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Evolution Navigator
For Technical System Innovation

Dissertation work for TRIZ certification
To highest level (TRIZ Master)

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Contents

Abstract: Technology innovation is critical for organizational and economic development and thus has been widely discussed. In spite of the extensive research, however, the research community has made few efforts to guide the direction of innovation, considering the general evolutionary patterns of technical systems. This research suggests a novel approach to predict prioritized directions of innovation as well as to create the most promising design of practical concept design. The mainstream of suggested approach includes analysis of the main function of the target system with using of well-developed functional analysis technique. Then according to developed Evolution Opportunity Map, based on the TRIZ Laws of Technical system Evolution and results of existing patent database analysis, the most suitable concepts of next generation system could be generated. At the final stage of suggested approach the technical challenges, that might arise in realizing of chosen concepts, should be provided. This stage uses mostly Substance (Element)-Field analysis, which can help to obtain more feasible solution for real project's conditions. Suggested approach was firstly successful adopted in Samsung Advanced Institute of Technology (South Korea) for providing a few R&D projects. The suggested approach could be also useful for those who in charge of innovation management or new product development processes.

Keywords: Technology innovation, technical systems, technology evolution, morphology analysis, TRIZ, Samsung Advanced Institute for Technology, TEOM

1. INTRODUCTION

1.1. Actuality of dissertation topic.

Organisational and economic development, growth and wealth require technology innovation (Feldman & Desrocher, 2003; Ritsila, 1999). Usually, new technologies and processes contribute to a better utilization of resources, higher quality of routine tasks and higher productivity. Innovation is the process of implementing new technologies and new processes (Porter, 1990; Rogers & Shoemaker, 1971; Voss 1994) and companies that use innovative technologies and processes can generally create better quality and cheaper products, thereby enjoying high potential growth (Minitti et al., 2006; Bonnardel and Zenasni, 2010). Especially in the global marketplace where the pace of technology change rapidly reduces product and service lifecycles, new product introduction through continuous innovation is crucial for a firm to survive (Oliver et al., 2004). Consequently, innovation has been widely discussed and attracted extensive research efforts particularly on how to search for the possibilities of innovation (Isaksen and Ekvall, 2010). Various approaches to creating innovation by examining functions of products and then trying to improve them, such as Quality Function Deployment (QFD) (Cohen 1995), Functional Analysis and Systems Technique (FAST) (Kaufman 1977), the Kano model (Kano et al. 1984), conjoint analysis (Huertas-Garcia & Consolacion-Segura 2009) and Morphology Analysis (MA) (Yoon and Park 2006) and other innovative design methods (Chen et al. 2009), have been studied actively in marking, product engineering and technology management areas. Although these studies are meaningful in that they suggest a systematic process that can help thinking about the possibilities of new products, they are seldom interested in pointing out the desirable direction of improvement or the possible directions of innovation. Customer information can lead to the way to improve as in QFD, Kano model or conjoint analysis, but its usage is limited to market-driven products for which customer needs are clear and well-specified. For high-tech products and services, the role of technology is critical in their innovation (Bonnardel and Zenasni, 2010; Burkhardt and Lubart, 2010) and different strategies to find innovation opportunities are required.

1.2. Goal and research tasks

This research has a goal to develop the way of predicting priority directions of innovation as well as creating the most promising design of practical concept design especially for technology-based products.

1.3. To reach the goal

- Theory of Inventive Problem Solving (TRIZ) was adopted as a main method to facilitate creativity, which purposes to solve technical problems and offers innovative product structures by employing a knowledge base built from the analyses of approximately 2.5 million patents (Altshuller 1996). Since it was first proposed, TRIZ has gained a wider application area and its success has attracted many people in academia (Ishihama 2003; Kim and Cochran 2002; Rissone, 2004; Stratton and Mann, 2003). Also in practice, many large manufacturing companies such as Ford Motor, Motorola, Boeing and NASA are trying to use TRIZ to increase their creativity (Moehrle 2005). Nevertheless, there is limited knowledge of how to find new technology opportunities using TRIZ in the context of technology management, because most of TRIZ research has emphasized case studies, not a TRIZ-based new technique, through there are some exceptions (Jiang and Shie, 2011; Li and Huang, 2009).
- As part of an effort to link TRIZ to technology management tools, this research proposes a novel approach to identifying technology innovation opportunities by utilizing Su-field model together with TRIZ. Su-field model is used to analyze the system functions before TRIZ techniques are applied to the map and an Evolution Opportunity Map (TEOM), which is a map to help identify innovation opportunities, and a main idea of this research. The suggested approach was applied to the new technology generation process in Samsung Advanced Institute for Technology (SAIT), a private research centre in Korea, and verified its feasibility and utility.
- This research can be considered as an effective and powerful approach to support creating innovative ideas and also be practical since it was conducted from the perspective of company needs.

