A systematic exploration for conceiving function and behaviour of a new technical system

Davide Russo, Tiziano Montecchi, Daniele Regazzoni

University of Bergamo
Phone +39 035 2052353/ Fax 077
E-mail: {first name, last name}@unibg.it

Abstract: Nowadays the landscape of knowledge exploitation tools is significantly changing, the use of patents grows and information availability for different fields of knowledge too. For this reason, problem solving methods based on knowledge are more effective than any other approach based only on personal creativity and background.

This work aims at proposing a methodological approach to guide the user to generate technical solutions during the conception of a new system. Such a step by step method is inspired by an implementation of classical tools from TRIZ, a theory to systematically define a problem and support the creative idea generation process.

A combination of a selection of ontologies for the functional representation of a system, and knowledge (KM) management strategies and tools for extracting knowledge by patents DB is provided. The aim is to trace a repeatable path to support the inventor to get ideas in case of a new system generation.

The authors explain every step of the method by means of an industrial case study in order to show concisely the effectiveness and the ease of this application.

Key words: TRIZ, Patent search, Knowledge Management, technical creativity

1- Introduction

Nowadays commercial success is increasingly due to the quality of technical solutions in terms of functionality, cost saving, maintenance. This work shows the huge potential of generating a set of technical solutions by combining functional modeling methods with knowledge management systems, such as scientific effects DB and targeted patents searches.

In the section 2 an overview on the most important methods for creative problem solving at the state of the art is presented. From those, TRIZ is selected and analyzed more in detailed, as a very representative method to show how a systematic approach based on modeling and synthesis of the problem can work. Particular attention is set on the importance of knowledge during problem solving and on the TRIZ tools used to support this activity.

In the third part, the proposal of authors consists of a selection of the most effective approaches for the functional description of a technical system and it continues in section four with a presentation of a method that combines suggested approaches with a knowledge analysis process in order to generate a set of solutions.

Finally a case study is presented showing how the method can be applied in a real industrial application.

2- Overview on creativity methods

Problem solving methods can be essentially divided into 2 macro classes.

First class includes methods that, starting from a given problem, enhance personal creativity of the problem solver by a trial and error approach. Among all we mention Brainstorming [O1] and all psychological methods to stimulate personal inventiveness, to avoid mental archetypes in order to generate bright and original solutions, such as lateral thinking [D1], to take important decisions from a number of different perspectives [D2], to sort solving approaches by means of mental maps [B1], to stimulate not obvious relations, such as synectics [G2], or a checklist helping you to think of changes you can make to an existing product to create a new one, such as scamper [E1] or ASIT [H1], attribute listing [C1], Creating Workforce Innovation [M2-M3], Morphological Analysis [Z1].

The second class collects methods for finding a solution, not based on personal skills but mainly focused on a preliminary modeling of the problem according to precise rules; only after having modeled the system a synthesis phase follows in order to define the solution. The core of most of these representation models is based on functional language; the description of a situation is obtained by defining and combining a logical network of functions performed by the system. For example using cause-effect chain diagrams [I1],
chain of problem statement [D3], functional hierarchies [L1] or defining objects and describing how they interact one each other [M1]. Finally, there are some models expressing functional goals and harmful effects related to a technical system that use implicit representation of the function by a variation of flows as in EMS model [P1] or a modification of specific attributes such as in ENV model [C3].

Regardless of the language used (functional or object-oriented, rather than declarative), methods of the second class potentially provide results qualitative more effective than trial and errors methods. From those, TRIZ was considered by authors the most effective and complete.

3- TRIZ: a functional approach based on patent knowledge

The Theory of Inventive Problem Solving (TRIZ) [A1-A2] was born in the 40's through the work of G.S. Altschuller. The particularity of the method lies in the attempt to build, from an initial problem, an identikit of the solution. The Altschuller’s ambitious project was to find a convergent solving process that guided inventors with very different styles, background and skills towards a single representation of the problem, thus towards a unique model for constructing the conceptual solution and finally to a set of related real solutions.

To fulfill this goal, TRIZ has been developing a systematic process, combining models for functional representation of the problem (for the analysis phase), with modern techniques of knowledge management (for the synthesis process). The idea is that a better understanding of the world of technology can be built by studying many thousands of patents, analyzing the way inventors have solved problems in their own expertise domains. In this perspective tools have been developed in order to rely both on personal skill and on the global knowledge shared by scientists and inventors. Actually, the robust foundation of extracted knowledge in TRIZ is based on the following fundamentals:

- **Inventive Principles** [A1-A3]. Hundreds of thousands patents were analyzed by Altschuller and his collaborators. This work, a mere abstraction process, produced a concise list of 40 inventive principles. These principles include all the ways by which an inventor can move from the abstract model of its problem to the model of the conceptual solution.

