} UWi = 1$, $\sum_{j}^{m} HWj = 1$

STEP3: Setting up "Desiring Level (DL)" for each" UF" and "Acceptable Level (AL) "for each "HE"

We have to define "DL" for each "UF" and "AL" for each "HE" of the technical system (for instance, new product in the pipeline).

minRi: Value of "DL" for *UFi*

maxURj : Value of "AL" for *HEj*

STEP4: Estimation of "Weight (Degree of Relative Merit)" of each" DP" for each UF and HE

In order to measure the outcome of each "DP", we have to estimate the achievement (weight) about "DL" for each "UF" and "AL" for each "HE" respectively through AHP including "DL" and "AL".

**minRi*: "DL" of *UFi* normalized to "1"

UW (*i, k*): Weight of"DP" *k* for **minRi* of *UFi*

**maxURj* : "AL" of *HEj* normalized to "1"

EW (*j, k*): Weight of "DP" *k* for **maxURj* of *HEj*

STEP5 Estimation of "Total Score (TS)" of each "Design Proposal (DP)" for a series of "UFs" and" HEs"

We have to calculate "TS" of each "DP" by method of weighted mean between the weight of each "DP" for each "UF" and the weight of each "UF" to be estimated at step2. After that, we calculate "TS" of each "DP" related to each "HE" by same method.

Uk : "TS" of "DP" *k* for a series of "UFs"

$$Uk = \sum_{i=1}^{n} UWi \times UW(i,k)$$

UminR : "TS" of "DL"

**minRi* : "DL" of *UFi* normalized to "1"

Note, however, that *UminR* = $\sum_{i=1}^{n}$ **minRi×UWi* = 1

Hk : "TS" of "DP*k*" for a series of "HEs"

$$Hk = \sum_{j=1}^{m} HWj \times HW(j,k)$$

HmaxUR : "TS" of "A L",

**maxURj* : "AL" of *HEj* normalized to "1"

Note, however, that *HmaxUR* = $\sum_{i=1}^{n}$ **maxURj* × *HWj* = 1

STEP6: Estimation of "Ideality Index (II)" of each DP

We have to calculate" II" of each "DP" based on" TS" of each" DP" to be estimated at STEP5.

Ik :"II" of "DP" *k*

$$Ik = \sum_{i=1}^{n} UWi \times UW(i,k) \Big/ \sum_{J-1}^{m} UEj \times HE(j,k)$$

Min I :"DL" of "II"

$$MinI = U\min R \big/ H\max UR = 1$$

4 CASE EXAMPLE (1) -EVOLUTION ABOUT PORTABLE MUSIC PLAYER "WALKMAN" (CASSETTE-TYPE TAPE) [2]

4.1 Making two types of "Hierarchy Structure Diagram (HSD)" according to the procedure of STEP1

We drew up two types of "HSD" focusing on "Portable music player" developed by Sony in 1979. We called it "Walkman" (the brand of portable music player) at that time. One is "HSD" for "UFs" (fig.3) and the other is "HSD" for "HFs" (fig.4).

"HSD" for "UFs" is the structure diagram showing the required "UFs" of "Portable music player". On the other hand, "HSD" for "HEs" is the one showing the predictable Side effects of it.

The objective of making these "HSD" is to evaluate each "DP" (in this case, DP means each generation about portable music player) rationally at next step or later (STEP2 through STEP6).

Three main portable music players selected from the point of view in time axis are as shown below (see Fig.5, 6, and 7).

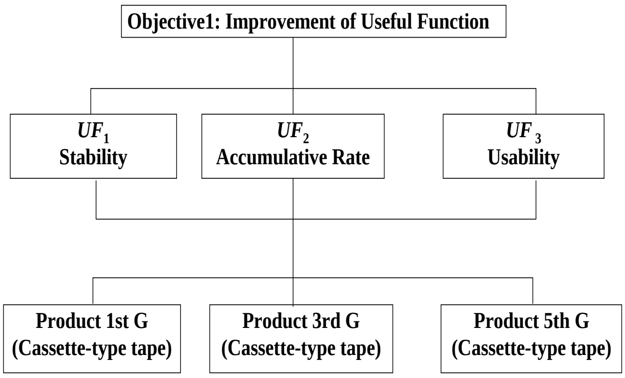

Figure 3: “HSD” for “a series of UFs” about “Portable music player (Cassette-type tape)”.

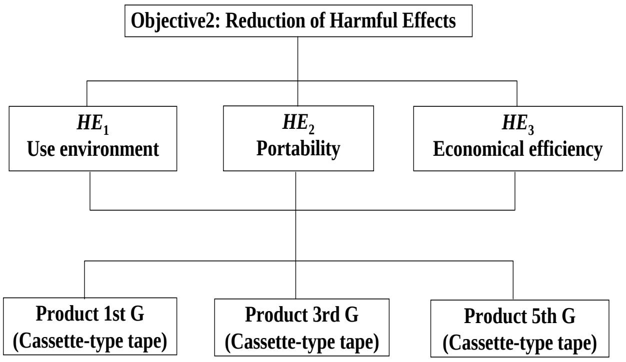

Figure 4: “HSD” for “a series of HEs” about “Portable music player (Cassette-type tape)”.

1st Generation (TPS-L2) （Sale 1979.7.1)

Figure: 5 Product 1st G.

3rd Generation (WM 501) （Around 1987)

Figure: 6 Product 3rd G.

4.2 **Estimating of “Weight” of each “UF” and “HE” according to the procedure of STEP2**

In this case, we utilized usual AHP (“Relative Measurement Approach”) to estimate “Weight” of each “UF” and “HE”.

5th Generation (1990’s-)

Figure: 7 Product 5th G.

In order to utilize AHP correctly, we have to keep in mind the meaning of “Weight” of each “UF” and “HE”. To be concrete, keeping in mind that “Weight” of each “UF” is “level of importance for customers”, we estimated “Weight” of each “UF” from the point of view in improvement of “UFs”. On the other hand, we estimated “Weight” of each “HE” from the standpoint of reduction of “HEs”, keeping in mind that “Weight” of each “HE” is “degree of incidence” against the users.

Paired comparison judgments in the AHP are applied of homogeneous elements. For example, a series of “UFs” and “HEs” are homogeneous elements of “HSD” for “UFs” and “HEs” (See Fig.3, 4) respectively. The fundamental scale of absolute values for representing the intensities of judgments is shown in Fig.8, though we are not concerned with the detailed theory of AHP because of limited space in this article.

Intensity of Importance	Definition
1	**Equal importance**
2	Weak
3	**Moderate importance**
4	Moderate plus
5	**Strong importance**
6	Strong plus
7	**Very strong or demonstrated importance**
8	Very, very strong
9	**Extreme importance**
Reciprocals of above	If actively “*i* ”has one of the above numbers assigned to it when compared with activity ”*j*”, then ”*j*” has the reciprocal value when compared with “*i* “

Figure8: The fundamental scale.

(*****The fundamental scale is quoted from “THE ANALYTIC NET WORK PROCESS by Thomas L. Saaty”.)

The scale shown in Fig.9 has been validated for effectiveness not only in many applications by a number of people but also through theoretical comparisons with many other scales (like these scales focusing on “UF” & “HE” in TRIZ field).

According to basic theory of AHP [3], [4], the numbers are used to represent how many times the larger of two elements dominates the smaller one with respect to a property or criterion they have in common. The smaller element has the reciprocal with respect to the larger one. Based on the fundamental scale, we estimated “Weight” of each “UF” as shown in figure 9.

3 items		Consistency Index(IC)=0.009		IF CI<0.1, it's "OK"	
	UF1	UF2	UF3	G M	*UW* *i*(*i*=1-3)
UF1 Stability	1.000	2.000	1.500	1.442	0.455
UF2 Accumulative Rate	0.500	1.000	0.500	0.630	0.199
UF3 Usability	0.667	2.000	1.000	1.101	0.347
			Total	3.173	1.000

Figure 9: "Weight" of each "Useful Function (UF)"for "Portable music player (Cassette-type tape)"

We estimated "Weight" of each "HE" on the basis of same scale, too (fig.10).

3 items		Consistency Index(IC)=0.005		IFCI<0.1, it's "OK"	
	HE1	HE2	HE3	G M	*HWj* (*j*=1-3)
HE1 Use environment	1.000	1.000	1.500	1.145	0.370
HE2 Portability	1.000	1.000	2.000	1.260	0.407
HE3 Economical Efficiency	0.667	0.500	1.000	0.693	0.224
			Total	3.098	1.000

Figure 10: "Weight" of each "Harmful Effect (HE)" for "for "Portable music player (Cassette-type tape)".

According to AHP, if "Consistency Index (C.I)" is less or equal 0.1, the results of evaluation (like Fig8 and 9) are usually acceptable [2].

4.3 Setting up "Desiring Level (DL)" for each" UF" and "Acceptable Level (AL) "for each "HE" according to the procedure of STEP3

We tried to define both "DL" for each "UF" and **"**AL "for each "HE" with considering the perspective of purchasing the highly-valued "portable music player (Cassette-type tape) "as shown in Fig.11 and Fig.12, putting oneself in the position of customers in1980's.

Useful Function	Desiring Level (DL) (Way to advance "＋") Concrete performance measures
UF_1 Play back music longer **(Stability)**	Throughout the journey, it's possible for users to listen to music for a long moment (At least **more than 6 hours** is required.)
UF_2 Make a recording of more songs **(Accumulative Rate)**	"Walkman" is capable of recording **a lot of songs**. (At least **more than 20songs** in a cassette tape is required.)
UF_3 Provide additional functions to improve usability **(Usability）**	The majority of the customers require additional functions to improve usability. (At least **more than one additional function** like "auto reverse" is required.)

Figure 11: Each "Desiring Level (DL)" for each "UF" about "Portable music player (Cassette-type tape)" (*Points to remember: Aesthetic functions like colour, shape, texture and so on will be omitted in this case).

Harmful Effect	Acceptable Level (AL) (Way to advance "0") Concrete performance measures
HE_1 Prevent leaking sound **(Use environment)**	In order to avoid making trouble to those around user, product has to prevent leaking noise from its air horn. "Noise reduction function" **less than xx DB** is required**.**
HE_2 Make easy to move with holding body **(Portability)**	It's possible to listen to music easily while walking (or running). Customers require lightweight body which is **less than 200g.**
HE_3 Reasonable cost of portable music player **(Economical efficiency)**	Customers want reasonable price. At least **less than 30,000 yen** is required.

Figure 12: Each "Acceptable Level (AL)" for each "EH" about "Portable music player (Cassette-type tape)".

4.4 Estimating "Weight (Degree of Relative Merit)" of each "Product" for each UF and HE according to the procedure of STEP4

In order to estimate the effectiveness about "Three main portable music players" (see fig.4, 5, and 6) as true to customer's spirit in 1980's as possible, we utilized "modified AHP", which is AHP including "DL" and "AL" shown respectively in figure 11 and 12. The results of "Paired Comparison Table" about "Main portable music players" by AHP including "DL" are as described below.

UF1		Consistency Index(IC)=0.022			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*minR* 1	GM	weigh t	*UW (1,k) K*=1-3
1st G	1.000	2.000	0.125	1.000	0.707	0.103	1.030
3rdG	0.500	1.000	0.111	0.500	0.408	0.060	0.595
5th G	8.000	9.000	1.000	9.000	5.045	0.737	7.348
minRi	1.000	2.000	0.111	1.000	0.687	0.100	1.000
			Total		6.847	1.000	

Figure 13: Paired Comparison Table including DL of UF1 about "Portable music players (Cassette-type tape)".

UF2		Consistency Index(IC)=0.000			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*minR* 1	GM	weight	*UW (2, k) K*=1-3
1st G	1.000	0.900	0.900	1.000	0.949	0.237	0.995
3rd G	1.111	1.000	1.000	1.100	1.051	0.263	1.103
5th G	1.111	1.000	1.000	1.100	1.051	0.263	1.103
min Ri	1.000	0.909	0.909	1.000	0.953	0.238	1.000
			Total		4.005	1.000	

Figure 14: Paired Comparison Table including DL of UF2 about "Portable music players (Cassette-type tape)".

UF3		Consistency Index(IC)=0.047			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*minR* 3	GM	weight	*UW (3, k)* (k=1-3)
1st G	1.000	0.333	0.143	0.333	0.355	0.059	0.439
3rd G	3.000	1.000	0.200	1.000	0.880	0.147	1.088
5th G	7.000	5.000	1.000	7.000	3.956	0.659	4.890
*minR*3	3.000	1.000	0.143	1.000	0.809	0.135	1.000
			Total		6.000	1.000	

Figure 15: Paired Comparison Table including DL of UF3 about "Portable music players (Cassette-type tape)".

These tables by AHP including "HL" are as described below.

HE1		Consistency Index(IC)=0.000			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*Max UR*1	GM	weight	*EW (1, k)(k=* 1-3)
1st G	1.000	1.000	5.000	5.000	2.236	0.417	5.000
3rd G	1.000	1.000	5.000	5.000	2.236	0.417	5.000
5th G	0.200	0.200	1.000	1.000	0.447	0.083	1.000
*Max UR*1	0.200	0.200	1.000	1.000	0.447	0.083	1.000
			Total		5.367	1.000	

Figure 16: Paired Comparison Table including AL of HE1 about "Portable music players (Cassette-type tape)".

HE2		Consistency Index(IC)=0.013			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*Max UR*2	GM	weight	*EW (2, k(k=*1 -3)
1st G	1.000	6.000	7.000	5.500	3.899	0.664	5.020
3rd G	0.167	1.000	2.000	1.000	0.760	0.129	0.978
5th G	0.143	0.500	1.000	0.500	0.435	0.074	0.560
*Max UR*2	0.182	1.000	2.000	1.000	0.777	0.132	1.000
			Total		5.870	1.000	

Figure 17: Paired Comparison Table including AL of HE2 about "Portable music players (Cassette-type tape)".

HE3		Consistency Index(IC)= 0.019			IF CI<0.1, it's "OK"		
	1st G	3rd G	5th G	*Max UR*3	GM	weight	*EW (3, k)(k=* 1-3)
1st G	1.000	3.000	7.000	2.000	2.546	0.476	1.565
3rd G	0.333	1.000	4.000	0.500	0.904	0.169	0.556
5th G	0.143	0.250	1.000	0.143	0.267	0.050	0.164
*Max UR*3	0.500	2.000	7.000	1.000	1.627	0.304	1.000
			Total		5.343	1.000	

Figure: 18 Paired Comparison Table including AL of HE3 about "Portable music players (Cassette-type tape)".

We have to keep in mind a feature of results with respect to these three tables based on a series of "HEs". In other words, when using AHP including "AL", we have to consider that the more the weight of each "product" with respect to a "HE" decreases, the more the value of each "product" increases. This is because the direction of "AL" is in the Way to advance "zero" (See Fig.12). Therefore, the "Weight" of each "HE" is reciprocal value compared to the one of each "UF".

4.5 Estimating "Total Score (TS)" of each "Product" for a series of "UFs" and" HEs" according to the procedure of STEP5

Figure 19 shows "TS" of each "Product" for a series of "UFs".

"Total Score" of each "Product" for a series of "Useful Functions"

	UF1 Stability	UF2 Accumulative Rate	UF3 Usability	Total Score
Weight of *UFi*	0.455	0.199	0.347	1.001
**minRi*	1.000	1.000	1.000	1.001
1st G	1.030	0.995	0.439	0.819
3rd G	0.595	1.103	1.088	0.868
5th G	7.348	1.103	4.890	5.260

Figure 19: Total score of each Product for a series of UFs.

After that, we calculated "TS" of each "Product" for a series of "HEs" by same method as show in figure 20.

"Total Score" of each "Design Proposal" for a series of "Harmful Effects"

	HE1 Use environment	HE2 Portability	HE3 Economical efficiency	Total Score
Weight of HE j	0.370	0.407	0.224	1.001
**maxURj*	1.000	1.000	1.000	1.001
1st G	5.000	5.020	1.565	4.244
3rd G	5.000	0.978	0.556	2.373
5th G	1.000	0.560	0.164	0.635

Figure 20: Total score of each Product for a series of HEs.

4.6 Calculating "Ideality Index (II)"of each "Design Proposal (DP)"according to the procedure of STEP5

Based on "TS" of each" Product" for a series of "UFs" and "HEs", we calculated "II" of it.

Estimation of "Ideality Index" for each "Product "

	ΣUF Total score	*ΣHE Total score*	Ideality Index
"Desiring Level"	1.000	1.000	1.000
1st G	0.819	4.244	0.193
3rd G	0.868	2.373	0.366
5th G	**5.260**	**0.635**	**8.283**

Figure 21: Ideality Index about three portable music players.

5 CASE EXAMPLE (2)-EVOLUTION ABOUT PORTABLE MULTI-PLAYER (MD TO"MEMORY-TYPE MULTI-PLAYER WALKMAN")[5]

After the age of "cassette-type tape Walkman", SONY moved to next S-curve focusing on "CD/MD-type Walkman". In other words, SONY continued to develop "next type Walkman" as practice of Innovation pattern 3 for HEC". But, after the age of "CD/MD-type Walkman", in a time of transition to nest S-curve, SONY hesitated to move next S-curve focusing on "memory-type multi-player Walkman". Because "memory-type multi-player" has the attractive function for customers which makes a record of enormous quantity of data (like not only music but also moving picture) from PC easily. That is, SONY thought that an attractive factor for customers is an adverse affect on CBS SONY to sell a variety of music CDs at that time.

In other words, SONY's behaviour at the time facilitated realization of "i-POD". As the result of it, "iPod" actualized "Innovation pattern1". Because "iPod" had a strong power not only to invade walkman's share but also to create new huge market for new users to enjoy portable multi-player with doing a variety of things. On the other hand, SONY decided to continue the development of sophisticated "Memory-type walkman" as "Innovation pattern3". Because, this type of walkman just chases "HEC" in same market of "iPod". Therefore, in this chapter, I would like to introduce "Evolution about "memory-type multi-player Walkman" based on the utilization of proposed "D-MM".

Figures 22 and 23 show "Desiring Level (DL)" for each "UF and "Acceptable Level" for each "EH" about "Portable multi-player" respectively.

Useful Function	Desiring Level (DL) (Way to advance "＋") Concrete performance measures
UF_1: Play back music longer **(Stability)**	Throughout the journey, it's possible for users to listen to music for a long moment (At least **more than 30 hours** is required.)
UF_2: Make a recording of more songs and movies **(Accumulative Rate)**	"Walkman" is capable of recording **a lot of songs**. (At least **more than 300 songs** in a memory are required.)
UF_3 :Provide additional functions to improve usability **(Usability)**	The majority of the customers require essential additional functions like not only playing back music with increased flexibility but also connecting with PC easily. (At least **additional function** to record screen image like "Movies or TV programs" through either TV or PC are required.)

Figure 22: Each "Desiring Level (DL)" for each "UF" about "Portable multi-player (memory-type)".

Harmful Effect	Acceptable Level (AL) (Way to advance "0") Concrete performance measures
HE_1:Prevent leaking sound **(Use environment)**	In order to avoid making trouble to those around user, product has to reduce the noise from its air horn. **"User friendly noise reduction function" is required according to the customer's situation.**
HE_2:Make easy to move with holding body **(Portability)**	It's possible to listen to music easily while walking, even running. Customers require lightweight body which is **less than 100g.**
HE_3 : Reasonable cost of portable music player **(Economical efficiency)**	Customers want reasonable price. At least **less than 30,000 yen** is required.

Figure 23: Each "Acceptable Level (AL)" for each "HE" about "Portable multi-player (memory-type)".

As both Fig 22 and 23 indicate, both "DL" and "AL" are not fixed level. That is to say, these levels change in response to changes in the social environment. We calculated each "Ideality Index" for three types of Walkman (See Fig24) based on New "DL" and "AL" (See Fig22 and 23)according to the procedure of proposed "D-MM".