1.4. Scientific novelty of this work

- First in the world, this work provided a visual map for technology development prediction according to evolution vectors
- Developed new unified methodology of using function analysis together with Su-Field analysis in conjunction with lines of TS evolution for mapping of technology prediction
- Developed the new methodology for patent analysis with using Su-Field model
- Suggested model of work for inventor with top-management of enterprise and company needs

1.5. Practical impact/value of work

- Implementation of results of this research can be useful for all R&D work because suggested methodology takes in consideration not only abstract categories but real conditions of each enterprise
- Integrity with MOT(management of technology) system of industry innovation project planning
- Provide clear direction of drafting DOI(disclosure of invention) of patent for innovation direction

1.6. Main items for defense

- First in the world introduce connection between LTSE, Su-Field analysis, patent analysis as unified form for practical prediction of technology evolution
- Visual Technological opportunities map so called TEOM
- Platform for cooperation of inventor with top-management and MOT system

1.7. Personal impact of candidate

- Some part of Su-Field analysis and methodology of LTSE implementation appear as result of fruitful discussion with N.Khomenko, V.Leniachin, N.Shpackovsky.
- All another parts including statement of research, development of methodology and it practical implementation for lab on a disc has been done by candidate personally

1.8. Work approbation

- Main items of dissertation were introduced by candidate on TRIZ conferences (ETRIA, TRIZ Fest, etc)

- Practically the suggested methodology was successful use in Samsung Advanced Institute of Technology (since 2006 till now)
- This work guided a successful drafting "industry product" from "R&D concept" with short time

1.9. Structure and volume of work

This dissertation work consists of 7 sections: introduction, theoretical background of usual methodologies, and main part to describe the TEOM method and real application of TEOM for LOD (lab on a disc) project with following summary and conclusion. Part 1 introduction includes the description of the goal of this research and approach method of this research. In Section 2, two main techniques used for this research are explained briefly. Then, in Section 3, an approach to identify new technology opportunities is described, followed by a TEOM applied project of Lab-On-a-CD (LOD) by SAIT in Section 4. Finally, the limitations and future direction of this research are discussed in Section 5 with conclusion of TEOM in section 6 and section 7 with list of literatures.

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2. BACKGROUND

2.1. System function analysis

System function analysis techniques have been the main focus of value engineering. We review three representative techniques here. Firstly, *FAST* is a technique to systematically organise and represent the functional relationships of a technical system. In FAST, the system functions, both the basic and the secondary, are a fundamental concept and are displayed graphically in a *FAST diagram*, which emphasises the "how – why" relationships between them. The diagram shows the whole structure of a technical system with the inter-relationships of its functions and the system's relationships to the external system of which it is a part. This helps everyone to understand the system as comprehensively as possible.

FAST is a powerful technique to decompose a system, while *Morphology Analysis (MA)* is a technique to create a new idea from the decomposed system. MA was developed by Zwicky (1969) and can design solutions for multi-dimensional and non-quantifiable problems where casual modelling and simulation do not function well (Pidd, 1996). Basically, a system is composed of sub-systems, each of which can be shaped in different ways. MA identifies the various shapes that each sub-system may take and, by combining those shapes, examines all possible alternatives that the system may adopt. The number of alternatives may be reduced by eliminating illogical combinations using cross consistency assessment (Ritchey, 1998), which increases the practicability of MA. This technique is applicable to a wide spectrum of scientific disciplines in zoology, geology, linguistics (Huckvale & Fang, 2002), astrophysics (Zwicky, 1969), product engineering (Belaziz et al., 2000) and scenario planning (Rhyne, 1995). MA enables one to model a complex problem but only has a limited capacity to solve it. In other words, it only has a limited capacity to offer a desirable combination among alternatives.

On the other hand, *Quality Function Deployment* (QFD) technique can produce the most desirable system concept. It is a method to transform user requirements into quality design and relevant functions, and to guide someone along the way to achieving the design quality into subsystems, components, and ultimately specific elements of the manufacturing process. Now, QFD has extended its analysis beyond quality development to include cost, reliability, products and services, components, manufacturing and technology deployments.

Those functions can be linked to technologies using the *Technology Tree* (TT) abstraction. TT is used as an abstraction of technology and science, usually in the hierarchical visual representation of technologies associated with system functions. The tech tree is the representation of all possible paths of research with concerns the system. The TT concept has been implemented at an R&D division of large companies but the approach to develop TT is different by companies. For example, in Siemens, TT is an open process allowing all engineers the possibility of initiating their own knowledge network for a promising technology of their own choice (Heiss & Jankowsky, 2001). In Samsung Electronics, all R&D planning processes have included TT since 2000. After a function deployment is completed, each function is connected to patents and other technology information as a part of TT process, based on which R&D project work breakdown is produced and R&D strategy is established (Cheong, 2006). Once the system functions are well defined, making the decisions on how to improve the systems will be easier. Accordingly, this research deals with the issue of combining system function analysis techniques with TRIZ, a tool for innovative design, to direct the way to improve the system and ultimately to lead to technical innovation.