Unfortunately, such an elegant tool suffers of low efficiency without a methodological approach to set the problem in terms of a contradiction (a conflict between 2 technical requirements or parameters). A specific tool, called “contradictions matrix”, was invented by Altschuller to map problems and the 40 principles, but it was discarded at the end of 60’s, and overcame by more efficient tools.

- **FOS: Function-Oriented Search**. Theorized by Altschuller and after structured by Litvin [L2], FOS is a technique for extracting information from patents DB. It is based on searching all the subjects of the Subject-Action-Object triples, and for this reason it needs for working of semantic processing software. Once the function and the object are known, the search, for all subjects corresponding to the given triad, is the set of technologies that we are looking for.

FOS research is certainly still present but the efficacy is limited by the fact that most of the patents is not written with a functional logic or language. To make it really effective it needs improvements to enlarge the set of potential search targets.

- **Pointers to Effects** [G3-S1-V1]. It is the result of the work of many Triz collaborators. Pointers of effects consist of an extensive and accurate collection of physical and chemical effects, well organized according to a predefined set of functions, parameters and substances.

Despite of many efforts done during the last decades, such a classification doesn’t cover the whole field of knowledge.

- The “76 Standards Solutions” [A1-P2]. They were compiled by Altschuller and his associates between 1975 and 1985. They are structured rules for the synthesis and reconstruction of technical systems. Typically, they are used as a step of a more complex algorithm, called ARIZ, after the model has been developed and any constraints on the solutions have been identified. The core of the problem is described by an interaction (missing, insufficient or harmful) from a single tool to a single substance, and a very general model of the solution is proposed in order to complete or destroy the given system, build a new one, measure or detect something within a technical system, transform it from the base system to a super-system or to a micro level.

Standards have to be used together with a knowledge base but there are no effective strategies to link graphical schema of the solution into a function and a structure of the solution.

Let see an example taken from Class 1 of Standards solutions:

“Class1. Modifying a system in order to have a desired outcome or to eliminate an undesired outcome. [...]This group includes the necessary solutions for completing an incomplete model (in Su-Field terms, an incomplete model is one that does not have S1 or S2 or F, or the force F is inadequate.) Remember that the fields include: mechanical, thermal, chemical, electrical, magnetic, gravitational, weak nuclear and strong nuclear.

- 1.1 Improving the performance of an inadequate system

- 1.1.1. Complete an incomplete model. If there is only an object S1, add a second object S2, and an interaction (field) F. ”

As shown above, Standard 1.1.1 suggests a direction but doesn’t explain how to complete the system.

So, in order to show how TRIZ suggestions can be better integrated with proper KM tools and strategies, the authors show an exemplary case of incomplete system, that occurs when the creation of a new system is required.
4- Function modeling selection

The starting point to conceive a new system is to define 3 different classes of variables describing different aspects [G1]:

- Function (F): “is the motivation for Technical System existence”, i.e. what it is for.
- Behavior (B): “sequential changes of objects state governed by the Laws of Nature, is the link between Function and Structure. Different behaviors can produce the same Function, as well as different Structures can be characterized by the same Behavior”; i.e. what it does.
- Structure (S): describes the components of the object and their relationships; i.e. what it is.

Let consider some problems dealing with functions.

The best way to search a function within a text patent is to replace the desired function by a set of potential different targets. Such a target generation is described in [R1] by a method based on the integration between conceptual design ontologies and a query expansion obtained by linguistic relations.

A selection of the key approaches for functional representation of technical systems is suggested in this work in order to introduce their combination in the following case study.

4.1– FUNCTIONAL ANALYSIS

Born around ‘40s by Larry Miles within the Value engineering, function analysis has been implemented and developed in TRIZ with the aim of mapping systems with problems by listing all the components and all their interactions. Such a target generation is described in [R1] by a method based on the integration between conceptual design ontologies and a query expansion obtained by linguistic relations.

TRIZ Functional Analysis differs from other forms because it includes all the negative, ineffective and excessive interactions in the system. Function modelling is performed in the Operative Zone, the crucial area where the problem occurs. In this area, two substances (elements) and a field (energy) must be present. Analysis of the S-Field model helps to determine changes necessary within the technical system in order to improve it.