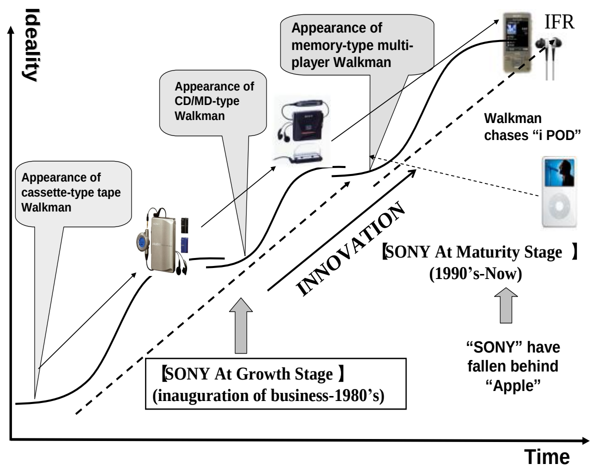

Figure 24: The positions based on the S-curve about three types of Walkman.

We show the final result of evaluations based on new "DL" and" AL" regarding three types of Walkman. Figure 25 shows Ideality Index about three types of Walkman.

Estimation of "Ideality Index" for each "Product"

	ΣUF *Total score*	*ΣHE* *Total score*	Ideality Index
"Desiring Level"	1.000	1.000	1.000
Product 5th G	0.453	2.833	0.160
MD-type	0.339	1.770	0.191
Memory-type	**1.930**	**0.682**	**2.830**

Figure 25: Ideality Index about three types of Walkman.

Based on S-curve analysis, we want to show the result of evaluations (Ideality Index) about "new three types of Walkman (See Fig26)". As Fig26 indicates, when new S-cure appears, not only "DL" but also "AL" usually changes in response to changes in the social environment.

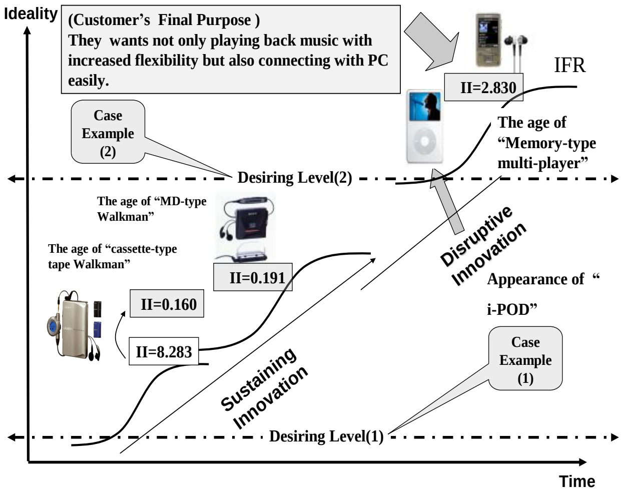

Figure 26: Ideality Index about new three types of Walkman.

6 SUMMARY

First result of Ideality Index table (See.Fig.20) clearly shows that "5th Generation Walkman" must be the most attractive "portable music player" for customers in 1980's.

In the meantime, as second result of Ideality index table indicates (See. Fig.25), "5th Generation Walkman" rapidly changes from the most attractive position ("II"=8,283) to the worst one ("II"=0.160) because of paradigm shift made possible by IT Revolution. Customers in 2000's need huge memory to makes a record of enormous quantity of data from PC easily. That is, their fundamental requirement shifted from "portable music player" to "portable multi-player". Therefore, engineer's task focusing on new product activities lies in improving product's Ideality with predicting both near future's advance technology and paradigm shift of society. In other word, they always have to chase their "IFR" with putting oneself in the position of near future's customers. Therefore, I'd like to emphasize the importance of "II" calculated through the proposed "D-MM". To be concrete, if not only engineers with new product activities but TRIZ practitioners utilize this model, it's possible for them to predict the most valuable "DP" (alternative) quantitatively before preceding the production stage. Finding out the most valuable" DP" (which on the TRIZ-oriented thinking corresponds to the highest "II") more than "II=1" (it means passing grade of "II"), we could possibly solve the serious "Contradictions" before appearance in front of us in real field. In fact, "Product 3rd G" shown in Fig.6 was evaluated as highly-valued idea in 1980's because of the solution to a contradiction in "stronger power of motor vs. smaller size of body"[6]. I suggest that TRIZ practitioners utilize the proposed "D-MM" when predict the most valuable "near future's product in your field" through TRIZ activities.

List of abbreviation

Abbreviation	Long title
D-MM	Decision- Making Model
ETII	Evolution Towords Inceased Ideality
UF	Useful Function
HE	Harmful Function
DP	Design Proposal
AHP	Analytic Hierarchy Process
HEC	High-End Customer
II	Ideality Index
HSD	Hierarchy Structure Diagrams
DMU	Decision- Maker Unit
DL	Desiring Level
AL	Acceptable Level
TS	Total Score

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An Eco-friendly Design of Electrical Discharge Machine (E-EDM) Using TRIZ Approach

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Abstract

Electrical Discharge Machine (EDM) is one of the non-traditional machining processes. EDM process is based on thermoelectric energy between the work and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporization. The electrode and the work piece must have an electrical conductivity in order to generate the spark. Dielectric fluid acts as a spark conductor, concentrating the energy to a very narrow region. There are various types of products can be produced and finished using EDM such as Moulds, Dies, Parts of Aerodynamics, Automotives and Surgical components. This research work reveals how an Eco friendly EDM (E-EDM) can be modelled to replace die electric fluid and introducing ionized oxygen in to EDM to eliminate harmful effects generated while machining by using dielectric fluid and to make pollution free machining environment through a new design of E-EDM using TRIZ (a Russian acronym for Theory of Inventive Problem Solving) approach, since Eco friendly design is the need of the hour.

Key words

EDM, Die Electric, Ionized Oxygen, Model, Eco Friendly, TRIZ

1 INTRODUCTION TO ELECTRIC DISCHARGE MACHINING (EDM)

In 1770, the English scientist, Priestley, first detected the erosive effect of electrical discharges on metals. More recently, during research (to eliminate erosive effects on electrical contacts) the soviet scientists, Lazarenko and Lazarenko, decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943, they announced the construction of the first spark erosion machining. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and an improved form is being used in many current application[1].

The EDM process can be compared with the conventional cutting process, except that in this case, a suitably shaped tool electrode, with a precision controlled feed movement is employed in place of the cutting tool and the cutting energy is provided by means of short duration electrical impulses.

EDM has found ready application in the machining of hard metals or alloys (necessarily electrically conductive) which cannot be machined easily by conventional methods. It thus plays a major role in the machining of dies, tools, etc., made of tungsten carbides, stellites or hard steels. Alloys used in the aeronautics industry, for example, hastalloy, nimonic, etc., could also be machined conveniently by this process. EDM is also used to machining of exotic materials, refractory metals and hard enable steels. This process has an added advantage of being capable of machining complicated components and making intricate shapes. Most of the surgical components (we all know how well the Surface Quality(SQ) is required, must for surgical components) are being machined by this process since EDM is one of the unconventional processes which can produce better surface quality.

1.1 Fundamentals of Electric Discharge Machining

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece. Thus, a replica of the tool surface shape is formed on the work piece as shown in figure 1. If the tool is held stationary, machining would stop at this stage. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the work piece.

The schematic of an EDM machine tool is shown in figure 2.The tool and the work piece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the work piece is generally provided for maintaining a constant gap distance between the tool and the work piece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the work piece, the tool is moved downward towards the work piece to maintain a constant inter-electrode gap. The tool and the work piece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap. Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the work piece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300 cubic mm/min can be achieved during EDM. The surface finish (Ra value) can be as high as 50 µm during rough machining and even less than 1 µm during finishing.

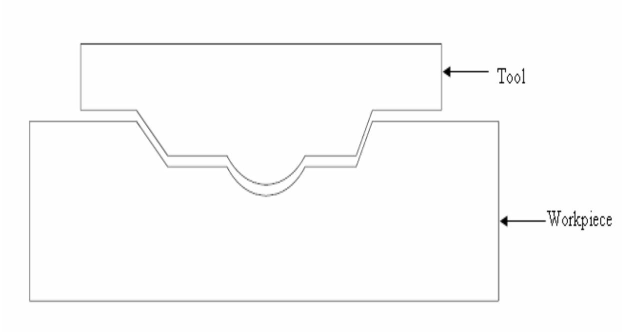

Figure 1: Tool shape and corresponding cavity formed on work piece after EDM Operation.

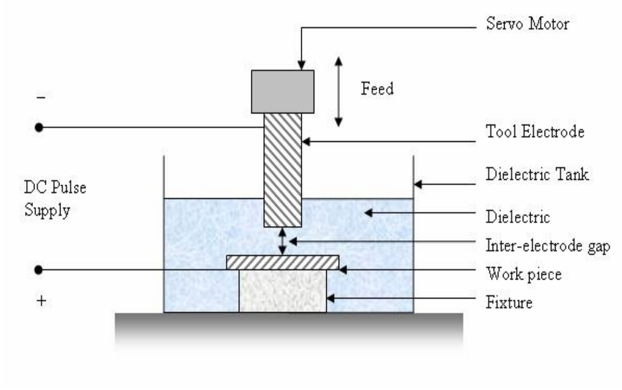

Figure2: Schematic of an Electric Discharge Machining (EDM) machine tool.

1.2 Limitations of EDM

There are quite a number of problems still to be solved to enable the process to be adopted on an extensive process:

1. Lower Material Removal Rate (MRR) , Poor Surface Quality(SQ) are the real time EDM process limitations. In other words, maximizing the MRR, minimizing the surface roughness value [9] are the real time EDM process objectives.
2. The wear rate on the electrode is considerably higher. Sometimes it may be necessary to use more than one electrode to finish the job.
3. The work piece should be electrically conductive to be machined.
4. The energy required for the operation is more than that of the conventional process and hence will be more expensive.
5. Environmental concerns associated with the process have been a major drawback of EDM. The dielectric fluid used in EDM is the primary source of pollution from the process. Hydrocarbon based oils are the most commonly used EDM dielectric. Dielectric wastes generated after machining are very toxic and cannot be recycled. Also, toxic fumes are generated due to high temperature chemical breakdown of dielectric during machining. The use of oil as the dielectric fluid also makes it necessary to take extra precaution to prevent fire hazards. Since an environment friendly alternative for replacing the EDM process is not available, changing or totally eliminating the liquid dielectric medium provides a feasible solution.
6. The ignition of spark discharge in a contaminated die electric fluid is another real time process limitation since contamination of the dielectric fluid will affect machining accuracy. To start with, the die electric is fresh, that is, it should be free from eroded particles, since eroded particles from the work piece contaminates the die electric fluid. The die electric should be filtered before reuse so that the contamination of the die electric will not affect machining accuracy [1].
7. The pollution caused by the use of liquid dielectric which leads to production of vapour during machining [2].

2 CURRENT RESEARCH TRENDS IN EDM DEVELOPMENT

There are two kinds of research trends are carried out by present researchers as for as EDM is concern. One is called Modelling technique and other one is called Novel technique [2]. Modelling technique deals with Mathematical modelling, Artificial Intelligence and Optimization techniques like Regression analysis, Artificial neural network, Genetic algorithm etc., respectively are used to validate the efforts of input parameters on output parameters since EDM is a complicated process of more controllable input parameters like machining depth, tool radius, pulse on time, pulse off time, discharge current, orbital radius, radial step, offset depth and output parameters like Material Removal Rate (MRR) and Surface Quality(SQ)[2]. Novel techniques deals how other (unconventional) machining principle such as ultrasonic can be incorporated into EDM to improve efficiency of machining process by get better material removal rate, surface quality. Novel techniques have been introduced in EDM research since 1996 [2]. This research work is a revelation to introduce TRIZ in EDM novel research trend.

3 PROBLEM CONTEXT OF EDM RESEARCH

To increase the machining efficiency of Electrical Discharge Machining (EDM) in terms of improving the Material Removal Rate (MRR).

3.1 Discussion of Problem

This is an excellent example of a non-trivial (and hence interesting) problem. There is a desirable output characteristic that we need (in this case material removal rate) that unfortunately appears to be associated with something costly or unwanted (in this case, increase in machining time). In the language of TRIZ it is called a technical contradiction [10]. As we try to improve one parameter (material removal rate) the other (machining time) becomes worse, and vice versa.

3.2 Tackling the Problem

In this case, it has been decided to use one of the classic tools from the TRIZ toolkit for solving technical contradictions: The Contradiction Matrix [11]. To resolving contradictions, the method is a three-step systematic process [11]:

Step 1: Identify the contradiction(s) in the problem, and classify them according to the nature of the contradictory system parameters.

Step 2: From the TRIZ toolkit, use a statistically derived look-up table (the Contradiction Matrix) to determine which generic Inventive Principles have been successfully used in the past to resolve contradictions.

Step 3: Take the generic Inventive Principles suggested in Step 2 and interpret/apply them to the problem to be solved. Though this final step it is possible to generate not just one possible solution, by usually a surprisingly large set of candidate conceptual solutions.

Step 1: Identifying the Contradiction(s)

It is necessary to map the specific problem parameters (material removal rate and machining time) onto the generic parameters used by the Contradiction Matrix. In this particular case, an appropriate mapping was arrived as:

Parameter 26 = Amount of substance matched well with Material Removal Rate (MRR)

Parameter 25 = Loss of time matched well with Increase in Machining Time

The full description of each of this parameters is given below [11]:

Parameter 26 - Amount of substance: The number or amount of a system's materials, substances, parts or subsystems which might be changed fully or partially, permanently or temporarily.

Parameter 25 - Loss of time: Time is the duration of an activity. Improving the loss of time means reducing the time taken for the activity. Cycle time reduction is a common term.

Step 2: Using Contradiction Matrix

The Contradiction Matrix is based upon a statistical analysis of a very large number of existing patents. The matrix maps the inventive principles according to the generic contradictions (defined by opposing engineering parameters) that were most frequently solved by them. This contradiction is used with the Contradiction Matrix to obtain suggested Inventive Principles.

Contradiction to improve the Amount of substance i.e. Material Removal Rate (MRR)

Improving Parameter	Amount of substance (MRR)
Worsening Parameter	Loss of time (Increase in machining time)

These two parameters are used to cross-index the Contradiction Matrix to obtain the following four Inventive Principles that (statistically) have been found to be the most successful ways of obtaining better material removal rate without more machining time.

Step 3: Inventive Principles

The following inventive principles are suggested by contradiction matrix between the parameters Amount of substance and Loss of time.

# 18 Mechanical vibration	# 38 Strong oxidants
# 35 Parameter Change	#16 Partial or excessive action

3.3 Application of suggested inventive principle(s)

Having derived some suggested Inventive Principles, to apply the principles to this particular problem. This is the part of a recurring theme in TRIZ that the sequence follows a chain like Specific Problem-General Problem - General Solution-Specialized Solution to Specific Problem. The next step is, to understand the suggested inventive principles to appreciate the full definition of each principle before attempting to apply it. In this case, the suggested four generic principles' definitions with some examples are given below for better reference to understand, validate the research findings and to propose a new design.

- Principle 18: Mechanical vibration

A. Cause an object to Oscillate or Vibrate.

B. Increase its frequency even up to the Ultrasonic. (E.g. distribute powder with vibration)

C. Use an object's resonant frequency.

D. Use piezoelectric vibrators instead of mechanical ones.

E. Use combined ultrasonic and electromagnetic field oscillations.

- Principle 38: Strong Oxidants

A. Replace common air with Oxygen - Enriched air.

B. Replace enriched air with pure Oxygen.

C. Expose air or oxygen to ionizing radiation.

D. Use ionized oxygen (E.g. ionize air to trap pollutants in an air cleaner).

E. Replace ozonized (or ionized) oxygen with ozone (E.g. Speed up chemical reaction by ionizing the gas before use).

- Principle 16: Partial or Excessive Action (Application of Principle 3 and 9)

A. Change an object's structure

B. Make each part of an object function in condition most suitable or its operation.

C. Make each part of an object fulfil a different and useful function (E.g. Multi function tool).

D. Replace with anti- actions to control harmful effects (E.g. Buffer the solution to prevent harm from extreme of PH).

E. Create beforehand stresses in an object to oppose undesirable working stresses.

- Principle 35: Parameter Change

A. Change an object's physical state.

B. Change the concentration or consistency.

C. Change the degree of flexibility.

D. Change the temperature.

At this point in the problem solving process, appropriate problem and technological domain knowledge is important. The final solution derived from these principles were used to validate the previous research findings and to justify how well this novel approach TRIZ can be used in emerging engineering and technological research domain to reduce the research time, cost and to give right direction, solution to research.

4 VALIDATION OF TRIZ WITH EXPERIMENTAL RESEARCH FINDINGS ON FOLLOWING SUGGESTED MATRIX PRINCIPLES

- Principle # 18: Mechanical Vibration

Rajurkar [3] has indicated some future trends activities in EDM machining on advanced materials, mirror surface finish using Powder Additives and introduction of Ultrasonic Vibration to the electrode is one of the methods used to expand the application of EDM and to improve the machining performance on difficult to machine materials.

Guo et al. [4] has proposed the higher efficiency gained by the employment of Ultrasonic Vibration is mainly attributed to the improvement in die electric circulation which facilitates the debris removal and creation of large pressure change between the electrode and the work piece, as an enhancement of molten metal ejection from the surface of the work piece.

Ogawa et al [5] proved that the depth of micro holes by EDM with Ultrasonic Vibration becomes about two times as without ultrasonic vibration and machining rate increased.

Kunieda et al [6] introduced an improvement of dry EDM characteristics using Piezoelectric Actuators to help in controlling the gap length to elucidate the effects of the piezoelectric actuator an EDM performance simulator developed to evaluate the machining stability and MRR of dry EDM.

- Principle # 16 Partial or Excessive action

This principle is an application of Principle #03 Local Quality and Principle #09 Preliminary Anti-Action.

Principle # 3 suggests change an object structure, Q. H. Zhang et al[8] has proved this suggested principle by introducing an investigation of Ultrasonic-Assisted Electrical Discharge Machining in gas with thin walled pipe electrode i.e. Tube Electrode.

Principle #9 suggests that do an action with harmful effects, for example, buffer a solution to prevent harm. Q. H. Zhang et al [8] has proved and validated this suggested principle by introducing gas in Ultrasonic Electrical Discharge Machining (UEDM) by avoiding using dielectric fluid.

- Principle # 35 Parameter Change

Zhang et al. [7] studied the ultrasonic EDM in gas. The gas is applied through the internal hole of a Thin Walled Pipe Electrode.

5 NEW DESIGN OF E-EDM USING TRIZ FOR BETTER MATERIAL REMOVAL RATE (MRR) IN EDM

Principle # 38 Strong Oxidants suggests replace common air with Oxygen - Enriched air, Replace enriched air with pure Oxygen, Expose air or oxygen to ionizing radiation, Use ionized oxygen, ozonized (or ionized) oxygen with ozone, e.g. speed up chemical reaction by ionizing the gas before use.

As per the principle # 38 recommendation, we propose a new design E-EDM by introducing ionized, ozonized oxygen into EDM process by replacing die electric fluid from the existing EDM process, since EDM current research already started introducing dry EDM (i.e. introducing gas medium) by removing dielectric fluid, it validates our findings that dielectric can be eliminated from the existing design of EDM. As per our team's recommendation that by introducing ionized, ozonized oxygen into EDM by eliminating die electric fluid, it can speed up material removal rate at the cost of introducing an eco friendly design of EDM. Since the principle # 38, recommends both ionized and ozonized oxygen.

The following research literatures, statements have been found and the same validate our recommendations in terms of implementing in real time EDM design with respect to ionization and ozonization. The following findings on ionization and ozonization were presented below in detail for better understanding. Schematic of new experimental design of E-EDM using TRIZ is shown in figure 3.