4.2– ENV MODEL

The ENV (Element, Name of the property, Value of the property) model is an universal model proposed in OTSM-TRIZ [C2] for describing a system or a problem, an inventive solution. The structure has been derived from a well known model in Artificial Intelligence Object-Attribute-Value (SAO).

Element (E) is any kind of item in the system under analysis (both material and immaterial). The Name of the property N indicates any characteristic, feature, variable which can be associated to the element E. Whatever is the property, it must have at least two possible values (V), i.e. the element E can assume at least two possible states distinguished by different values V1 and V2 of the property. An example of ENV application for a motion description: “a tool moving an object”, is a tool that changes the value of the object’s (E) speed (N) from zero (V1) to a certain value (V2) measured in m/s.

4.3– Tool- Object- Product model

To better understand and describe the physical interpretation of the way in which the system works it is suggested to adopt the Tool-Object-Product model (fig.1). This allows, describing only the essential part of the analyzed system, saving time without losing crucial information.

4.4– EMS model

Any engineering system can be initially modeled as a black-box with energy, material and signal inputs and outputs from the system. In black box modeling, energy is represented by a thin line, material flows by a thick line, and signals by dotted lines. The engineering system therefore provides the functional relationship between the inputs and the outputs, in other words the system works transforming inputs into outputs.

5- Functional models and knowledge procedure for designing a new product – with a case study

The method proposed is a step by step method based on a simple combination of the different perspectives presented in the section 4 with strategies for knowledge searching.

![Figure 2 Step by step procedure](image-url)
An industrial project was used as case study dealing with a system for cutting ultra-thin polypropylene tapes used for personal care products and installed on production machines at very high speed. The current system uses a mechanical cutting technology where a polypropylene sheet goes through a system based on coupling between a rotating shaft with a blade and a counter-rotating shaft with an anvil. Increasing the process speed, such a cutting system doesn’t guarantee the performance needed, and it also increases noise, instability and many other side effects that forced the company to search for an alternative solution. Therefore, a new system must be conceived.

In this work a four steps procedure is presented with the aim to guide a re-design activity of a new system of cutting ultra-thin polypropylene tapes.

- **Phase 1 – Starting functions identification**

The starting function can be easily identified as the action “to cut”. In this phase the ENV model application is suggested in order to abstract the given function (table 1). Just listing all value changes of polypropylene tape before and after the cutting, a list of correlated functions was generated for every feature variation.

<table>
<thead>
<tr>
<th>element</th>
<th>feature</th>
<th>value object</th>
<th>value product</th>
<th>correlated functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>tape</td>
<td>thickness</td>
<td>0,2</td>
<td>0 mm</td>
<td>to thin</td>
</tr>
<tr>
<td>tape</td>
<td>length</td>
<td>∞</td>
<td>500 mm</td>
<td>to divide to separate</td>
</tr>
</tbody>
</table>

**Table 1 Functional identification by ENV model**

- **Phase 2 – New functions exploration**

Phase 2 consists of exploring new alternative functions, by means of a very simple tool that helps to radically change the perception of the interaction we have with the object. Such a psychological barrier breaking is provided by imagining the given system at extremes: Size and Time are changed systematically from 0 to ∞.

You imagine that your system’s size has to be either minute (or non-existent), then think of how you could create a system like that, what challenges it would pose, what advantages it would have, and then you imagine it at the opposite extreme: infinitely large, how you could make it like that and the challenges and benefits that it would give you.

You also perform this for time (happens in no time, or takes an infinitely long time). This simple tool is very effective in making you think of your system as it really is, what you really want from it, and helps you to get rid of any false constraints. For our specific scope, the tool is used not only as trigger to generate alternative verbs for the verbs cut, thin, divide and separate but also to identify potential technical domains to be used as an International Patent Classification filter in order to increase the rate of information retrieval from Patent DBs.

The specific questions to fill out the table of the case study will be the following:

- How should I cut/thin/divide/separate, if dimensions move from 0 to ∞?
- How should I cut/thin/divide/separate, if available time goes from 0 to ∞?
- For every change what are the systems where a similar problem has already been faced or solved?