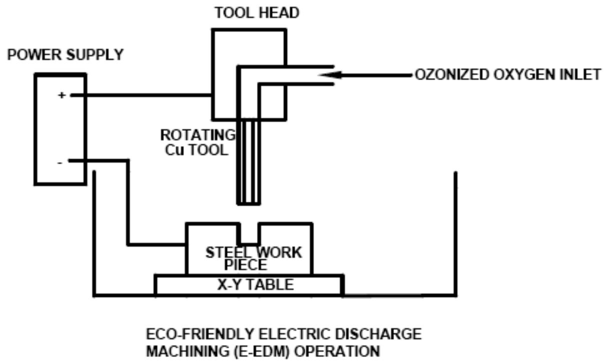

Figure 3: New experimental design of E-EDM using TRIZ.

5.1 Advantages of ionization in new design of E-EDM

Ionization is part of a healthy atmosphere. It is one of nature's tools for maintaining and cleaning the air. Ionized gas molecules make up more than a very small percentage of the atmosphere. However, despite their small numbers, these molecules play a profound role in maintaining the health of the atmosphere by removing particulate and chemical pollutants. In the indoor environment, ionization provides an even wider spectrum of benefits, including the destruction of bacteria and elimination of odors. In particular, negative ionization has the effect of cleaning the atmosphere by removing particulate and chemical pollutants. Ionized gas molecules will help eliminate chemical and particulate pollutants from the indoor air, however, the greater the volume of pollutants the more the ionization is reduced [11-13]. Negative ionization is generally considered to be beneficial, positive air ions appear to cause harmful effects. The acceptable minimum concentration of negative ions for indoor air is 200-300 ions per cubic cm. The optimal level is 1000-1500 negative ions per cubic cm.

5.2 Advantages of ozonization in new design of E-EDM

In term of introducing ozonized oxygen, the new design will have the following eco friendly advantages. Ozonized oxygen is nothing but a molecule composed of three oxygen atoms, it is highly reactive state of oxygen and Ozone degrades to oxygen and only oxygen. Ozone (O3) is a high energy form of oxygen, so it is quite ready to revert to the lower energy, more stable form of molecular oxygen (O2).Once the oxygen atoms are ionized, they enter into a series of very rapid reactions, including re combinations with electrons to become neutral species again. They do not "remain ionized" much at all. But there is a continuing pool of ionized oxygen atoms because new ones are being formed all the time.

5.3 Environmental acceptability and safety of introducing ozonized oxygen

Ozonization is proven technology that has been used for years in the industrial purpose like food, waste water purification, process industry and in many engineering applications. No harmful residuals are reported that should be treated or removed. Ozonization also increases the amount of dissolved oxygen, which is a benefit in many industrial applications. It is also a greenhouse gas. Recommendations on the usage of ozonized oxygen based on safety at normal atmospheric conditions are discussed here. As far as EDM design utilization is concern, the entire machine unit will be kept under closed environment with at most safety [14-15]. In case of manual interventions needed during machining process for process parameter selection, the following guidelines may be taken into account .According to Andersen et al. (2001), the Permissible Exposure Level (PEL) or time weighted concentration for ozone to which workers may be exposed is an average of 0.1 ppm (parts per million) over 8 hours and 5 days a week. The short-term exposure limit is an average of 0.3 ppm over 15 minutes. A concentration of 10 ppm in the air is generally accepted as immediately dangerous to life or Health. When setting the threshold limit for ozone, the vital issues are the effects of ozone towards the respiratory ducts and lungs. The health protection threshold limit for 8hours according to the EY Directive 92/72/EEC is 0.055 ppm (EY, 1992). The detrimental effects of ozone may occur if the concentration in the air exceeds 0.05 ppm in exposure over eight hours and 0.2 ppm in exposure over 15 minutes (FIOH, 2001).By the Degree on Concentrations Known to be Hazardous (109/2005), the Ministry of Social Affairs and Health in Finland has confirmed a list of concentrations of impurities in workplace air known to be hazardous Human Toxic Potential (i.e. HTP values). The HTP values for ozone has been defined as 0.05 ppm (0.1 mg/m3) in exposure over eight hours and 0.2 ppm (0.4 mg/m3) in exposure over 15 minutes. In human health risk assessment, Environmental Protection Agency (EPA) assigns a health risk to every hourly average concentration above 0.04 ppm. The Occupational Safety and Health Administration (OSHA) in the U.S.A has determined the maximum ozone concentration levels in the atmosphere of work places to 0.1 ppm in exposure over eight hours and 0.05 ppm over a 24 h exposure. U.S.A EPA believes that natural background levels of ozone range from 0.03 to 0.05 ppm

5.4 **Added Advantages of new design E EDM**

Added Advantages of new design E EDM are:

1. Flushing is not required to circulate liquid die electric since die electric is replaced by ionized oxygen.
1. It is a power saving new EDM design since die electric circulating pump, filter have been removed from the circuit.

5.5 **Limitations of new design E EDM are:**

Limitations of new design E EDM are:

1. Ozone is unstable at atmospheric pressure and thus it must be generated onsite, this may cause on increase in investment and it is toxic in high concentrations which should be taken care with at most care.
2. The limitation on toxic in concentration may be overcome by adhering strict guidelines issued by OSHA and EPA.

6 CONCLUSION

This research work reveals how TRIZ has been used in EDM novel research to overcome the limitations of existing EDM process and to a new design of Eco friendly Electrical Discharge Machine. TRIZ is a vibrant tool in all means with its powerful search features and offers maximum results with minimal effort. As EDM novel research is concern, works have been started during 1996 and till research continues on improving the machining performance. In this work, using TRIZ, how novelty in EDM research could be achieved with maximum results with minimal effort through a new design of E-EDM. This novel tool can be used to extend in EDM research further.

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Educational Papers

Building New Bridges – TRIZ Tools for Approaching the Science Fiction Text

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Abstract
The article sums up the results of a greater endeavour to apply to the science fiction text the basic principles of TRIZ and the ARIZ instruments enriched with the OTSM strategies for dealing with products of the imagination. They can all be used to critically approach the literary text, while Altshuller's own ventures in the domain of science fiction offer a good starting point for evaluating the quality of the fantastic ideas and revealing their sources. Thus, the method of analysis is in itself an imaginative exploration and expands the mind preparing it for future confrontations just like the object of its study does.

Keywords
Literary Criticism, Science Fiction, TRIZ/OTSM, ARIZ Instruments

1 INTRODUCTION

Today's society is suffering from the plague of narrow specialization. While classical science has reached its limits – it is no longer universally valid and, as such, it can no longer pretend to offer a complete knowledge of the world – however, it leaves little room for the Third Culture, so optimistically prophesized, by C.P.Snow in 1963, to close the communication gap between the two groups: the literary intellectuals and the scientists. TRIZ, as a cross-disciplinary methodology, may appear to be the missing link.

2 SCIENCE FICTION LITERATURE AND TRIZ

2.1 Why new tools for criticism are necessary

Nowadays, to a much greater extent than in the past, science is closely connected with culture. Prigogine and Stengers [1] assert that "today's science can no longer arrogate to itself the right to deny the pertinence and the interest of other points of view, and especially to refuse to take into account the points of view expressed by humanistic sciences, by philosophy, by art." But this functions both ways: the literary critic will find scientific truth relevant to his/her analysis of the literary text, especially in the case of science fiction literature, otherwise the truths that science fiction expounds about the human condition become disordered metaphors, irrelevant to our universe. The researcher will therefore be endowed with an interdisciplinary and transdisciplinary vision and attitude which involve "thinking, and inside experience, and knowledge, and consciousness, and awareness, and effectiveness, and affectivity" and opens the possibility of finding innumerable connections between the "different cultures that represent the different aspects of the Human" [2]. One of them, as proposed here, is a transfer of the methods and tools used within the science of inventions, TRIZ, and its later development OTSM, to the study of literature.

It took science fiction literature a long time to change its status and to pervade the mainstream but once it did the necessity to critically approach it increased. One of the problems connected with science fiction and its criticism is that its poorest examples were always used by critics to attack the genre. In Malzberg's [3] words: "A lousy western is a lousy western, a seriously intentioned novel that falls apart is a disaster … but a science fiction novel that fails illuminates the inadequacy of the genre, the hollowness of the fantastic vision, the banality of the sci-fi writer." A strong point of the method proposed is that, while one certain work can fail in its attempt to give a pertaining view of the society it describes, or is weak in depicting relationships between human/non-human characters (a weakness always associated with the genre), it can still exhibit virtues when it comes to measuring the imagination involved in the creation of its science fiction devices or the quality of the solutions found for solving the contradictions underlying its plot line, and this is where TRIZ tools prove invaluable. The role of the critic is not reduced to applying censure or inducing blame and the work flawed with imperfections is as worthy of critical judgment as the one exhibiting the greatest originality or technical excellence.

In the case of science fiction however, the old tools do not seem to be either appropriate or enough. Russ [4] observes that "not only do academic critics find themselves imprisoned by habitual (and unreflecting) condescension in dealing with this particular genre; quite often their critical tools, however finely honed, are simply not applicable to a body of work that – despite its superficial resemblance to realistic or naturalistic twentieth-century fiction – is fundamentally a drastically different form of literary art." Later in the same article she asks herself: "How can a criticism developed to treat a post-medieval literature of individual destinies, secular concerns, and the representation of what is (rather than what might be) illuminate science fiction?" and she concludes with words which are very important for one further justification of the necessity to consider TRIZ/OTSM as a source of viable tool for science fiction analysis: "Without knowledge of or appreciation of the 'theology' of science fiction – that is, science – what kind of criticism will be practised on particular science fiction works?" Russ thus articulates the same necessity of a view pertaining to both the values of science and literature as Prigogine above, and this is one of the major assets of the method presented: TRIZ, while originally devised for technology and therefore closely related to science, later, through OTSM and its formulation of universal axioms and postulates, extended to other domains and became a pertinent tool for both technical and humanistic breakthroughs. It can deal with products originating in both sides of the brain alike and see them as dynamic process.

2.2 Altshuller's illustration of his own concepts

In the Preface to his book *Creativity as an Exact Science*, Altshuller [5] remarks that the idea of controlling a particular process (whether thermonuclear energy, genetic engineering, the movement of the stars or rainfall) does not really astonish anyone, the possibility of achieving any such thing being considered just a matter of time. "Yet only the idea of controlling the process of creativity as a rule encounters hefty resistance."

Aware of the necessity of developing imagination in engineers and writers alike, Altshuller started CID (Creative Imagination Development) classes and strongly advised the participants to his course to read science fiction literature because there they could find the strongest and most daring fantastic ideas. During the courses, several tools were born that are still precious both to the author and the investigator: the Register of Science Fiction Ideas is a fund, which just like the fund of patents, includes more than several thousand ideas; the Scale "Fantasy-2" can be used, as shown below, for the evaluation of fantastic ideas; the Four Floors' Scheme identifies four distinct levels in the evolution of any fantastic theme and thus points out the empty spaces for the writer to exercise his own imagination; the Fantogram, based on TRIZ principles, is the strongest tool for the author who wants to generate singular fantastic ideas, with each of its cells able to produce a new idea. On the other hand, flexibility of the critic's imagination allows for tracing back nearly every fantastic idea from existing science fiction literature to one specific cell of the Fantogram.

Being himself a science fiction writer in a period when it proved difficult for him to find another job, Altshuller contributed a lot to raise the status of this marginalized type of literature and to push it out of the ghetto to which it had long been confined. He was convinced that a qualitative not quantitative difference will cause the change in status. Because of mental inertia people have the tendency to increase what they already have instead of coming up with new fantastic ideas that technology could then implement. Altshuller's short story, "The Donkey Axiom," [6] contains an example of the way in which low level imagination works: "Do you remember how Edgar Allan Poe described the future of air flight? An enormous balloon for two thousand passengers. a most characteristic mistake. We consciously make our predictions quantitatively: we increase what already exists. But we have to foresee what is qualitatively new." And this Altshuller did in technology just as in science fiction literature.

In 1964 Zhuravlyova [7] published a booklet on *The Development of Inventor Fantasy* in which one of the basic assumptions reads: "In SF literature the ideas are 'made' by tools which are similar to those used for the generation of new scientific or technical ideas." What she refers to are TRIZ tools. As shown in [8] Altshuller's stories, as well as Valentina Zhuravlyova's, are an illustration of the belief in the necessity of a new quality and of the Inventive Principles of TRIZ. Some examples are given below.

Altov's (Altshuller's penname) "The Star River Test" [6] contains an unusual idea obtained by superimposing a popular TRIZ technique, the STC Operator, to one of the methods used in the CID courses – Changing the Unalterable. The speed of light, which is a universal constant, is modified, specifically, increased. The scientist in the story is aware that "every physical law is correct only within certain limits," therefore, he has to defeat psychological inertia in order to enlarge those limits.

In Zhuravlyova's "Adventure" [6] Kira Safray, the main character in several of the short stories, comes with the idea of changing another universal constant, gravitation, by using the same method, Changing the Unalterable. She says "Change it: that is increase it or decrease it" and by this she tries to challenge Sergey Gorchackov, a genius in physics who gave up his research work with no apparent reason.

The same story uses the Principle of Separation: Kira Safray, now a psychologist, undertakes a psychological study of Sergey Gorchackov. She has never met him however, she undertakes to solve the puzzle of his intention to give up physics for ever. How she finally does it? Easily: "I just forgot about Gorchackov." But then: "Whoever said that psychology was not an exact science?" This permanent shift between the humanities and technology, happening without any apparent effort, is a dominant characteristic of which one becomes aware both when reading Altshuller's books or working with ARIZ.

The same principle, Separation, appears in another story by Altov [6], "The Donkey Axiom." In it spaceships are envisaged which are separated from their propulsion system, a laser beam directed from the Earth, which also fulfils another objective, that of providing the spacemen with information from the Earth. Thus, Principle 6, Universality that is integration of different functions into one object is demonstrated. Antenna, the main character, also offers an example of the Ideal Final Result obtained by using the STC Operator: "the size of receivers and measurement devices should, in his opinion, tend to zero."

"The Ballad of the Stars" [6] is the most complex short story in the collection and perhaps the most profound. At the same time, it is the best illustration of the STC operator and also of the existence of different types of contradictions to be solved every time a problem appears. The story refers to a period when man has already conquered the outer space and found life on several planets. But during interstellar travels many ships had perished owing to a black corrosive dust that attacked the metal body. Shevtsov, the captain, experiments with increasing and decreasing the speed of the ship which leads to two types of contradictions: sometimes the ship resisted if speed was reduced, but it required months to decelerate from near-light-speeds. Reducing speed increased time. Increasing speed to a maximum reduces time, but also increases the destructive force of the black dust – these are technical contradictions. The physical contradiction is represented by the fact that the ship has to travel slowly not to be destroyed by the black dust but also very fast to save time for the astronauts.

The innovative ideas contained in science fiction works often proved to be the starting point of many inventions. The universal material devised by Antenna in "The Donkey Axiom" is based on Principle 15, Dynamization, and does not contradict any known laws of physics, therefore its implementation is very convincing and it might cause one of the future revolutions in technology. This ferromagnetic material can, within seconds, change its shape and turn into any structure desired by the user – a car, a milling machine or whatever else.

3 INDIVIDUAL TOOLS APPLIED TO TEXT ANALYSIS

A close investigation of the tools of ARIZ and OTSM and the possibilities they offer when it comes to using them as instruments for a critical approach to literary texts shows that individual methods can be applied to undertake complex, whether unilateral approaches, while a combination of tools and shifts in the perspective of the analysis offer additional insight and a great variety of options to the person involved in the exercise. Some examples are illustrated below.

3.1 Isaac Asimov's *Foundation Trilogy* and Frank Herbert's *Dune*

While a traditional comparative approach to Asimov's *Foundation Trilogy* [9] and Frank Herbert's *Dune* [10] would be busy revealing the similarities and/or differences in these two writers' works (there being quite a few examples of both) and evaluating their story-telling abilities, an application of the 40 Inventive Principles, of the Patterns of Evolution of Technical Systems and of the Standard Solutions to the science fiction ideas contained in these works would reveal great differences in the type and quality of the writers' imagination. In Asimov's case a penchant towards a great number of nuclear gimmicks is the only science fiction element in a quite comprehensive trilogy, which is, otherwise, a reproduction of the history of the Roman Empire. While, after almost sixty years, the *Trilogy* still continues to attract an enthusiastic readership, its qualities must be looked for elsewhere since the use of only 29 principles, with an overuse of Principles 6 (*Universality*) and 28 (*Replacement*), are signs of the writer's deficiency in imaginative vision. Herbert, on the other hand, was less interested in individual devices of the nuclear gadget type. The empire he creates and every detail in it are part of a whole which is the result of his fantastic vision.

Such differences between the two authors as to the science fiction ideas exhibited by their works would be surprising without a further application of an analysis of the Resources of the two writers. Since they both come from the same part of the world and were around at the same time to achieve their monumental literary works what can be the justification for such inequalities and, ultimately, even for their completely different world vision? A study of the Resources would firstly reveal a social and economic reason: Asimov published serialized stories in magazines often under pressure from editors with deadlines to meet and payments to be made, while Herbert took his time: eight years to complete his, in fact, never finished masterpiece, novels that started as a result of an ecological project of the government and were written out of an interest in and passion for ecology and problems relating to hero-worship.

But a second reason, even more interesting although less obvious, is that Asimov, whose *Foundation Trilogy* appeared fifteen years earlier than Herbert's *Dune*, is, to a much greater extent than Herbert, a result of the period he lived in. His *Foundation Trilogy* is undoubtedly a work of speculative fiction that was supposed to function largely in the context in and for which it was written. Asimov was a biochemist, a scientist mainly, and the period after the WWII when he started writing was a flourishing time for developments in classical nuclear technology as well as in new branches, such as nuclear fission. A new source of energy had been found, different from the one based on natural fuel whose resources at that moment were publicised as being limited. Experimental progress achieved due to particle accelerators, as well as the involvement of scientists and personalities from the sphere of politics in research connected with nuclear technology, added up to very strong currents of opinion concerning the future of this energy and made it seem a panacea. Under the circumstances, an author with scientific training would inevitably be drawn by psychological inertia towards substituting key elements in the existing systems and subsystems for elements based on nuclear energy. That is the source of Asimov's "nucleics," his household items, his jewellery and weapons but also of the nuclear propulsion system in his spaceships. Asimov did not care too much whether the gadgets he devised corresponded to the systems' evolution towards ideality. Just like the scientists of the time, he ignored the multitude of negative collateral effects associated with the technologies that made use of the new form of available energy: pollution, accident risks, overuse, etc.

These aspects may not be readily obvious to the modern audience who, however, experience a "sense of wonder" when faced with the multiple possibilities of nuclear energy. Herbert, on the other hand, had a humanistic training, he was a full time journalist, and consequently, had different assumptions about science than the ones he saw reflected in Asimov's work. His *Dune* describes a distinctly peculiar galactic empire, he reaches different conclusions as to the outcomes of science and his focus is different, turned toward the myth-making hero and the ones who assist him in this transformation.

Therefore, in his case, an application of two of the major principles in TRIZ, the Resolution of Technical and Physical Contradictions and the Ideal System and Ideal Solution, as well as an observation of the appearance of a Network of Contradictions in the progress of his novel (an OTSM vision), could be much more revealing. ARIZ implicitly uses the principle that all problems must be solved in accordance with specific conditions of the system and using exclusively the resources available in the given situation. Thus the approach should start, as in [11] with a presentation of the specific situation at the beginning of the novel. This would involve: a description of the desert planet Arrakis, also called Dune because of the dunes of sand covering most of its surface, of the gigantic sandworms, dangerous for people but the only source of the invaluable "geriatric spice" and of the Fremen, the inhabitants of the deep desert, the only ones able to cope with the planet's hostility and doomed to wearing "stillsuits" that recycle their own bodies' water; a description of the conflictual situation initiated by the recent relocation to the planet of Duke Leto Atreides; and a review of the forces involved in the story: the conflicting Houses of the Atreides and the Harkonnens, the Bene Gesserit Mothers and their secret plan of a genetic breeding program, the Mentats, human computers used by the Empire to calculate probabilities.

At the very beginning of the novel, Paul Atreides' father, the Duke, is killed and he and his mother are left alone in an environment that is completely new and hostile to them.

When accepting this reversal of his family's situation, Paul, the main character, is thinking of the first thing to be done, *"running like cowards,"* [10] but, in that very moment, he has already built an image of the **ideal result** he wants to reach: not only avenging his father, not only getting his dukedom back, but becoming Emperor of the Known Universe. Is such an early description of the most desirable result utopian? Maybe, but not for Paul who analyzes the **core of the problem** in terms of a contradiction between the objective situation and his wish to avenge his father. What could he do in order to turn the situation in his favour? He chooses what seems to be the **impossible solution** especially since it comes from a fifteen-year-old boy and, from this point onwards, the reader, knowledgeable in TRIZ, follows Herbert as he magnificently builds layer upon layer of specific situations in which opposing forces and heroes interact in magnificently designed complex plots and in which Paul reaches partial solutions, redefines the specific situation and re-evaluates the new resources, looking for other partial solutions in a permanently winding movement, similar to that of the sandworm, forwarding the story and moulding meaning, themes, problems and questions never totally answered, into one big, extraordinarily dynamic whole, until the IFR is achieved. The diagram below represents one starting point for building the network of problems in *Dune*, where:

- 1 = How to avenge his father?
- 2 = How to survive?
- 3 = How to gain back the Ducal power?
- 4 = Flee danger (escape into the desert)
- 5 = Finding the resources for coming back and fighting

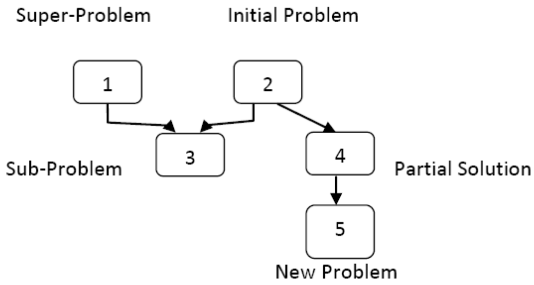

Figure 1: Fragment of the network of contradictions in *Dune* by Frank Herbert.

The tools used with Herbert's work if applied to Asimov's *Trilogy* would clearly show that, while Asimov is unable to handle a lengthy plot, unless he divides it into small lines of action (which would involve building separate networks for each of his chapters), and he is not really a master in creating conflictual situations, these are among Herbert's most valuable strengths. Obviously, the critic can choose his tools depending on the purpose of the demonstration.

3.2 Different tools used for an approach to Philip K.Dick's work

The Su-F Models

As already mentioned, most of the instruments in ARIZ can be used for a critical approach to the science fiction text. While the following examples are very schematic, yet they offer an idea of the kind of analysis that can be engendered.

The Su-F model applied to two of Philip K.Dick's works and the films that they inspired prove to be extraordinarily revealing for determining the complexity of the literary achievements. Following the pattern of technology, the construction of these models or, on the contrary, their destruction, can prove to be beneficial or harmful to the work as a whole. Just as they connect substances and fields, they can connect people and reveal the richness or the lack of emotions involved in their relationships.

Two observations have to be taken into account when constructing the models. One belongs to Semyon Savransky [12]: "The presence of a field always assumes presence of a substance, as it is a source of the field." The other belongs to James Kowalick [13]: "a field comes from an object. There is an object behind every field. And it is often the case that two or more "fields" - as Altshuller defines the word - are associated with a particular function." Therefore, when constructing Su-F models for literary works, "object" should be used in its largest meaning, real or imaginary, animate or inanimate.

In [14] a comparison between Dick's short story "The Minority Report" [15] and Steven Spielberg's film with the same name reveals that, while the rhythm of the short story is too alert to leave space for character and relationship development, with only a few touches, that is, a few Su-F models completed, the film fills in the missing dimensions and constructs round characters with rich personal lives while answering, at the same time, the demands of an electrifying thriller. One example is the introduction in the film of a character that is missing in the short story. This is Anderton's little boy, who was kidnapped. And although he is not a real presence in the film, he can act as a field because he is the "container" of strong feelings on behalf of both his parents. With only one model completed, the possibility is open for a supplementary plotline, for a much more convincing motivation of Anderton's actions, as well as for a better defined relationship between husband and wife. Thus a mostly unexplained bond in the short story gains in complexity and richness in the film.

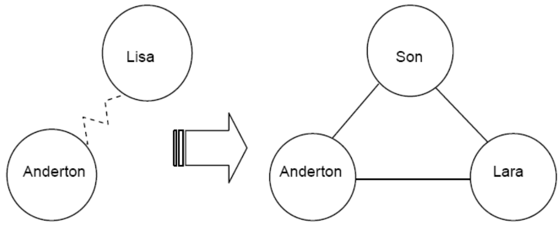

Figure 2: Change from an incomplete Su-F model (in the short story) to a complete Su-F model (in the film).

The opposite situation can also be met. A comparison [14] between Dick's novel *Do Androids Dream of Electric Sheep?* [16] and Ridley Scott's version of it, *Blade Runner,* shows that, by removing almost all the concepts on which the story is built, the deeper level of the film comes to suffer from serious impoverishment. The initial complex model, which uses the basic Su-F model but also the double, dual and chain models, is built around the main character, Rich Deckard, and includes, among others, his job and family relationships, his attraction to the android Rachel, his strongest desire that of owning a live animal, and Mercerism, the religion that is the only link left to connect the people remaining to live on an Earth that is no longer appropriate for hosting life. This model is deconstructed in the film. While the initial model is too complex to be represented here, the one in the film would look as below: the only relationships maintained are those connecting Rick to his job and a harmful and incomplete one representing the human Sebastian's attraction to the android Pris.

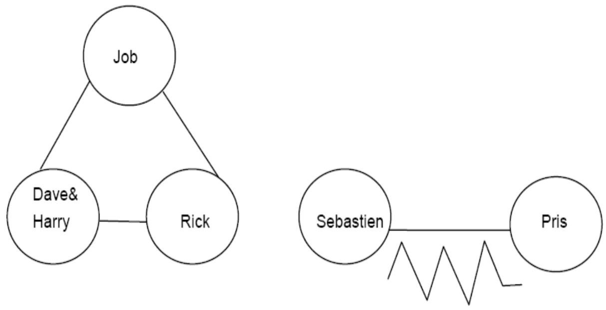

Figure 3: The deconstructed Su-F model in Blade Runner.

The educated cinema goer can still enjoy the open end as well as other remarkable aspects of the film which other TRIZ tools can highlight.

The Multiscreen (OTSM System Operator)

The System Operator, the OTSM version of the Multiscreen, is one of the most valuable tools when approaching a writer such as Dick, who is famous for successfully creating multiple, disintegrating realities. In TRIZ the Multiscreen has three dimensions, Hierarchy, Time and Opposition. OTSM, by adding a fourth dimension, Imagination, with an infinite number of features, allows for mental experiments and interpretations in the fictional domain. A writer with such a manifold vision of the world as Dick, feels at ease shifting between the different levels of the real and the imaginary and a diagram representation can reveal these shifts. The System Operator can be built individually for different novels or for different objects in the reality of the novels.

In [11] the diagrams built for two of Dick's novels, *Time Out of Joint* [17] and *Ubik* [18] reveal not only the two different story lines but also specificities of each novel, such as: the existence of a division in the present dimension of the subsystem (which is explained below by using Separation Principles); a quite uniform covering of the screens in *Time*; and an emphasis on the time continuum and centrifugal dynamism in *Ubik* as opposed to an upward motion in the former novel. A look at the dimension related to Imagination, namely the fictional dimension, reveals striking differences between the two works: while in the first one the imaginary reality almost totally succumbs to Dick's contemporary society, in the second it witnesses a dramatic cavalcade of samples belonging to the so-called "phildickian" effect: reality turns into hallucination and becomes difficult to separate from it, moreover it becomes reversible and demonstrates a perpetual tendency towards shifting.

The Separation Principles

One main difference between Dick's two works is discovered when applying the Separation Principles. In *Time* there is a Separation in Space at work. Ragle Gumm, the protagonist, has to live in the present (to predict the place of future attacks from the Lunars) but he also has to live in the past in order to be able to do his job (the possibility of defining a nice Physical Contradiction opens here). This is explained by the fact that in the present world a nervous breakdown, as well as a change of sides, prevents him from fulfilling his duties. But the time difference is a fake. Thus, the characters simply travel linearly in space from the fake reality they live in to the actual one. While they are surprised to find that they live in a time space which is forty years behind the rest of the world, this time lag exists in their minds only and is part of a gigantic hoax. In fact they live in a different space. In *Ubik* the situation is more Intricate. Here the imaginary reality can be accessed by a departure from real time and space, namely by death. The Separation in both Space and Time was the solution worked out by Dick in order to create the reality of life in death, and the possibility of an afterlife. The agonizing questions tormenting the privileged character, Joe Chip, help the reader accept the possibility of all the characters having died at the very beginning of the novel. But then, is this the truth? One can never expect to find a satisfactory explanation for Dick's breakthrough worlds.

3.3 Some further points

While *Formalists* insisted on the connection between form and content of a literary work, *Structuralists* shifted the attention towards literary systematicity and its analysis, *Marxist* critics disclosed the social roots of literature, the *New Criticism* considered the text nothing else but a work of art, and examples could continue, a critical approach based on the tools of OTSM/TRIZ could cover most of these perspectives and add a unique angle: the possibility of appreciating the writer's strength of imagination and the quality of his/her literary solutions, as well as the ones of the characters.

Some examples are below:

- Altshuller's Scale "Fantasy-2" can be used as a basis for a comparative analysis between several authors and their works which can be assigned distinct values on the scale and thus have a starting point for a more detailed comparative analysis.
- Smart Little People (Agents) can be used to identify the solutions used in the literary work, as well as other possible solutions in an exercise of creative imagination.
- A study of the resources can be made referring not only to the plot line itself but to the author's variety of resources as well, both exemplified in my approach to *Dune*.
- The STC Operator can be used in two directions: by the author to extrapolate from actual science in an exercise of finding new subjects for his artistic creation, or by the critic to go backwards from an extrapolated idea, thus connecting literature to science and to future devices but also concepts. As Palumbo noticed in [19] "Authors' concepts extrapolate from scientific premises" and therefore "informed appreciation of their artistry must recognize those scientific premises from which they extrapolate" and thus we are able to obtain "startling insights into literature's relationship to science, the profound interconnection of concept, form and content."
- The evolution of technical systems can be used to analyse the evolution of the plot line in a certain novel or typical patterns of plot lines can be found in several works. Alexandr Moldaver in Anatomy of a Fiction Plot," (2002) (unfortunately available in Russian only but reviewed by Semyon Savransky [20] as being "one of the most important contributions to the modern theory of fiction after the Propp books,") unveils the internal unity existing between trends of technical evolution and the structure and philosophical essence of literary plots and builds and illustrates seventeen possible circuits.
- The Multiscreen (System Operator), in my opinion the most complex tool for the critic, can be applied to all the specific elements of the literary work, story line (as shown above), historical background, characters, science fiction devices, etc., and by superposition, a composite chart is obtained which can be used for evaluation of the individual work or comparative appraisal.

Again, examples could continue. At the same time, some more advantages of working with such an approach are worth emphasizing: just like when trying to find a technical solution in TRIZ, in this case too, there is no need for the appropriation of a conventional critical jargon and there are no constraints and immutable rules to be respected. The approach to the literary work is independent of socio-political judgements and this gives greater independence to the aesthetic manipulation.

4 SUMMARY

This paper describes the possibilities of a TRIZ/OTSM approach to the science fiction text. At the same time I would like to maintain the following averment: whether used as individual tools or in combination, the methods shown should be seen as strategic devices rather than formalized statements of rules for reading or interpretation. While also being self-sufficient, I would advocate their use alongside other critical appreciations, since the way they could be integrated into an individual methodology has yet to be worked out.

Applying TRIZ/OTSM tools to literary achievements is probably not the ultimate method but still, it offers an invaluable multiplication of the literary critic's perspective. Through this transfer of a method devised for finding technical solutions to the study of literature, TRIZ may, just as science fiction does, bridge the two cultures.

One has to bear in mind the following statement from Altshuller and Zhuravlyova's [6] story, "Ballad of the Stars": "The individual of the future will be both poet and scientist. More exactly, both simultaneously, for the two concepts will join."

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Function Modeling Issues

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Abstract

The paper reviews function modeling and further investigates the Function/Attribute Analysis, according to the Subject-Verb-Object typology. Some difficulties in function modeling arise from time dependencies, subsystem definitions, choosing the verb and number of functions. An attempt is made to describe a more strict formulation of function modeling. An analogy with thermodynamics and systems theory is suggested resulting in new definitions such as function states and process functions, equilibrium of a system, dynamics of changes in a system and irreversibility of functions resolving the former mentioned conflicts. Several laws of evolution provide an additional help to complete the function model.

Keywords

Function Modelling, System Modelling, Thermodynamics, Process Function, Law of Evolution, State Function

1 IN SEARCH FOR THE IDEAL FUNCTION MODEL

The notion of function modelling is one of the most important in TRIZ because it lays at the basis of achieving the Ideal Final Result. A “function” is defined as the effects of a tangible object to change the parameters of another tangible object [1], [2], [5], [24]. The notion of “function” was used by Altshuller in several ways such as representing the main function (used in Su-Field or vepole as it was called in Russia, A Su-field is a minimal, functioning model of a Technical System [17]), as an ideal function in the development of a Technical System and as the purpose of a Technical System (as described in ARIZ 85C 1.1).

The primary function of a Technical System is the reason why the Technical System was designed for mankind. A pen was designed for writing. A car was designed for driving. Ideally the technical system will disappear and the function will be performed by the product/object itself [28]. Ideally the object will no longer have need of a Technical System. This means writing without a pen but leaving a trace on the surface of paper [29]. Using computers could be seen as writing without a pen, but of course the pen was replaced by another Technical System, the computer. Ultimately it would mean that we are able to write without any means unless this function transitions to the super system. The latter means that we no longer need a surface to leave a trace on the paper or the person hasn’t got the need for a paper any more. (Law of Transition of a system to a super system) The function will be inherent in the object.

A Technical system is characterized through the law of completeness [4]. I have added “information” as an extra element in the law of completeness.

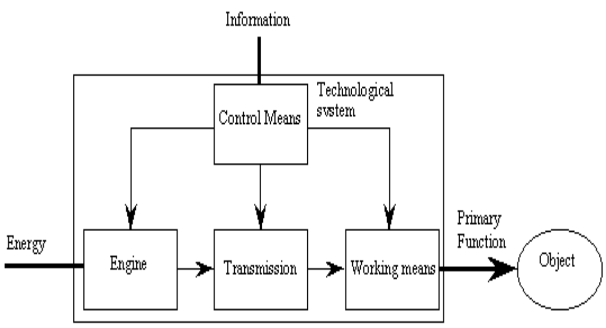


Figure 1: Law of System Completeness [4].

Of course this notion of a function is only an abstracted representation of what the object or Technical System is doing enabling us to describe situations we can repeat and even predict. A system is called complex when the relations between the objects are unknown [16] so function modelling can be used to describe the unknown relations, trying to make “the unknown known”. This can never be correct without proper checks in reality and or with tests accordingly. This is exactly what science is about.

The different roles that a Technical System can play in different environments or super systems, creates a lot of ambiguity in defining functions [1] [3]. A pen for example could also be used to stir the coffee or used to blow darts. This is ambiguity more clear in archaeological finding of a supposed Technical System.

The concept of functions was introduced in Technical Systems by General Electric’s Lawrence Miles, the father of value engineering [22]. It is worth mentioning that in the beginning of VAVE the ladder of abstraction was used [7].

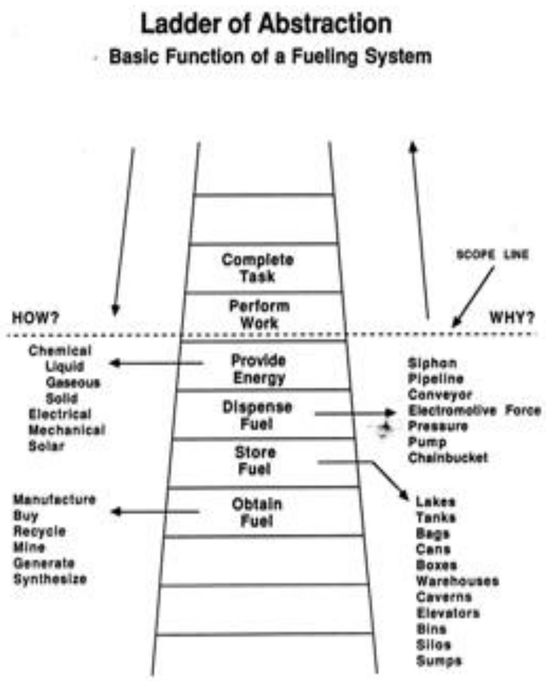


Figure 2: Ladder of abstraction [20].

Climbing up the ladder means asking the "why" question and moving down means asking the "how" question. A similar technique was developed by De Bono called "Concept Fan" [8] [13].

This jumping back and forth between can be considered as a creative process in which moving is more important than evaluating the alternatives.

Building further on the work of Miles, Charles Bytheway developed the concept of function models in 1965. The technique Bytheway developed was called Function Analysis System Technique or FAST [6]. In building a FAST model, the engineer asks how, when and why things happen in a system looking like the ladder of abstraction but tilted 90°. Bytheway liked the idea of function modelling but was bothered with the difficulty of getting an agreement on the basic function of an assembly or product. In 1975 a five day seminar between seven value specialists was held to discuss function modelling. This resulted in two types of FAST. One developed by Ruggles called Technical Oriented FAST and another called Task Oriented FAST as developed by Snodgrass. [20]

A function tree also used in VAVE tries to describe the several levels of dependencies as the example in an overhead projector shows in figure 3.

Originating from VAVE in the early 1980's S. Litvin, V. Gerassimov, B. Zlotin and others acting as engineering managers gradually used and improved function modelling often called Function Cost Analysis while learning TRIZ from Altshuller. [6] [30] [31]

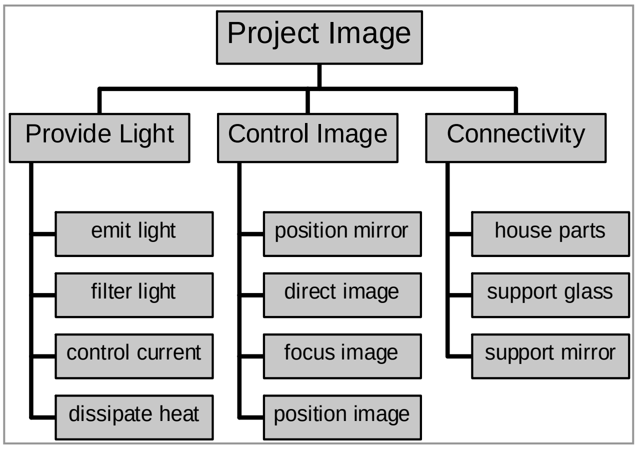


Figure 3: Functional tree.

Malkin et al introduced useful and harmful functions into function models [6]. The use of harmful functions makes it possible to use the function model to identify three basic ways to improve system performance: improve useful functions, reduce harmful functions and resolve contradictions between useful and harmful functions. This is basically a cause and effect analysis approach which has been perfected, patented and implemented in the Innovation Workbench software [15] on the one hand and Goldratt [9] [16] on the other hand.

The problem formulator shows four types of arrows: providing something (->, green), eliminating something bad (->, red), causing something bad (-/->,red) or hindering something good (-/->, green). These 4 arrows are shown in figure 4.