In table 2 the results of Size-Time tool are shown.

| Current cutting dimension (thickness) = 0,2 mm |
|-------------------------------|----------------|
| **Trigged Ideas** | **Related domains** |
| Dimension | ∞ |
| 0,01 mm | Tape is divided by impact | mechanical cutting |
| 0,001 mm | Tape is divided by simple deformation | yarn production domain |
| 0,001 mm | - tape tears by itself, adhesion forces generated with any solid surfaces or fluids - collapsed under gravity or its own weight | - gold-beater |
| 0 mm | Precut tape | Towel |
| **Dimension** | ∞ |
| 10 mm | Tape is divided by mechanical cutting by shears, scissors, blade, knife, etc. | paper industry |
| 100 mm | - Tape is divided by machining using mill, rotating mill, saw, circular saw, etc. - Tape is divided by pressing or bending it | - marble cutting, wood cutting, drawing domain - metal working domain |
| 1 m | Tape is divided by a sequence of drills and breaking action | concrete building, demolition, marble mining domain |
| 10 m | Tape is divided by explosion | demolition, mining domain |
| 100 m | Tape is divided by excavator | construction domain |
| 1 km | Tape is divided by earthquake, meteor shower, acid rain, lava river | geological, abrasive blasting machine, ultrasonic label cleaning domain |
| 1000 km | Tape is divided by planet collision | ?? |

**Table 2 The table shows in the columns the modification of parameters value, trigger concepts and domain.**
• **Phase 3 - Solution identikit: function-behavior identification.**

Taking inspiration from the Size-Time table, new ways to conceive the given functions or completely new alternative functions to realize separate pieces of tape, are provided.

Ultimate solution will be generated after a semantically search, on Patent DBs, of all Subjects of each combination of the trigged Actions and wanted Products/given Object; for those classical SAO triads, every query is expanded by adding also the behavior (according to mechanical, acoustic, thermal, chemical, electric, magnetic, electromagnetic and biological fields) and the related technical domain (optional).

In this way, a list of effects by which the tool can produce the function in order to transform the object into the product is provided. In figure 3 a very partial list of results is shown (most of them belonging to mechanical field).

In order to make a research more comprehensive, all effects can be taken from specific effect DBs opportunely prepared by authors just merging international research works and translating them into related keywords.

Boolean combination strategies, IPC filter management, advanced query expansion with lexical and semantic relationships, are then used by authors in a so called KOM approach [R2-R3] in order to refine searches once a more precise identikit is defined.

**CONCLUSION**

A selection of methods for functional representation of a system is collected here and combined with a TRIZ tool traditionally used for exploring unconventional perspectives about a given system or problem. Trigger Idea and related domains are generated using a step by step method then they are processed by semantic parsers and combined in appropriate queries in order to find in patent literature all the technologies and procedures which the function of the new system can be performed by.

Using a new kind of search not only based on keywords related to the function but also on a plurality of keywords related to the behavior, it is possible to explore patents DB in order to find solutions; in other words finding the way a similar problem have already been solved in a different technological area.

The same strategy can be also used to perform accurate

<table>
<thead>
<tr>
<th>Effects</th>
<th>Representative patent</th>
<th>Mosaic</th>
<th>Effects</th>
<th>Representative patent</th>
<th>Mosaic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandblasting</td>
<td>Sandblasting US-7640641 Method for producing parts for passive electronic components and parts produced</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Explosion /Jet Forces</td>
<td>Explosion GB-1502350 Explosion cutting apparatus for linearly cutting material</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Friction forces</td>
<td>Friction forces US-2009113656 Apparatus for isolated bevel edge clean and method for using the same</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Piercing</td>
<td>US-20020188224 Test media cassette for bodily fluid testing device</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Gravitational forces</td>
<td>Gravitational forces US-3896201 Method of processing raw materials for the manufacture of glass (under own weight)</td>
<td><img src="image5.png" alt="Image" /></td>
<td>Multi-milling</td>
<td>US-20060162159 Substrate slot formation</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>Fracture</td>
<td>Fracture US-3712379 Multiple Fracturing Process</td>
<td><img src="image7.png" alt="Image" /></td>
<td>Plasma/laser</td>
<td>US-6051803 Plasma arc cutter</td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>electrical/thermal</td>
<td>electrical/thermal shock US-5501385 Spark erosion</td>
<td><img src="image9.png" alt="Image" /></td>
<td>chemical/vibrations</td>
<td>US-200820229 line of weakness by chemical and then vibration or thermal stress</td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>

...and more others

**Figure 3 A partial list of identikits of solution generated by searching in Patent DB by a query composed of action, a list of physical effects, the given object and filtering in specific technical domain by IPC identification**
feasibility analysis about the best selected ideas.

A case study dealing with the cutting of a polypropylene tapes for personal care was provided to show how many possibilities can be explored by a systematic method instead of adopting a simple trial and error method just focused on finding other cutting devices.

References

[A1] Altshuller, G.S. Creativity as an exact science
[A2] Altshuller, G.S. Innovation Algorithm