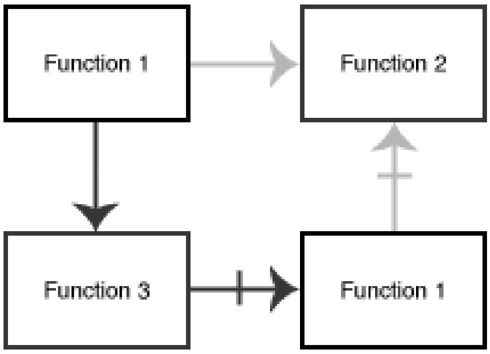


Figure 4: Functional Model from Ideation [15].

This type of function modelling reveals cause and effect in a system. These cause and effect function models are more functional models. They explain step by step what happens to the system or subsystem and evaluate (good or bad) the transition from step one to two.

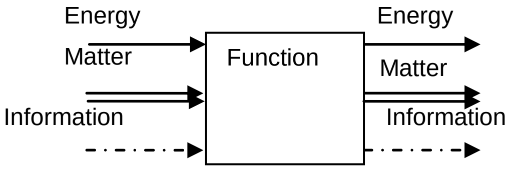


Figure 5: Flow model.

A distinct other representation of a technical system is based on flow of energy, matter and information (or signal) as seen in figure 5 [10] [11] [12] [27]. The arrows represent the flow of energy, matter and information. This is why I added information on the law of completeness earlier.

A Technical System can be represented by energy or fields (as in Su-Field), by function as in function modelling but also through information.

A function is here defined as a general and desired input/output relationship of a system with the purpose to perform a task. For static processes it is enough to determine the inputs and outputs; for dynamic processes (processes changing with time), the task must be defined further by a description of the initial and final magnitudes as well as all relevant magnitudes within the considered time span.

I will not go into the function models mentioned so far and focus on a specific way of function modelling characterised by the Subject-Verb-Object typology.

2 THE NOTION OF DEFINING FUNCTIONS IN A SVO WAY

Similar models were created based on the Subject-Verb-Object typology dating back to Larry Miles and TRIZ implemented by Invention Machine [14], Darrell Mann [13] and Alex Pinyayev [24].

Larry Miles used the phrase "what does the object do" to find the function being performed by the system. He suggested using "verbs and nouns". So another way of finding the function of an object is putting it in a sentence like "SUBJECT does VERB with OBJECT". For instance "PEN does LAYING ON with TABLE" or the "pen lies on the table". This approach is called the Subject verb Object typology and is also known in linguistics.

At first Larry Miles distinguished 2 types of function e.g. aesthetic functions and use functions. An aesthetic function were the elements of cost which are the purpose of pleasing the buyer through color, shape of feature, causing him to buy. The use functions are the costs that are required to cause the product to perform a use which the buyer wants and wants to pay for. Since the main goal in VAVE is decreasing cost it is logical that the functions were allocated with costs. Later on second degree functions were defined. These are functions necessary in order to cause the designers choice for means of accomplishing the basic function effectively. In production we could make the distinction between processes delivering the basic functions and second degree functions installed to reduce the time and improve the quality of the basic functions. For instance a gear wheel is not grinded at once. First it is milled speeding up the time for grinding afterwards. The choice of milling is done by the process engineer, the choice of grinding by the customer.

Adding harmful to functions was a big step in function modelling [6]. However it is subjective. Several other types of functions have been defined since.

Valeri Souchkov added insufficient, excessive and uncontrolled functions to the whole spectrum of function modelling [25]. Most function modelling is done to describe an issue, e.g. through the conflict between a "useful" function and a "harmful" function in an operational area [24]. This colouring is very subjective and depending on the problem. G. Yezersky & G. Frenklach proposed to consider a *neutral function* (NF) as opposed to harmful and useful [22].

3 THOUGHTS ON SYSTEM MODELING

The systematic study of technical systems and their system functions are considered the foundation of TRIZ [22]. I believe that function modelling is system modelling.

In analogy to Thermodynamics I would like to use the terms: state, irreversible processes, dynamic equilibrium. These terms will help to solve some difficulties in function modelling.

3.1 A system and Technical System

A system consists of objects (subjects), attributes and functions working together to perform a system function that is acting to the super system. It possesses behaviours and properties that cannot be reduced to the behaviours and properties of its separate subsystems. Altshuller said that the wing of an airplane doesn't fly. Nor does the motor, hull, cockpit, pilot. But together they do. This is a system delivering the function of flaying. Yet if the wing didn't have the light weight and specific shape, if the engine wouldn't provide enough power, if the pilot would know what to do: the plane would not fly. All the parts have specific functions with material and or function attributes. This statement is true for technical object and not for organic objects. A set of bones, meat, muscles, nerves and brain will not make a person.

If there was no air or pilot, which I would consider objects of the super system, the plane would not fly too. A super system contains those objects or systems that cannot be changed.

A technical system is a system that is characterized by the laws of system completeness, "energy conductance" and of rhythm coordination [29].

3.2 A system consists of objects

A single object without a relation to another object doesn't exist. What is the meaning of a pen without paper or a person to write with it? This means there is always at least one relation between an object and its surrounding. Even every word is connected through other words in a dictionary. For this reason I believe that Su-field 1.1 is not necessary. Every system will have at last one process (field) towards its surrounding. This leads to the fact that no product exists without having at least one process. So every product is having one process towards its surrounding.

3.3 A system is characterized by attributes through Thermodynamics

When a system is at a dynamic equilibrium under a given set of conditions, it is said to be in a definite state or condition. The state of the system can be described by a number of variables. The properties of the system can be described by an equation at an equilibrium state. The equation specifies the relationship between these variables. For instance: a pen contains a spring. When the pen is laying on the table, this spring is "active" what is called the spring tension. Although this force exists the spring and pen don't move. This dynamic state may be thought of as the instantaneous quantitative description of a system with a set number of variables held constant. This is the reason why all attributes don't need to be described. Adding the attributes or features in a function model decreases the readability. So, fortunately not all attributes need to be added. Where do you put them? Basically they should be added between brackets at either the functions or the objects. That fact that the objects and functions contain more attributes than being used in the system function contains a clue of possible improvements or resources. In an ordinary pen, the electrical, magnetic features of some of the subcomponents are normally not used providing an opportunity.

3.4 Thermodynamic process

A thermodynamic process is defined as the energetic evolution of a Technical System changing from an initial state to a final state. This thermodynamic process I would call "process function" differing from the reversible "state functions". State functions are functions not changing during the thermodynamic process. A clamp holding a work piece will keep on holding when a process function changes the work piece. The "process of holding" goes so slowly it appears that reversibility is at hand. If a process is reversible, there is no heat (entropy) lost to the environment. The spring has this spring tension. Another example is a battery. A rechargeable battery will wear down after numerous uses but appears when working to be fully reversible. A spring appears to be fully reversible too. Mark that if the period is long enough the battery doesn't have reversibility which means that state functions can only be described as in a "state" during a certain period.

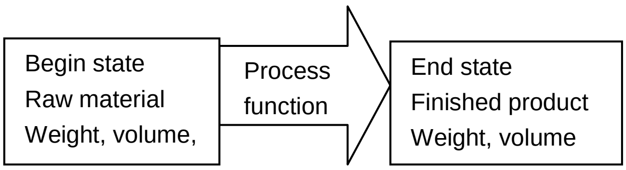


Figure 6: A process description.

4 SOME DIFFICULTIES IN SYSTEM SVO FUNCTION MODELING

The following issues & points I would like to bring up as possible difficulties in function modelling:

- What verb to use?
- Is function modelling cause and effect?
- Number of verbs.
- The verb in the correct state.

- Functions that act on functions.
- Completeness of function model.
- Different functions on the same object.
- Depth of function model

I can imagine that many more questions can be asked so I suppose this list is far from complete.

Before describing these issues, I have experienced that finding the correct set of objects is easier than starting with a function tree (see figure 3) without objects. However defining object sometimes misses obvious objects such as air and dirt. But in most cases it is easy to define all objects because they are tangible. Let's focus now on the issues when making a function model according to the Subject-Verb-Object typology.

4.1 What verb to use?

In making a function model I have encountered numerous times that defining the verb was an issue. Which verb should you use and also in which direction? Is it A towards B or the other way around? Normally passive verbs like "will, should, were, are, is being…" should be avoided. They usually express a more interesting inverse relation. E.g. "The object A is being held by this object B" is better changed to "B holds A". Try reversing the functions to define which one describes better what actually is going on. The question is not to find as many as possible verbs but rather to find the minimum of verbs describing the maximum of system effects. The system effects are those effects why the system was created. It is like creating a basis. If you consider XYZ as a base any forth axes will be a combination of the former three. So if you add verbs like A supports B and B stands on A you have created one function too many. I would not describe all the possible functions but only those that are independent and describe how the system works.

Also the type of function is important. In studying technical English verbs I defined four classes of verbs. The first class is something like "Subject A changes Object B". This type of verb is absolutely useless. You don't know what it changes, except if you specify which parameter or attribute is being changed. But even so I try to avoid these verbs. I call these functions general functions, other examples are: alter, cause to, and improve. The second class I call generalized functions. These are types of functions like increase, decrease, start, and stop. These functions express to my impression a bit more than change. It gives a clue what happens although it is not specific enough. The third class of functions I call specified functions. Examples are: cool, heat, melt, move. These verbs already have an association with a specific attribute, like melt and temperature. One should try to avoid these verbs in describing a specific problem. Instead one should use in making a function model what I call class 4 verbs. Suppose you we look at riding a horse. Asking the question "What specifically does this do?" helps to find the specific function.

Class type	Name	Example
Class 1	General function	Horse changes (position) rider
Class 2	Generalized function	Horse increases (relative position) rider
Class 3	Specified function	Horse transports rider
Class 4	Specific function	Horse carries the rider

Table 1: 4 classes of functions

The classes of functions are apparently interrelated. In a later article I will give a more comprehensive overview of these classes and relations.

The law of completeness also points to the control, motor and transmission system. The motor and transmission system in this case is the horse itself. The control system is the rider. But this is not entirely true. The horse follows up the commands and 'controls' its own functioning.

I prefer to use the specific functions in describing the current situation. Although, going down the classes changes psychological inertia. [22] TRIZ general purpose is to alter the viewpoint and stepping away from the slang used in the specific model to find solutions. The specified, generalized functions can help to find higher level solutions. Mark that these classes are connected as the functions in the ladder of abstraction.

4.2 Cause and effect?

Function model is not necessarily a cause effect model in my view. A pen is laying on the table and doing nothing but laying; no cause and no effect. But is this a Technical System? No, it is more a system of technical objects [29]. However, this system is in dynamic equilibrium. All the functions acting at that time are state functions.

A system can evolve when another object of the super system acts but it is in the variation of possible functions (process functions) that a change will occur in the system. Not just one function will change. Several processes occur simultaneously when the person is calling. When using a phone, the battery is wearing down but this will not affect the normal state. The person might accidentally drop the phone also. Several states of the function model may be described. For instance when describing the use of a cellular phone following system states could come into mind:

- Normal working conditions while calling,
- Phone is dead,
- Phone is on but not used,
- Working conditions in the beginning or end of the product life cycle,
- When being bought,
- When being maintained,
- When being charged (too quickly),
- Under conditions that cause wearing down such as in the pocket, falling on the floor, being put in car kit

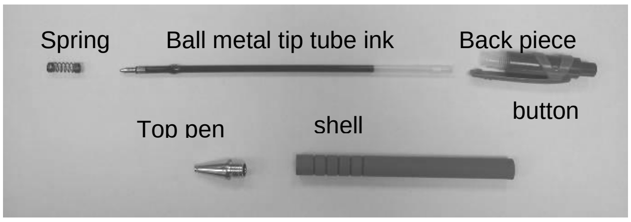
So a system model may contain reversible and irreversible functions. When drilling a hole, this cannot be "undrilled".

Defining the states of a system means zooming out in time. What will happen within 1 second, 1 hour, 1 month, 1 year, 1 lifetime, 1 millennium? For instance: an operator can lift an object of 23 kg easily but what will happen in 20 years with his back?

4.3 Number of verbs between subject and object.

Normally one tries to identify all different kind of functions that can be associated with the subject relations to object. I would consider only direct relations; in the sense of if this object touches or influences the other object directly there is a function.

If a pen is laying on the table and we want to define more precise which objects do what one could argue that the tube holding the ink is not touches the table so there is no direct relation or function between the table and the shell. At this point I introduce a "dash dot dot dash" box surrounding objects to visualise that the object inside it act as one piece. I use this dashed box surrounding the objects ball/metal tip/tube because the act together. Also the back end of the pen is on piece (at this time). It is clear that even further back in time these pieces are manufactured as separate parts and assembled.



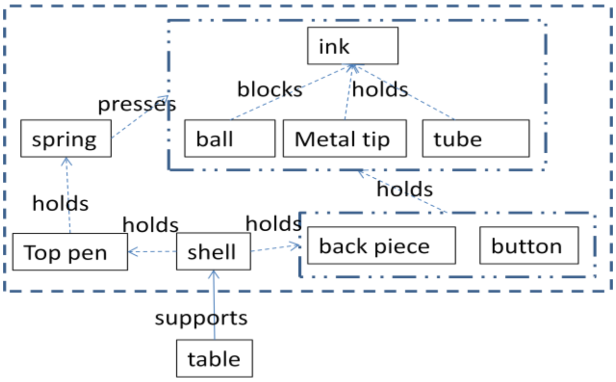


Figure 7: Function model of pen laying on table (the ink will also have contact with metal tip and ball, but this is not mentioned here, also the back piece and button relation)

Mark in the example that the pen is not writing and no ink is flowing. This model doesn't contain process functions. I would like to notice that function modeling of a system doesn't really need a problem. All the functions are in equilibrium so these are all state functions. The process function of ink transport only appears when a "person writes with the pen". However, the spring is in a dynamic equilibrium because it will press the ball/metal tip/tube for as long as the person or another object from the super system in this case doesn't alter this condition or state. The whole pen is also one object we normally accept as one part.

4.4 The verb in the correct state

A process function changes the condition or state of a tangible object. But once it has been changed the function appears as an attribute of the object. Let's look at how the pen in our previous example was assembled. Now disassembled to show the relations. In the production process a process step will be the assembly of all the parts as seen in figure 7. Lets consider 3 process steps.

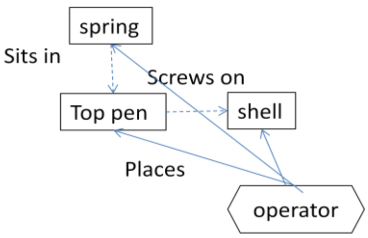


Figure 8: Function model of assembly step 1.

The first step in the assembly might look like above. The operator first takes the spring from a shelf or table (since we don't know this at this time we'll leave these objects such as table, box and pallet etc. out) and mounts it in the top pen. Then the operator screws the whole in the shell.

As soon as the parts have been screwed the function changes to "sits in" with the attribute "force". The dash dot box means that this part cannot be disassembled any more without destroying it (irreversible). The dashed box means that in this moment these parts behave as one part.

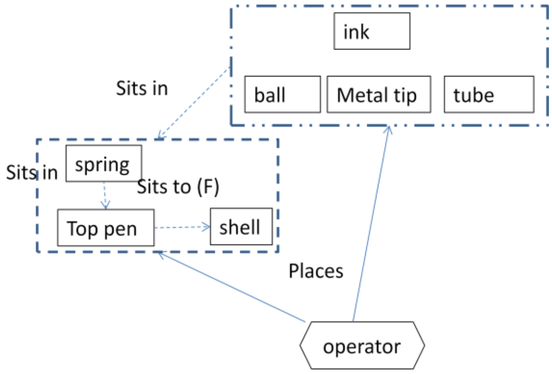


Figure 9: Function model of assembly step 2.

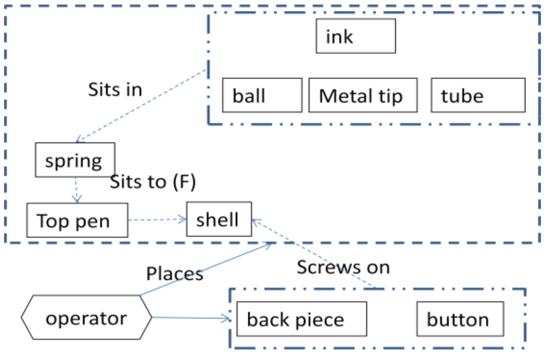


Figure 10: Function model of assembly step 3.

The next step is to mount the back end. The final assembled end product looks like figure 6. (I left out the packaging, transporting, buying, opening of packaging, etc.)

Note also that the operator takes the whole (dashed) subsystem so the function is stopping at the dashed line, not the object itself! A similar description can be found in [21].

4.5 Functions that appear to act on functions

Describing a catalytical reaction means that a relation between the functions is needed [13]. What did we do with objects that seem to act on the function between 2 other objects? This can easily be solved with the dashed boxes. Note that "attaching" changes to "sitting on".

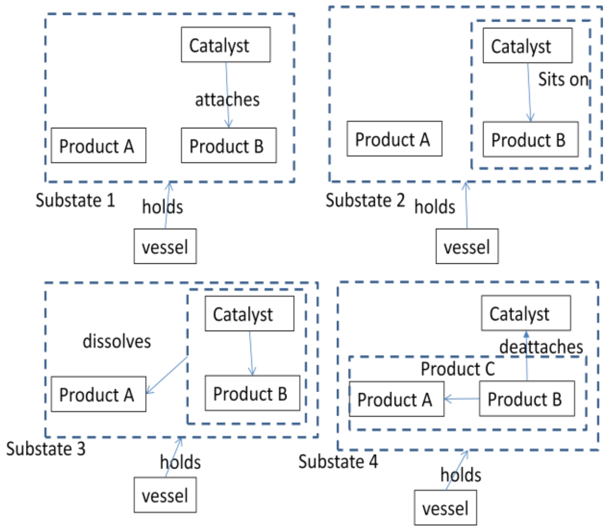


Figure 11: Example of lock open en closed.

4.6 Completeness of system

A pen laying on the table is missing an "engine" and "transmission" and "control system". It is not a Technical System but merely a system, a set of object that are grouped together [29]. If energy does not pass freely through the entire system, a certain part of it will stay without energy and will not operate [22]. The pen laying on the table will not write by itself. So it useful to describe the motor, transmission and control subsystem associated with providing the necessary energy. (See example next paragraph although in this case the control system is poorly controlled by the operator). Note that the arrows used in figure 1 are in fact also functions and that the box indicating the technical system has always been there which is nothing else than the dashed box! A changed "law of completeness" is found in figure 12. The full lines though from Energy and Information are according to the Su-Field analysis symbols.

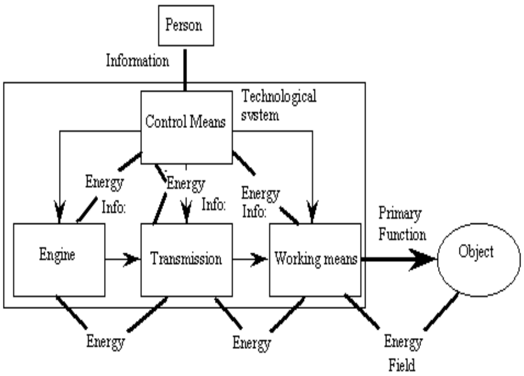


Figure 12: Interpretation of Law of Completeness.

4.7 Different functions on the same object

If a function is acting on one part of an object (zone, space or time) and another function on another part of the object it is interesting to have a formalism that shows that the part is one.

In the pen example we could write ink 4 times. Once for the tube, once for the ball, once for the metal part and once for the paper but in fact it is all the same ink merely at different times. So it is not necessary to write ink four times.

To give a more precise example of this issue is to consider a case where two different subjects act on the same object at the same time in such a way as if the part 'acts' on itself. A large metal sheet is being held by means of a blocking system (eg. a clamp) and at the same time but at another place of this object the sheet is being deformed. If we would divide this into more virtual parts such as a crystal metal structure we could argue that one structure is pulling the blocked structure.

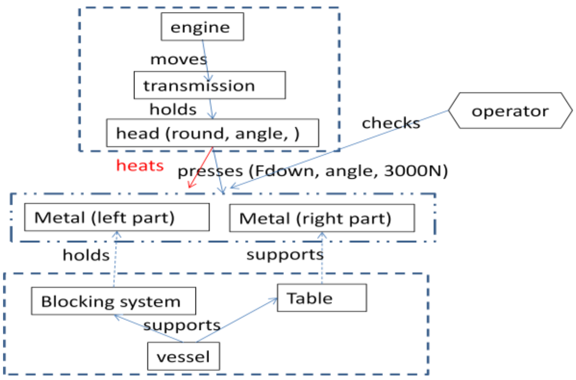


Figure 13: Example of imaginary split up product.

4.8 Depth of function model

Following the example of imaginary splitting up a metal part, a question that comes in mind is how "deep" the function model should go? Considering a problem, a logical answer is "so deep" that the model shows how the system works and there is a thorough understanding of the problem so the problem can be solved. The model can be described so deep that you can imagine the atoms or molecules as being little dwarfs acting as living people☺

5 SUMMARY

This article's main function is to give an alternative solution to several function modelling issues such as number of verbs, completeness of model, 'correct' verb, ..

A set of classes are suggested to help clarify the type of verb to use. This subject needs to be explained in a new article.

Refuge is found using the structure of Thermodynamics and the laws of evolution.

Introducing a dashed (and dash dot dot dash) box indicating a sub state, an undividable object or an object containing different parts but acting as one object helps to overcome some of the issues.

I can imagine that not all issues in function modelling were described and that the alternative provided solves every case.

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Applying TRIZ in Technical and Economic Higher Education

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Abstract

The paper presents the author's attempt to deliver academic lectures and TRIZ method's presentations and adopting specific and comprehensive practical applications, for students in both technical and economic fields of higher education: in "Politehnica" University and the Academy of Economic Studies from Bucharest, as well. The main TRIZ tools are re-stated in the Romanian context, and they are aimed to be applied for innovative problem solving, in general, and for the product development, in particular. Some efforts were focused to provide a proper implementation of the TRIZ method for the specific industrial context of the Romanian economic stage.

Keywords

TRIZ, Technical, Economic, Higher Education

1 INTRODUCTION

The authors concerns toward delivering of some competences aimed to enhanced innovation and creativity for the graduates of some technical and economic university programmes have lead for the last decade to introducing and implementing the TRIZ method in the curricula of academic subjects courses such as: innovation and invention, innovation management, management of technology transfer; this was done in parallel with developing TRIZ related tools for completing the discipline projects. The main TRIZ tools are reformulated to be applied for innovative problem solving, in general, and for product development, in particular. Many of the 40 innovative principles were readjusted to the specific Romanian industrial and technical context. All efforts were focused to allow a proper implementation of the TRIZ method with teaching purpose. By involving different academic institutions, a more comprehensive understanding was available, in both technical and business prospective, for recognising the theoretical and practical value of the TRIZ methodology. An important place takes the development of TRIZ method with some well-known methods, such as: QFD, Taguchi, FMEA, etc.

2 HE ORIGIN OF TRIZ DEVELOPMENT IN UPB AND ASE

Starting 2000, UPB has been involved in several international student exchange programs with universities from Ireland, France, Germany, etc. Many students followed the courses of the last university year, graduated and continued with master and doctorate studies at prestigious universities from the mentioned countries. Part of these students returned and they are currently employed as teachers at UPB. One of the most intensive collaboration is between Faculty of Engineering and Management of Technological Systems and GMIT Galway, Ireland. Within this collaboration there have been accomplished engineering diplomas, master studies, PhDs especially in medicine engineering, product development methods, TRIZ, etc. One of the most accomplishments of the professors and master students from UPB and GMIT is adapting the TRIZ method in environmental design – Design for Environment (DFE) [16]. Analysing and applying TRIZ approach to problem-solving for Design for Environment and taking in consideration the DFE strategies, TRIZ principles for DFE are obtained, and can be implemented successfully in the early stages of the design process. First, the TRIZ methodology has been analysed in an attempt to identify how it can be implemented or adapted to fulfil the DFE strategies, especially focusing on the Inventive Principles of TRIZ (that have a well-known importance in TRIZ to solve the contradictions between the design parameters). Secondly, through a process of comparison between TRIZ principles and DFE strategies, by *adoption*, *adaptation* and *elimination*, the authors obtains the TRIZ principles for DFE, as presented [16], which by the evaluation of the desired solution can be implemented successfully in the Conceptual Design phase. Therefore the algorithm of the new methodology is presented in four steps as following.

Step 1. Problem formulation and establishment of the contradiction: In this stage an analysis of the problem is made in order to identify the basic functions of the system, the sub-systems, supra-systems, the environment, useful, unuseful and harmful systems. In this stage it has been established the technical contradiction (the conflict) ought to be solved during the analysed problem.

Step 2. The establishment of the specific DFE TRIZ principles using the contradiction TRIZ matrix for DFE: Based on the technical contradiction from the first step it has been established the parameters that should be improved and the parameters that are affected by the improvement of the first parameters. The row of the Contradiction Matrix is entered with a parameter that it is desired to improve, and this is intersected with the column of the parameter that is producing an undesired result.

Step 3. Establishing generic solutions using TRIZ principles for DFE: The cell in the intersection gives the number of the inventive principles that are suggested as being able to resolve the contradiction.

Step 4. Establishing specific solutions: By obtaining the inventive principles needed, the designer is applying them to the product for obtaining the desired solution. Data is then re-synthesised from the model and the process begins again. This continuous improvement process continues by iteration, until the best solution is found.

The new methodology has been applied for virtual prototype design model of the car-mirror assembly.

Along with the development of the partnership with GMIT, there has been developed collaboration between UPB and ASE for several research projects as well as mutual invitations to hold lectures from both technical and economic fields. This way there have been developed non-technical applications of TRIZ in the domains such as Management, Business, Quality Management and this method has been introduced in several lectures in ASE.

3 DEVELOPMENTS AND APPLICATIONS OF TRIZ METHOD IN UPB AND ASE

The main concern of authors relating to implementation of TRIZ method to form competencies of creativity and innovation in technical and economic education focuses on such topics as detailed below.

3.1. TRIZ Philosophy. Based on the data in technical literature, the authors reconsidered and reorganised the structure of TRIZ philosophy, so that this philosophy is easy to be comprehended and applied, to find inventive solutions in the technical and economic domains [8, 9, 18]. In facilitating the TRIZ method's study, a rigorous historical perspective [19] was structured and delivered on three stages of accomplishment: the *Classical, the "Kishinev", and* respectively, the *Western* Period one.

The TRIZ Method Philosophy is based on several fundaments of great scientific value that make this method different from other methods. The first fundamental and special characteristic that strengthen and enriches the method with originality is that TRIZ is based on the most actual discoveries and scientific and technical accomplishments from all fields, so that, as shown in Figure 1, the problem to be solved is compared with a large number of solved problems, identifying the existing solutions as a starting point in finding the sought solution. The second characteristic consists in inventive problem solving by taking in consideration and disposing the contradiction that may occur. The third characteristic is the ideality solving following the definitive elements such as: *Ideal Final System (IFS), Ideal Final Result (IFR), Ideal Product, Ideal Process and Ideal Substance.*

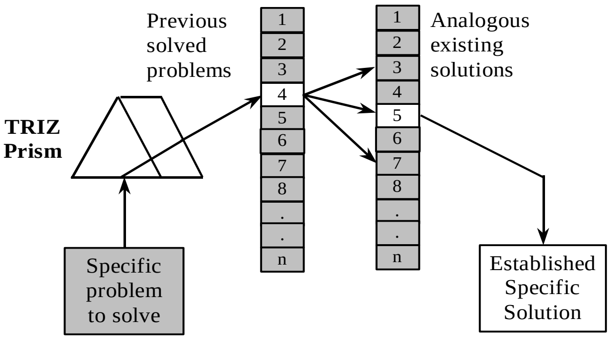
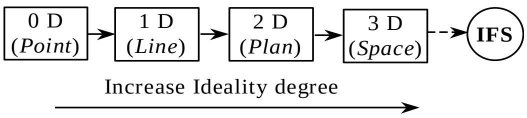


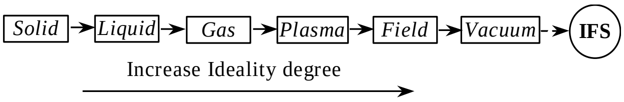
Figure 1: TRIZ Method Philosophy [11]

3.2. Development of basic concepts. The main TRIZ concepts (ideality, contradictions, and resources) were adapted in view of their utilisation in the works and projects prepared with the students. Special attention was given on the quantification of the product ideality [8, 18]. Several ideality indicators were established taking in consideration different bibliographic sources and their unitary treatment within an integrated system. So, according to the intricate nature of the application, the following ideality indicators can be involved, in entire set or partially:

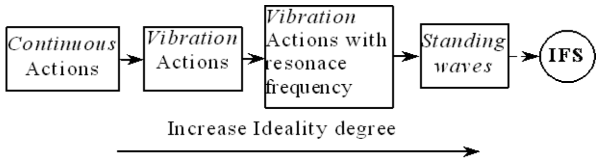
1. Dimensionality degree of the system



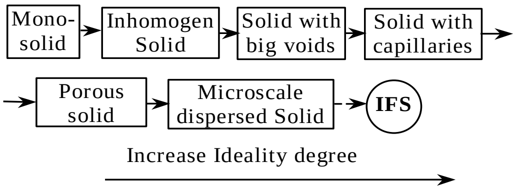
2. Aggregation phase of the system



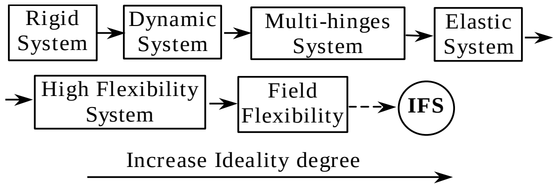
3. The type, nature and frequency of actions applied on the system.



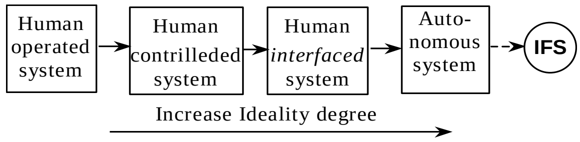
4. The "porosity" degree of the system



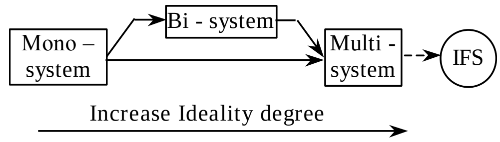
5. Dynamic capability degree of the system



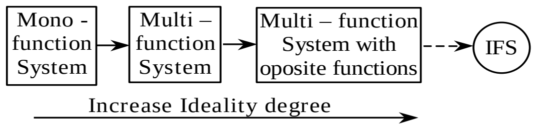
6. Human involving degree



7. The multiplicity degree of the system



8. The nature, type and dimensionality of the functions and features of a system



9. The convolution degree of a system.The convolution coefficient *Cc* is defined as the "ration between the number of fields and the total number of elements of the system – substances and fields" or "the ration between the number of functions and the total number of elements involved in the function's accomplishment "[1].

The selected indicators were checked by implementation in a wide range of works, including the achievement of an assessment methodology of the innovation degree of products that was later adapted to processes, scientific works and research projects [7, 8].

3.3. Laws of technical systems evolution. A unitary picture was prepared of technical systems evolution laws, including the 8 laws of Altshuller [1], the 7 laws of IdealTech [23] and the development of Petrov regarding the laws of technical systems evolution [12]. The eight fundamental laws of Altshuller were adopted as an important instrument of work in product analysis and development. In consideration of these data, function of a product level of conformity to each of the 8 laws, grades can be assigned on a scale from 1 to 10. Based on these grades, a spider diagram can be prepared to determine the priority trends of product or system development. All the eight laws were used in the practical application with the students for improving and developing a significant number of products: paper stapler, paper clipper , mouse, vacuum cleaner etc.

3.4. Customising the principal TRIZ methods and instruments. One of the author's main concerns was to adapt the main TRIZ methods and instruments to the Romanian scientific theoretical and practical expertise in industrial techniques and economics, to make them easily accessible and applicable by, both students and professionals in the process of inventive solving of problems, in general and relating to the product concept and development, in particular. Therefore, the main achievements in this respect are summarised below.

3.4.1. Adapting TRIZ instruments to solve technical contradictions – Matrix of Contradictions, the 39 Parameter, and 40 Inventive Principles. Table 1 shows the 40 Inventive Principles in three alternatives: the original name from the current American and West-European terminology (column 2) [1, 14], its restatement and adaptation into Romanian (column 3) and the English version of this restatement (column 4). Function of the degree of adaptation, the 40 inventive principles have been divided into four categories: entirely reformulated principles (black background numbers), principles expressed more explicitly (grey background numbers), principles that required little restatement (bold numbers with *) and principles that retain the original name.

Entirely reformulated principles, three in number, are such principles that the authors starting from practical expertise with students and other specialised practitioners, have estimated to be difficult to understand and therefore to implement. The principle 7, for instance, termed in the formerly developed methodology in Russia "Matrioshka" and called in the USA the "Nested Doll" could have been hardly understood in Romania under this denomination. The Romanian translation of the phrase "Nested Doll" is ambiguous and an approximate translation of it would have not rendered exactly this concept. Therefore, when customising this methodology, the authors rephrased this term as "Placing one object inside another" or "Using telescopic constructions" that both render clearly the intended generic solution. Principle 21 called "Skipping", in TRIZ philosophy as developed by Altshuller is suggesting the generic solution of passing with maximum possible speed through harmful effects, through aggressive media, and processes developing harmful effects, etc. For the same reasons as in the case of principle 7, the authors have considered redefining it as "Using high work speed". Principle 22 - "Blessing in disguise", or "Turn lemons into lemonade" are very suggestive in English as they are part of every day English, especially in the USA, but the Romanian translation is far from the idea and therefore difficult to implement. The authors considered necessary to restate it as "Using the harmful effects to produce useful effects" which renders more clearly the TRIZ philosophy generic solution.

Principles made more explicit: 7 principles (Principles 15, 18, 24, 27, 28, 34 and 35). The original name for these principles was clarified, to better render the generic solution. For instance, it is well known that in several domains, one tendency today is to develop cheap single-use products. Thus, principle 27, initially called "Cheap short-living objects" was made more explicit by its reformulation as "*Utilisation of cheap short-living object instead of expensive long-living ones".* Other principles were reformulated also and made more explicit in a similar way.

Principles that require little restatement (17, 19, 29, 30, 31, 36, 37, 38, 39, 40) were changed only insignificantly, as compared to their original name; in most of the cases this change resides in the insertion of the word "using" in front of the name phrase, for better understanding in the target language.

Principles maintained in original form. It was noticed that several principles, which some authors considered to clearly express the generic solution of inventive problem solving, were maintained under the original name with their exact translation in Romanian (1 – Segmentation, 2 - Taking out, 3 - Local quality, 4 – Asymmetry, 26 – Copying etc.).

The 39 Parameters were easily reformulated and a higher understanding was thus provided of their significance, each parameter being conceived as a system characteristic feature.

The 40 Inventive Principles and 39 Parameters, together with the matrix of contradictions were used in several applications with the students relating to product development and inventive solutions by solving technical contradictions, permanently improving the way of formulating and explaining notions, in accordance with the concepts detailed above.

From their work experience, the authors noticed that the restatement of some principles could bring a significant progress in teaching activities, both in the technical and economic fields.

3.4.2. The practical expertise of the Su – Field method implementing to identify inventive solutions in product development shows the need to provide a well structured approach, as a means of increasing this method efficiency. Therefore, the Su-Field analysis can be applied in five or six steps as follows [8]:

Step 1 - Problem Description- in this step the system is evaluated and there are emphasised the system's functions and the problems that should be solved.

Step 2 – Building up the Su-Field Model – in this step a scheme of the model shall be drawn emphasising for example: Substance S2 – the active substance, Substance S1- the substance ought to be operated upon, the field that induces the undesired action and the harmful action expressed through corrugated arrow .

Step 3 - Reconsidering the Su-Field Model. In this step it is reconsidered and redrawn the Su-Field Model trying to eliminate the harmful action by transforming it into a useful or neutral action.

Step 4 - Declaring the ideality In the Su-Field Analysis, the ideality is defined as "there is an element X which can transform the unwanted action into a useful one".

Step 5 – Looking for the X element – solution among the internal resources – one tries to identify the X element within the internal resources, among the system's elements. This can be done by reformulating the ideality definition inserting one by one instead of the X element, each component of the system trying to solve the problem first using only the internal resources without modifying the system.

Step 6 - Looking for the X element- solution among the external sources. When the solution cannot be found in step 5, the Su-Field analysis proceeds further with the last phase where the solving of the problem shall be considered by inserting a third substance S3 inside the system.

The Su-Field was referred as a basic tool in numerous diploma papers (discipline projects, diploma dissertations, scientific articles presented in various scientific conferences of the students), and, also, in quoting some state-of-the-art themes from scientific literature and in developing new original ones - (telpher, iron machine, microwave set, stool, apparatus for veterinary use etc).

No.	The original name	Restatement in Romanian	English version of the Romanian restatement
1	Segmentation	***Segmentarea***	Segmentation
2	Taking out	*Extragerea*	Taking out
3	Local quality	*Calitate locală*	Local quality
4	Asymmetry	*Asimetrizarea*	Asymmetry
5	Merging	*Combinarea*	Merging
6	Universality	*Universalitatea*	Universality
7	"Nested doll" (Matrioshka)	*Plasarea unui obiect în interiorul altuia*	Placing one object inside another
8	Anti-weight	*Contragreutatea*	Anti-weight
9	Preliminary anti-action	*Antiacțiune preliminară*	Preliminary anti-action
10	Preliminary action	*Acțiune preliminară*	Preliminary action
11*	Beforehand cushioning	*Compensare sau protecție preliminară*	Compensation or preliminary protection
12	Equipotentiality	*Echipotențialitatea*	Equipotentiality
13	The other way round	*Reversul medaliei*	The other side of the coin
14	Spheroidality - curvature	*Sferoidalitatea, curbarea*	Spheroidality - curvature
15	Dynamics	*Variabilitate, dinamism, flexibilitate*	Variability, dynamism, flexibility
16	Partial or excessive actions	*Acțiuni parțiale sau excesive*	Partial or excessive actions
17*	Another dimension	*Trecerea la o altă dimensiune*	Passing to another dimension
18	Mechanical vibration	*Utilizarea şi înlocuirea vibrațiilor mecanice*	Using and replacing mechanical vibrations
19*	Periodic action	*Utilizarea acțiunilor periodice*	Using periodic action
20	Continuity of useful action	*Continuitatea acțiunilor utile*	Continuity of useful action
21	Skipping	*Utilizarea vitezelor mari de lucru*	Using high work speed
22	"Blessing in disguise" or "turn lemons into lemonade"	*Utilizarea efectelor dăunătoare pentru a produce efecte utile*	Using harmful effects to produce useful effects
23	Feed-back	*Feedback*	Feed-back
24	Intermediary	*Utilizarea elementelor intermediare*	Using intermediary elements
25	Self-service	*Autoservire*	Self-service
26	Copying	*Copierea*	Copying
27	Cheap short-living objects	*Utilizarea obiectelor ieftine, cu durată de viață scurtă,în locul celor scumpe, cu durată de viață lungă*	Using cheap short-living objects instead of expensive long-living ones
28	Mechanics substitution	*Înlocuirea sistemelor mecanice cu câmpuri*	Mechanics substitution by fields
29*	Pneumatics and hydraulics	*Utilizarea sistemelor pneumatice şi hidraulice*	Using pneumatic and hydraulic systems
30*	Flexible shells and thin films	*Utilizarea membranelor flexibile şi a peliculelor protectoare subțiri*	Using flexible membranes and thin protection films
31*	Porous materials	*Utilizarea materialelor poroase*	Using porous materials
32	Colour changes	*Schimbarea culorilor*	Colour changes
33	Homogeneity	*Omogenitatea*	Homogeneity
34	Discarding and recovering	*Eliminarea, înlocuirea sau regenerarea unor părți ale unui obiect*	Eliminating, replacing or regenerating of some parts of an object
35	Parameter changes	*Modificarea proprietăților fizice şi/sau chimice ale unui obiect*	Changing physical and/or chemical properties of and object
36*	Phase transitions	*Utilizarea transformărilor de fază*	Using phase transformations
37*	Thermal expansion	*Utilizarea dilatării termice*	Using thermal expansion
38*	Strong oxidants	*Utilizarea oxidanților puternici*	Using strong oxidants
39*	Inert atmosphere	*Utilizarea mediilor inerte*	Using inert atmosphere
40*	Composite materials	*Utilizarea materialelor compozite*	Using composite materials

Table 1: TRIZ Principles

3.4.3. The 76 Standard solutions. The 76 Standard Solutions were taken over from the specialist literature [17], translated, adapted, organised in easily applicable summary tables and completed with many examples from authors' expertise, expressed in Su – Field language.

3.4.4. The 9 screens method. This method [10] is one of the instruments most widely used in application activities with the students, relating to product development. The main application trend of this method consists in studying the historical evolution of one product, with a view to forecasting the next generation of products, at system, subsystem and supersystem levels.

For a better application of all the TRIZ methods and instruments, a glossary was prepared that is a dictionary of TRIZ terms, English to Romanian and Romanian to English, starting from one glossary which is now in use and is currently referenced in specialist literature [6] (table 2 and table 3).

Abordarea Standard de rezolvare a problemelor (Soluții Standard, Tehnici Standard, Standarde) - Un set al celor mai eficiente transformări tipice ale sistemelor tehnice bazate pe legile evoluției Sistemelor Tehnice. Multe standarde sunt scrise în limbajul Su - Field.	**Standard Approaches to Solving Problems (Standard Solutions, Standard Techniques, Standards) -** A set of the most effective typical transformations of technological systems based on the Laws of Technological System Evolution. Many Standards are written in the Substance - Field language.
Acțiunea Fizică − Un mecanism fizic care face posibilă realizarea unei funcții specifice. De exemplu o funcție precum "curățarea unei soluții chimice de contaminați" poate fi bazată pe acțiuni fizice diferite precum "extragerea contaminatorilor din soluție", "dezintegrarea contaminatorilor" ş. a.	**Physical action −** A physical mechanism that enables performance of a specific function. For example, a function "cleaning a chemical solution from contaminants" may be based on such diverse physical actions as "moving the contaminants away from the solution", or "disintegration of the contaminants", and others.
Acțiune/Funcție dăunătoare − O acțiune/funcție care realizează frânarea realizării Funcției Primare	**Harmful function/action −** A function/action that hinders performance of the Primary Function.
Acțiuni/Funcții utile − O acțiune/funcție care contribuie la realizarea Funcțiilor Primare.	**Useful function/action −** A function/action that contributes to the performance of the Primary Function.

Table 2: TRIZ GLOSSARY: Romanian to English [6]

Algorithm for Inventive Problem Solving – ARIZ, The central analytical tool of TRIZ (ARIZ is a Russian abbreviation). Its basis is a sequence of logical procedures for analysis of a vaguely or ill - defined initial problem/situation and transforming it into a distinct System Conflict. Consideration of the System Conflict leads to the formulation of a Physical Contradiction whose elimination is provided by maximal utilization of the resources of the subject system. ARIZ puts together in a system most fundamental concepts and methods of TRIZ such as Ideal Technological System (Ideal System), System Conflict, Physical Contradiction, Substance - Field Analysis, Standards, and the Laws of Technological System Evolution.	**Algoritmul Rezolvării Inventive a Problemelor** − instrumentul analitic principal al metodei TRIZ. ARIZ are la bază o succesiune de proceduri logice pentru probleme/situații definite inițial greşit sau vag şi transformarea acestora într-un sistem. Luarea în considerare a sistemului conflictual conduce la formularea Contradicției Fizice a cărei eliminare se realizează cu utilizarea maximă a resurselor subiectului sistemului. ARIZ reuneşte în cadrul aceluiaşi sistem majoritatea conceptelor fundamentale şi a metodelor TRIZ cum ar fi Sistemul (Tehnic) Ideal, Conflict al Sistemului, Contradicție Fizică, Analiza Substanță Câmp (Su - Field), standarde şi legi ale evoluției Sistemelor (Tehnice).
Altshuller's Matrix − See Conflict Matrix	**Matricea lui Altshuller** − vezi Matricea Conflictelor
Altshuller's metrics − See Technology assesment curves	**Matricele lui Altshuller** − vezi curbele de evaluare tehnică
Anticipatory Failure Determination − A TRIZ - based method for analysis and prevention of design failure modes.	**Determinarea Anticipată a Defectelor** − Metodă bazată pe metoda TRIZ pentru analiza şi prevenirea modurilor de defectare, în faza de proiectare a produsului
Article − See Object	**Articol**−vezi obiect
Auxiliary function − A function supporting the system's Primary Function.	**Funcție auxiliară** − o funcție care asigură realizarea Funcțiilor Primare ale sistemului
Auxiliary tool − A tool supporting the performance of the maintool (s). Particularly, auxiliary tools perform measurement and/or detection in a system whose Primary Function is not measurement or detection	**Instrument auxiliar** − un instrument care asigură funcționarea instrumentului (instrumentelor) principal(e). de exemplu, instrumentele auxiliare pot realiza măsurări şi/sau detectări într-un sistem în care Funcția Primară nu este măsurarea sau detectarea.

Table 3: TRIZ GLOSSARY: English to Romanian [6]

3.5. TRIZ application methodology to product development. The authors have developed in many works the classical TRIZ methodology in five steps [3, 13]: identification of problem, problem statement, development of generic solutions based on previously known solutions, interpretation of generic solutions and determining specific solutions and solution assessment. Only in a little extent there were implemented when working with master students other related TRIZ methodologies, such as the ARIZ algorithm (ARIZ classic, ARIZ 2000, ARIZ Cavallucci [2[), Samsung methodology of TRIZ application and “Christmas Tree” diagram [15], etc.

3.6. Computer aided TRIZ applications – Creax. Considering the software of TRIZ implementation (shown in Table 4) [3, 22, 23, 24, 25, 26], we have successfully worked with the software CreaTRIZ for several applications in the framework of master students projects, by both taking over case studies from known specialist literature [3, 4, 5], as well as by developing students' original applications. A very important aspect should be mentioned here that allowed for the collaboration between the two institutes and also the parallel approach of technical and economic domains, namely the fact that the CreaTRIZ software comprises two modules: one for technical applications and the second for applications in the domain of Management and Business.

3.7. Implementing of TRIZ along with other methods. We mention here the combined methods associated with the TRIZ approach, leading to an increase of its innovation capacity, which the authors mostly used in their teaching practice: TRIZ - QFD, TRIZ - Technical Scenario – QFD, TRIZ – QFD – Taguchi and TRIZ - FMEA.

In the case of applying with the students the methods QFD - TRIZ - Taguchi for product development, the authors have prepared and applied the original General Model of the House of Quality consisting of four matrices (Figure 2): 1- Matrix of WHATs, 2 – Matrix of the WHATs correlation, 3 - Matrix of WHATs importance, 4 – Matrix of WHATs planning, 5 – Matrix of HOWs, 6 – Matrix of HOWs correlation, 7- Matrix of relations between WHATs and HOWs, 8 – Matrix of HOWs target values.

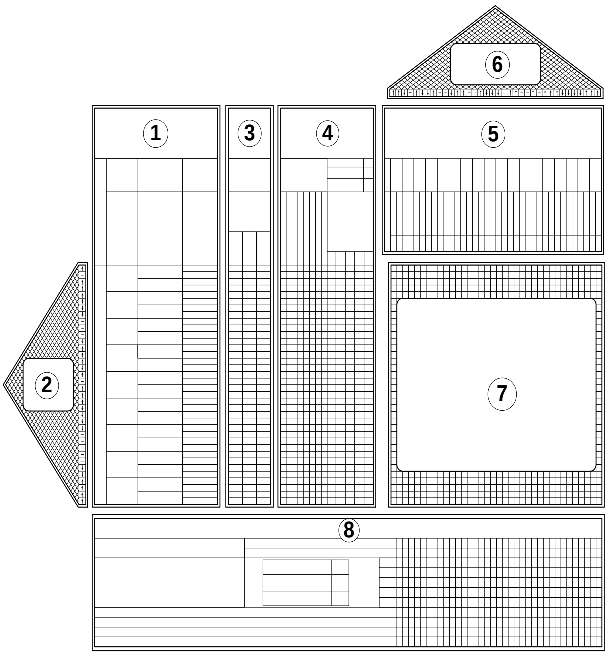


Figure 2: The House of Quality application of TRIZ method

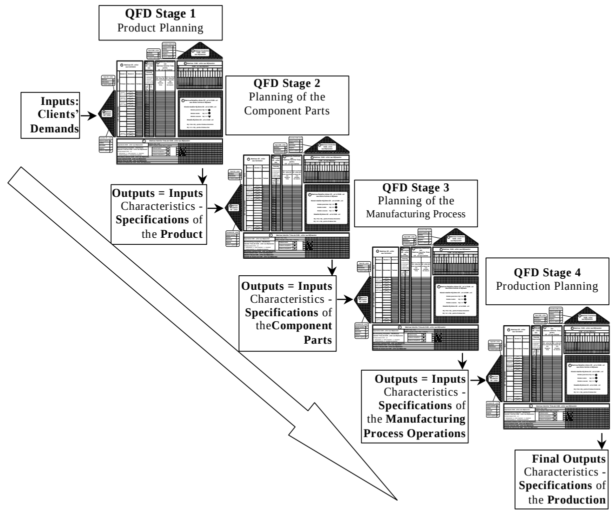


Figure 3: The characteristic steps of product development using QFD

The method QFD was applied for all the four characteristic steps of product development, name: QFD Step 1 – *Product Planning*, QFD Step 2 – *Planning of Product Component Parts*, QFD Step 3 – *Planning of Product Manufacturing Process* and QFD Step 4 – *Planning the Product Production.*

When working with students, in all the four application steps of the QFD method, the TRIZ method was used to prepare the Matrices 2 and 5 that is *for determining the Correlation of WHATs and HOWs*, and to solve the *contradictions* that may occur. Contradictions were solved by aid of the TRIZ Contradictions Matrix. It is a well know fact that in all the four QFD steps, when speaking of the Planning of WHATs (Requirements), the change of one Requirement can induce a desired or undesired change of other Requirement, with *contradictions* as a result. The same can happen in the case of planning the HOWs (Specifications).

For the purpose of TRIZ implementation, the WHATs and HOWs that is the Requirements and Specifications items of the four steps were classified by the authors, by applying the Taguchi theory into three classes, function of their effect on product quality: enhancer (ENH), including items that by their value increase engender also quality increase; optimizer (OPT), including those items with optimal values generating optimum quality; reducer (RED), including those items which by their increase produce low quality. Special results were obtained for many products developed by the authors, such as: car, flashlight, grill, agenda, washing machine, gyrocopter etc.

3.8. Applying the concept of ideality and Altshuller innovation levels in the field of innovation methodology. Based on the above mentioned aspects, the authors prepared and published [7] a general methodology to determine the innovating level of products, processes and scientific works based on a complex index using the Kano model, the five innovation levels of Altshuller and the degree of product ideality. The methodology of assessing the innovating level of products is based on the development of a global indicator build up through the weighting addition of three indicators proposed by the authors: the client satisfaction indicator I_{SC}, in accordance to the delightful characteristics from the Kano model, the inventiveness indicator, I_{IN}, associated with the Altshuller 5 levels of inventiveness and the Ideality Indicator I_{ID}, that reflects the ideality degree of the analysed product.

In order to evaluate the level of innovation of a product, the authors propose a global indicator of the innovation level I_{NI} that can be expressed as follows:

$$I_{NI} = I_{SC} \cdot p_{SC} + I_{IN} \cdot p_{IN} + I_{ID} \cdot p_{ID} = \\ = I_{SD} \cdot p_{SC} + I_{IN} \cdot p_{IN} + \left(\sum_{k=1}^{9} i_k \cdot q_k \right) \cdot p_{ID}, \quad (1)$$

where p_{SC}, p_{IN} şi p_{ID} are the weights of the three indicators , i_1, i_2, …, i_9 are the indicators of the ideality degree q_1, q_2 …, q_9 are the weights of the ideality degree indicators . The sum of the weights from every category equals 1, respectively: $p_{SC} + p_{IN} + p_{ID} = 1$ and $q_1 + q_2 + \ldots + q_9 = 1$. Depending on the field where the methodology is applied, some weights might be zero.

4 TEACHING EXPERIENCE

Table 4 shows a structural framework of lectures, such as innovation and invention (technical field) or innovation management and management of technology transfer (economics field).

No. ch.	Content
1.	Main concepts and notions regarding innovation and inventive problem solving (praxiological, psycho-gnoseological, psycho-pedagogical and logical – mathematics bases of the inventics; defining and classification of the inventions; Stages of inventive problem solving; the main impediments regarding technical creativity and inventive problem solving).
2.	Methods and techniques for creativity stimulation (intuitive techniques and methods, logical-combining-deductive methods, Edward de Bono techniques).
3.	The content and structure of the Theory of Inventive Problem Solving (History of birth and development of TRIZ; Concepts and main notions for inventive problem solving, TRIZ philosophy, the main stages of TRIZ, TRIZ structure, Advantages and limits of TRIZ, implementing TRIZ in an organisation)
4.	Methods, techniques and tools for inventive problem solving (Contradiction matrix, 40 inventive principles, 39 TRIZ parameters, separation principles for physical contradiction solving, 76 Standard solutions., Technical systems evolution laws, ARIZ Algorithm, Su – Field analysis, 9 screen method and multiscreen method, Smart Little People Method– emphatic methods, Operators system, Direct product evolution models, Anticipatory Failure Determination, case studies)
5.	Software for inventive problem solving (TRIZExplorer, Innovation WorkBench, Ideator, TRIZ Improver, CreaTRIZ, TechOptimizer, TriSolver, case studies).
6.	Using inventive problem solving in some product development methods (Using with QFD and technical scenario, Synergy TRIZ – QFD – Taguchi, Using AFD - TRIZ with FMEA, Using TRIZ with Value Analysis, case studies)
7.	Intellectual property (copyright; Related rights; Industrial property protection - Patents for invention, Trademarks protection, Industrial design protection, Geographical Indication protection, Plant variety patents, Topographies of integrated circuits protection, Protection against unfair competition).

Table 4: Course content

The chapter titles and applications shown in Table 5, including case studies investigated have been adapted to both domains of the two universities (UPB and ASE). This has been a joint research, based on the general theory of creativity and inventive solving of problems adapted from case to case, to either industrial techniques, or economics. As shown in Table 4, chapter one is dedicated to the main concepts and notions regarding innovation and inventive problem solving, the second chapter follows with several methods and techniques for creativity stimulation (analogy, inversion, empathy, combination, brainstorming, Gordon, Delphi, Philips 66, Panel, “6-3-5, Frisco etc.), including lateral thinking of Edward de Bono.

The lecture continues with several chapters containing various TRIZ methods and instruments and it ends with the chapter entitled Intellectual property. The lecture ends with the invitation launched to one representative of OSIM (Romanian Office for Patents and Trademarks), to perform the simulation of a Patent application (in the case of technical education), and Trademark application (in the case of economics education). Mention should be made here that given the way the practical side of the lecture was conceived (Table 5), by applying a wide range of methods for the same product (selected by the student, or suggested by the teacher), there were students who would really apply for a Patent, or a Trademark, although this is not required for course graduation.

No. work	Content
1.	Brainstorming meeting, 4-5 students teams for founding a technical solution for a certain problem
2.	Application regarding 9 screen method: evolutive systemic study for a product, establishing of the technological evolution of the product and prediction of the next generation of the product
3.	Application regarding innovation/invention realisation by technical contradiction solving for a specific product; case study presentation;
4.	Application regarding innovation / invention realisation by physical contradiction solving for a specific product; Application regarding Su-Field analysis for a specific product and case study presentation.
5.	Application regarding applying the technical systems evolution laws for re-design a specific product and case study presentation
	Application regarding a problem solving using CREAX software and case study presentation
6.	Application regarding using TRIZ, QFD, Taguchi and technical scenario in conceptual – innovative re-design of a specific product
7	Applications regarding copyright; related rights; patents for invention, trademarks protection, industrial design protection, geographical indication protection, protection against unfair competition; registration of a patent based an original solution developed by the (master) students. Registration of a trademark.

Table 5:. Applications content

Some examples of themes developed by the students in product development are: deburring some rubber components of small size, nuts’ cracking system in the industrial regime, sorting ripe tomato fruits and taking apart the green ones, garlic press etc.

These lectures were held in the last (fifth) year of study for the technical field and for the first year of study for the economic master degree program in the economic field. Since Romania has joined the Bologna system, these lectures are taught to master students.

5 SUMMARY

Considering the above mentioned assumptions, we may conclude that:

1. The authors of this paper as teacher in two well-known universities in Romania have joined in a partnership project with the common achievement of implementing modern methods of creativity and innovation in technical and economic higher education, based on a general theory of creativity and inventive solving of problems adapted to the domains of industrial techniques and economics

2. The nine-year expertise of the authors originates in collaborations with famous universities of Europe and especially with GMIT, Galway, Ireland.

3. One of the main concerns of the authors has been that of adapting the principal TRIZ methods and instruments to specific Romanian scientific research in the technical and economic fields, to provide clarity and correct understanding, as well as adequate implementation by students and professionals in the domain of inventive solving of problems in general, and in product conception and development, in particular.

4. The teaching experience of the authors resulted in the implementation of several lectures with similar structure, but different individual content specific for the two particular fields, technical and economic.

5. As a final note, the authors are interested in collecting feed-back for publishing these experience in a book, addresses to all those interested in the field of creating thinking for solving technical problems and fostering innovation.

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Altshuller's Algorithm in Identifying New Solutions

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Abstract

In the Technical University "Gheorghe Asachi" of Iaşi - Romania, an university subject aiming to develop the students technical creative abilities, was introduced some decades ago. The applicative activities to this subject had to offer a general image about the process of identifying new ideas and solutions. With these aims in view, one of the laboratory activities was dedicated to the study of the possibilities to use the Altshuller's algorithm in identifying new technical or technological solutions. The paper presents some authors considerations about the using of the Altshuller's algorithm within the university didactic activities.

Keywords

Altshuller's Algorithm, University Subject, Creativity Stimulation

1 INTRODUCTION

There are many definitions for the concept of *creativity*; the concept seems to be firstly used in 1937 by Gordon Alport, to define the integrative way by which the human being was succeeding not only to understand, to reproduce and to solve the numerous problems imposed by the live, by the profession and by the environment, but also to express the assembly of features able to ensure the identifying of new and original solutions [3]. If one takes into consideration only the technical field, *the creativity* can be defined as the capacity of a person to invent (to create) objects, processes or methods having a technical character.

There are many reasons to show why the human being must know, stimulate and apply the technical creativity. Along the time, as results of the applying of his technical creativity, the human being succeeded not only to permanently improve the material side of his live, but also the spiritual side of the life significantly benefited from results obtained in the field of technical creativity. It is difficult to imagine the actual development of the cinema and theatre art, of the literature, of the music etc., without the impressive using of the technical means.

If sometimes a physical object can be created without to elaborate before a technical project, when the same object must be produced in a great number of copies or rigorous technical requirements must be fulfilled, the so called *design method* should be used.

The more detailed analysis of the design methods by taking into consideration the presence of the significant creative component could highlight that there are two groups of design methods:

a) Routine design methods, when the designer has not time enough to search and to find new solutions and if it possible even original solutions; evidently, this aspect is especially valid for the so-called *emergency design situations;*

b) Creative design methods, when the finding new and original solutions are just one of the main objectives of the design activity. In this case, adequate methods to find new and improved solutions should be used.

Within the last situation (the applying of the creative design methods), the so-called *paradox of the science* could be discussed; indeed, by applying well known methods, the designer, the researcher or generally the specialist in a certain field has to find solutions at least partially unknown. The investigations about the creative design methods proved that by applying such methods, there is a high probability to succeed in finding new and original solutions for the technical problems.

Once accepted the possibility to apply certain methods to find new and original solutions, the researchers tried to identify and to apply the creative design methods. Thus, simpler or more complex methods, able to better use the creative capacities of the human being in general or especially of the designer in the technical field, were defined.

Nowadays, there are many methods able to help the designer to solve the problems appeared in different stages of the design activities, but there are not so many methods able to be applied within the entire design process or activity. In the specialty literature, there are information about *the method of morphological matrixes Zwicky-Moles*, *the method of the generalized object of the technical inventing*, *the method of the heuristic approaches, the Altshuller's algorithm, the method of the quality circles* [1, 2, 8, 9] etc.

The Altshuller's algorithm was proposed by Genrich Saulovich Altshuller in 1956 and it is considered as the base of the so-called theory of creative problems solving (in Russian language, *teoria reshenia izobretatelskikh zadach*, concept from which the acronym of TRIZ was created). Beginning of 1956, the algorithm was continuously developed, both by its initial creator, and by the contributions of many other researchers or specialists in a certain activity field [1, 6, and 7].

Cascini and Russo [4] appreciated that sometimes analysis of patents could be cumbersome and to accelerate the process of identifying of the technical contradictions on which the patented technical system is designed, an approach of this problem by means of the computer could be efficient. They proposed to use an adequate algorithm for solving the above mentioned problem; practical examples offered the possibility to validate the proposed algorithm.

The study and applying of TRIZ was taken into consideration inclusively within the university curricula [2, 10]; to offer supplementary knowledge to the future specialists to search and to find the innovative solutions for the technical problems means to give them adequate tools to contribute to the society progress.

2 THE STIMULATION OF THE STUDENTS TECHNICAL CREATIVITY AT THE TECHNICAL UNIVERSITY OF IASI - ROMANIA

More than forty years ago, within the Faculty of Mechanics of the Technical University “Gheorghe Asachi” of Iaşi - Romania, the university professor Vitalie Belous initiated the first activities able to better develop and use the students’ creative capacities. If initially his efforts were singular, along the years many other professors and researchers joined to the professor Belous’ efforts; as a direct result of these efforts, an university subject was introduced in the curricula for training the future engineers, initially in the field of mechanical engineering and afterwards also in the field of the industrial engineering.

If in the 80’s years, this subject (having the name *“Fundamentals of the technical creativity”,* but usually called “*Inventics*” by the students, researchers and professors) had an optional character, after 1990 the subject was included in the curricula for different specialties (machine manufacturing technology, machine tool and production systems, welding engineering etc.). Two hours of course and one hour of applicative activities developed in specialized laboratories were allocated weekly to this subject.

Usually, the student chooses or receives a certain design theme and he must creatively solve different aspects of the design problem.

The lectures still include various aspects regarding the techniques and methods for stimulating engineering creativity as well as elements that facilitate or obstruct the development of creativity, the procedures of moving through the different stages of an innovative process, from the elaboration of a theme to the practical application of the newly identified solutions. For example, education is an essential element for facilitating creativity, and the lack of creative environment may obstruct or inhibit the creativity.

During the practical activities, there are also tackled and analyzed in detail the best methods for the stimulation of engineering creativity. Furthermore, each student is handed a small project of innovation for which he has to identify a constructive or technological solution that must include elements of originality, inclusively those derived from the application of various methods of creative stimulation.

The last practical courses are usually focused on the elaboration of valid documents that are to be sent together as invention proposals to the specialized national office (The Romanian State Office for Inventions and Trade Marks of Bucharest). If one (or more) of the students succeeds in convincing their coordinating professor about the originality of the solutions developed and manages to elaborate the specific documents for an invention proposal, he is to be adequately rewarded with the mark obtained on the written or oral examination by which the subject is finalized. This last aspect being well known by the students (also due to the debates with their professors at the beginning of their university studies), there often occur situations when the students themselves put to word the themes of innovation that are to be developed during the applications of the Fundamentals of Technical Creativity (FTC) .

As mentioned above, during the first year there take place meetings between students and their professors who also coordinate the FTC subject; the students are advised to alternatively examine the objects around themselves in order to find out, later on, that many such objects involve either boring activities and much effort or uncomfortable positions while being used or a high consumption of energy. It is such objects and aspects that students are advised to focus on, in order to find solutions for their improvement. Thus, when students reach their third year of study and are confronted with the FTC subject, most of them have already developed an idea on the concept of technical innovation and even come up with their own solutions.

During the debates with their coordinating professors, students are also supported in clearly defining one or more themes or areas of innovation.

Moreover, the FTC applications professors also have to prepare a list of objects that present several disadvantages that students are to be told about; discussions and debates on such disadvantages are meant to lead to new themes or areas of innovation for those students who have not yet selected their innovation themes.

During the application classes, the students use various methods of creative stimulation (such as brainstorming, the method of the morphologic matrixes, the method of the diagram ideas, Altshuller’s algorithm etc.), in order to reach one or more creative solutions for their selected exercise of innovation.

Beside their educational effects, the FTC applicative activities have proved to be very useful in developing the students’ confidence in their own creative skills. It is demonstrated that, at the beginning, there can be noticed a low level in the students’ interest in this field of activity, many of them wondering whether they could really come up with new, innovative ideas, taking in consideration that inventions (and innovations) usually come from more experienced professionals. In this respect, the purpose of the applicative activities is to train the students in such a way as to make them confident in their own capability of seeking and finding new solutions by using appropriate methods. Thus, the patents obtained along the years from our former students have proved to be very useful as well as the small competition that develops among peer-students who tend to think that: “if my fellow students, who do not always seem to overpass my intellectual level, are able to reach important technical achievements, than why should I not be able to come up with new elements, as well?”.

The debates with the professors and other peers, the stimulation of creativity and the efforts invested may lead to students’ identifying solutions worth being patented. Under such circumstances, the student is advised by the professor to elaborate the specific documentation needed for an invention proposal. Such proposals are sent to the specialized Romanian institution by one of the administrative offices from our university (the student’s file needs also to include certain documents proving a possible deduction of the registration fees for the invention proposal, the student’s annual income being taken into account).

From the discussion with the university’s administrative officers, we have learned that 90% of the students who have been attending the FTC subject elaborated the documents for invention proposals, including solutions they themselves have identified during their practical courses. Out of these proposals, a percentage of about 30 – 60% turn out to fulfil all the necessary requirements in order to be patented (this statement was validated after the invention proposals had been examined by the specialized Romanian institution). The authors of the invention proposals are usually informed about their projects having been patented during their last year of study (at present, this being the 4th year) or after their graduation (in Romania, the legal period of examination time being up to 30 months).

After sending their proposals or receiving the patents, students are encouraged to participate with their original ideas in national and international invention showrooms and in technical and scientific events. Such showrooms have been organized, throughout the last years, in Iasi as well, most of the student participants having been remarked and awarded for their innovative skills; it is worth highlighting that sometimes there are organized special sections for the younger participants, so that they would not have to be confronted with less equitable conditions by competing with the more experienced specialists.

In addition to that, due to the methods of creative stimulation used both in the case of the professors and students of the Technical University “Gheorghe Asachi” in Iaşi, 150 up to 200 invention proposals are being elaborated annually, over 60% of these proposals being elaborated exclusively by students. Encouraged by the good results obtained at the FTC subject, many students continue their scientific research, seeking to identify further technical solutions after having finished their FTC learning activities. An eloquent example is represented by the former student Daniel Rezmireş. As student, he came up with his first invention proposal for a generator used in obtaining single pulse discharges (such generators are to be used during laboratory activities for specialized subjects, to study the influence of the electrical discharges characteristics on the craters sizes generated on the proof samples). Being very much encouraged by the outstanding result obtained in a relatively short period (the student’s idea was patented in only 6 months), Daniel Rezmireş managed to elaborate (even before graduating) over 30 invention proposals, a considerable part of them having been acknowledged as inventions.

The professors in charge with the coordination of the FTC subject are usually selected among professors who have proven creative proclivities, are well appreciated and prove an open attitude towards communication with their students. Students are to be counselled in developing their creative proneness in any circumstance, inclusive by trying to find an answer to the question: “Couldn’t there be brought any improvement to what I am reading, listening to, observing or might have already come in contact with?”

As didactic staff, we were sometimes really surprised by the creative capacities of the students; of course, usually the theme approached by the students to be developed by creative methods could be proposed by the professors who coordinate the applicative activities, but there are many situations when the students themselves propose different and interesting themes.

3 SURPRISING ASPECTS DERIVED FROM THE USING OF THE ALTSHULLER’S ALGORITHM WITHIN THE LABORATORY ACTIVITIES

To help the students, both within the courses and applicative activities at the subject “Fundamentals of the technical creativity”, different methods able to contribute to the stimulation of the technical creativity were investigated and applied. Such a method which was found as interesting and able to really guide the student in finding new and original solutions was *the Altshuller’s algorithm.*

Different aspects concerning the ways to apply the Altshuller’s algorithm were included in the didactic books; on the other hand, the presentation of the principles and stages of the algorithm were included in a laboratory handbook [5].

As didactic staff involved in the coordination of the activities belonging to the subject “Fundamentals of the technical creativity”, we accepted the assertion that the Altshuller’s algorithm has a high level of the ideas organization, guiding the thinking to the original results, by the conscious applying of the laws of the technique development [1, 2].

Of course, the applying of the algorithm stages implies sometimes surprising aspects; one can not neglect some mistrust or even negative reactions of the students to which the applying of the Altshuller’s algorithm is proposed, but we can consider that such reactions are generally possible in the case of many new aspects of the live. The students are not initially trustful in the efficiency of the modifying their conventional thinking system.

By applying step by step the Altshuller’s algorithm, some students are attracted by the original manner to tackle and to solve the problems corresponding to different algorithm stages and sometimes, real original solutions were highlighted.

As known, the Altshuller’s algorithm applied in the earlier ’90 years was including 9 main stages, with 40 steps of successive analysis and more than 70 rules and remarks.

Thus, within the debate dedicated to the finding solutions referring to a folding chair, and when the content of the discussions was oriented to the using a chair including articulated elements, at the tackling of the step 3.3 (which was meaning *the reformulation of the physical contradiction at a macro level*), the student A.Z. sad really angry: “If the chair must be found there, to allow to a person to stay on it and it must not to be there, to not complicate the constructive solution, we must probably use a pneumatic solution, of inflatable type”. After some years, really such chairs appeared in the market.

In other circumstances, when the theme of the discussions was a folding umbrella, the analysis of the using the resources from the over-system guided the student-girl M.L. to the idea of using some phosphorescent or reflective substances (within the over-system, such substances were used, for example, in the small plates placed on the terminals which emphasize the roadsides) on the canvas or on the umbrella handle, to make it more visible during the night.

A similar situation appeared in the case of the under pressure boiling pot. Analyzing the possibilities to use the resources from the over-system (during the discussion, the existence of the taps – valves was just remarked), the student S.S. formulated the suggestion to use a turbine acted by the vapours under pressure for a supplementary mixing of the pot content.

4 THE USING OF THE RESOURCES FROM THE OVER SYSTEM IN THE CASE OF THE HONING DEVICE

As one can see, the structure of the Altshuller’s algorithm is complex enough, but its rigorous applying can guide the applicant to the finding new and original solutions. By understanding and applying both the Altshuller’s algorithm and other methods able to stimulate the technical creativity, the student/the engineer becomes able to faster identify new solutions.

In fact, along his professional activity, each specialist can create his proper structure of approaches able to ensure to him the identifying of original and superior solutions. Finally, it is possible to be difficult to strictly separate which is the contribution of each studied method in

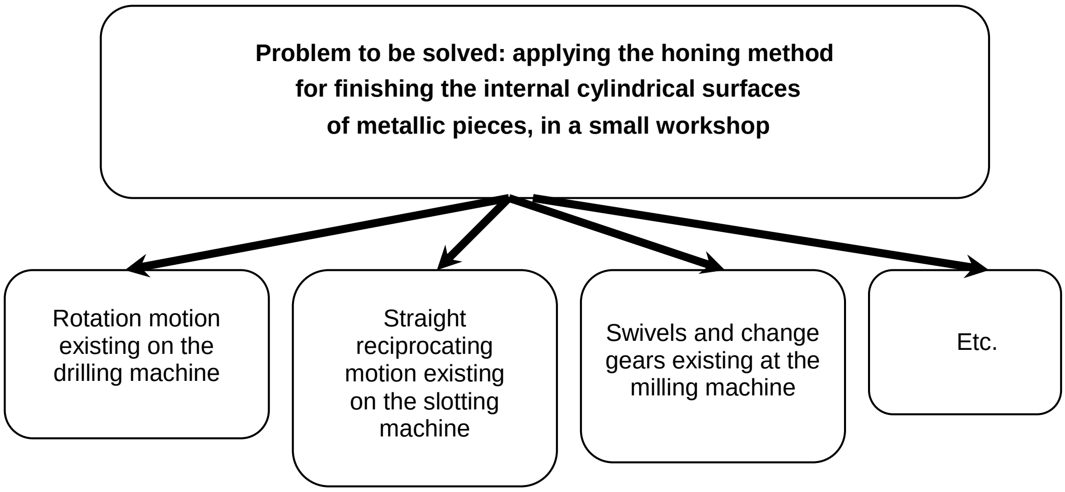

Figure 1: Investigation of some resources existing in the over-system.

stimulation of the engineering creativity. It is important to highlight that some stages specific to the Altshuller's algorithm can be successfully used just in the case of other methods dedicated to the better using of the technical creativity.

Afterwards, some aspects concerning the defining of a new solution in the case of honing device by the using of the aspects specific to the Altshuller's algorithm are highlighted; these aspects were used within the applicative activities developed at the subject "Fundamentals of the technical creativity".

We took into consideration the necessity to apply the honing operation in the case of a small enterprise; such a problem could appear, for example, for finishing the internal surfaces of certain cylinders used in the structure of the fuel-burning engine.

The problem could be solved by buying a honing machine, but its high price could be prohibitive for a small enterprise. Analyzing the resources existing in the over-system (fig. 1), one can find that a drilling machine could be used; buying only a honing head and eventually a cardan shaft, the honing operation could be performed by manual or mechanical moving the honing head (trained in rotation motion by the main shaft of the drilling machine) along the workpiece axis.

As known, the fourth stage of the Altshuller's algorithm requires the study of the substance and field resources; it is necessary to exam the available resources, to know if some existing solutions could or not could be used for solving the problem of the honing head.

At the step no. 4.1, the stimulation of the imagination could be made by means of the so-called small men; the graphical representations including "armies" of small men could be elaborated to a better clarifying of the problem. These small men should have to ensure the possibilities to achieve the straight reciprocating motion and, on the other hand, to modify the frequency and the amplitude of the straight reciprocating motion. The small men should have to help the researcher in clarifying the followed effect ("what must be obtained?"), but without to specify a certain solution.

In the case of the honing device, the graphical representation corresponding to the step no. 4.2 is showed in figure 2. The men could be placed on a fix structure (for example, on the flange existing round of the main shaft of the drilling machine). This flange could move the honing head and the cardan shaft along the axis of the rotation motion (obtained from the mean shaft of the drilling machine).

The withdrawal of some of the small men could suggest sometimes a viable solution. Because such a solution was not identified, the following steps of the algorithm could be approached. Thus, one knows that the step no. 4.3 supposes the analysis of the using a combination of a substance resources.

Trying to adequately answer the problems belonging to the step no. 4.3, one can find that within the over system (namely in the small workshop), there are used speeds boxes, sets of belt pulleys with different diameters, swivels (one can notice that in the workshop there are change gears at other machine-tools) etc.

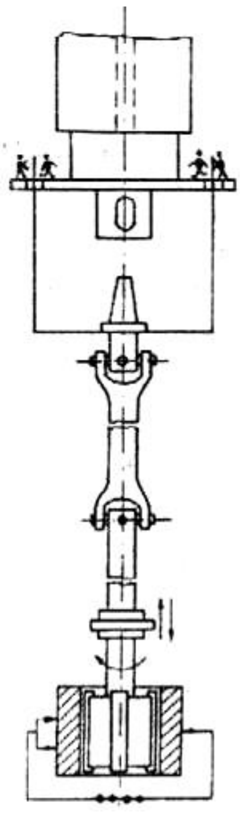

Figure 2: Metaphoric solving of the problem by means of the small men.

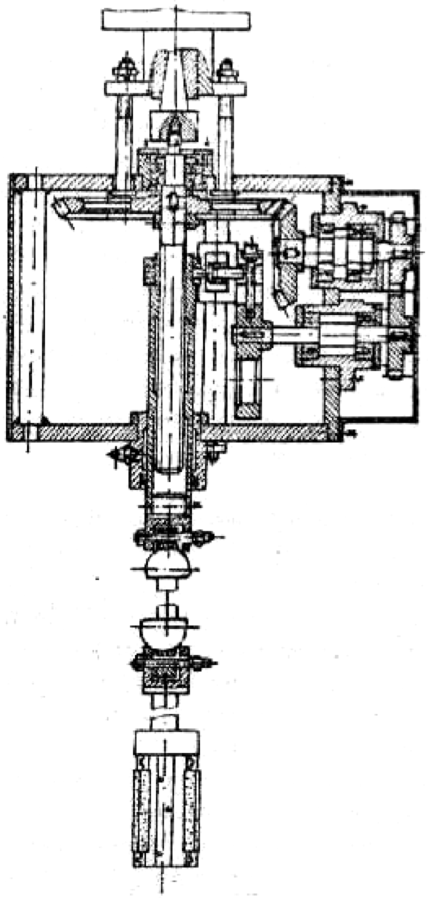

Figure 3: Honing head.

Insisting on the step 4.3, we can notice that in the over system, there are some solutions for obtaining the straight reciprocating motion.

Thus, in the case of the shaping machine, the mechanism including the so-called oscillating crank lever is used, while some mortising machines achieve the straight reciprocating motion to the work head by means of the crank and connecting-rod assembly.

In this sequence, we can ask ourselves if we can use the rotation motion of the drilling machine main shaft to obtain the straight reciprocating motion of the honing head, by means of one of the known mechanisms. To control in an independent manner the frequency of the reciprocating motion, one can use a swivel whose change gears although exist in the workshop.

Following these suggestions, one can imagine the solution presented in the figure 3 [9]. This solution is based firstly by taking the rotation motion from the drilling machine main shaft, by means of the conical gear. Afterwards, the swivel allows the independent control of the number of rotations per minute of the honing head.

The mechanism reciprocating rod – oscillating crank lever contributes to the proper materializing of the reciprocating motion. This honing head was built and its experimental testing proved the possibility to obtain good results concerning the surface quality and the accuracy of the machined surface.

5 SUMMARY

When the designer has sufficient time to search and to find a new solution for a product, some methods able to stimulate the technical creativity could be applied. Aiming to aid the students to develop and to use their creativity, within the University "Gheorghe Asachi" of Iaşi, a specialized didactic subject (called *Fundamentals of the technical creativity*) was introduced in the university curricula. One of the methods used to better develop the students technical creativity was *the Altshuller's algorithm.* The applying of this algorithm during the applicative activities belonging to the subject *Fundamentals of the technical creativity* highlighted some interesting and surprising situations. Trying to solve different stages characteristic to the Altshuller's algorithm, one can find situations when innovative solutions were identified. On the other hand, the applying the Altshuller's algorithm could help the creative specialist in enlarging his possibilities and methods to act in the direction of identifying new constructive and technological solutions. The paper highlights some aspects of an improved product (a device for the using of the honing method on a drilling machine) which could be found by the applying the Altshuller's algorithm.

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