2.2. TRIZ method

Technology system evolution theory

TRIZ is a patent data-based approach to solving difficult problems innovatively as well as predict the future of the technical system. The realisation that nearly all innovative patents contained a solution to some type of contradiction – technical or physical – is at the foundation of the theory and overcoming contradictions solves both simple and complex problems. The basic tools of TRIZ include the contradictions, 40 inventive principles, the contradiction matrix, ideal final results, ARIZ (Algorithm of Inventive Problem Solving), the Trends of Technical Systems Evolution and the Su-field Model, etc. The latter two are mainly used in this research.

Analysis of emerging technologies and their potential opportunities for business should provide reliable guidelines to provide the most appropriate strategic decisions with minimal risk in the future. There are more than fifty methods for prediction (Porter, 2004) and a number of studies have suggested their own methods to predict the future. Out of them, TRIZ provides a powerful scheme to interpret and predict a technology evolution trajectory.

Altshuller (1996) found that technical systems followed a ‘foresee-able’ pathway that intersected with all fields of science based on the observation of long term technical system evolution. For instance, one of the basic axioms of TRIZ is “increasing the degree of ideality,” which is defined as a benefit of the technical system compared to a harmful effect or a cost of the system. A technical system tends to evolve towards increasing ideality. In another example, TRIZ assumes that a conflict comes from uneven development of a system and an effort to overcome the conflict drives the evolution of a technical system. The basic trends of evolution are summarised in Table 1. Whatever the Trend may say, it is based on the assumption that once involved in the technological evolution process, the system starts facing contradictions, and overcoming the contradictions brings innovation.

Table 1. Trends of technical systems evolution (Altshuller, 1986)

Static Laws	The law of the completeness of the parts of the system The law of energy conductivity of the system The law of harmonizing the rhythms of parts of the system
Kinematic Laws	Law of increasing the degree of ideality of the system The law of uneven development of parts of a system The law of transition to a super-system
Dynamic Laws	Transition from macro to micro level Increasing the S-Field involvement

Altshuller’s Trends of evolution were the first framework for people to understand whole technical system lifecycle, and he established S-curve concept for technical system evolution. These trends are meaningful ones because it defines objective laws of system evolution at the first time. Moreover, it links such historical evolution with technical creativity. But these trends were just classical observation only without tangible toolkit to utilize for field projects, because there were poor guide to use such trends to apply analysis of real technical system.

Following the Altshuller's first and high-level trends of technical system evolution, many TRIZ specialists have tried to organise several diagnostics and/or prediction approaches for specific purposes with or without full product development schema.

Petrov (2002) provided a systematic evolution lines with very interesting features. Evolution lines contains more definite ruler for understanding evolution stage comparing to those of Altshuller's high level trends. However, it provides high level guideline to apply field projects, because field projects needs step-by-step working procedure with detailed guideline. Anyway, Petrov's evolution lines could provides many people to understand more definite part and level of evolution following specific lines.

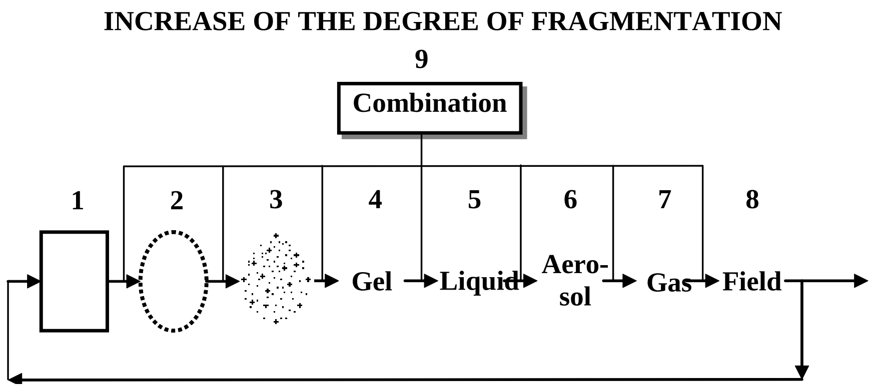


Figure 1. Evolution Lines of Petrov

Chuksin & Shpakovsky (2006) provided a visual analysis framework for technology evolution history which looks similar to a genealogical phylogenetic tree so called evolution tree (ET). ET provides visual way for understanding technical system evolution history which elucidates the 'real stream of evolution' of function, product feature. But it has limitation that it's too hard to create the real diagram of the evolution status and opportunity of real technical configuration as well as too hard to recognize to where is the more promising strategic direction. The most valuable feature of ET is its visual thinking which is useful for field engineers and high level managers to understand whole system evolution history at a glance.

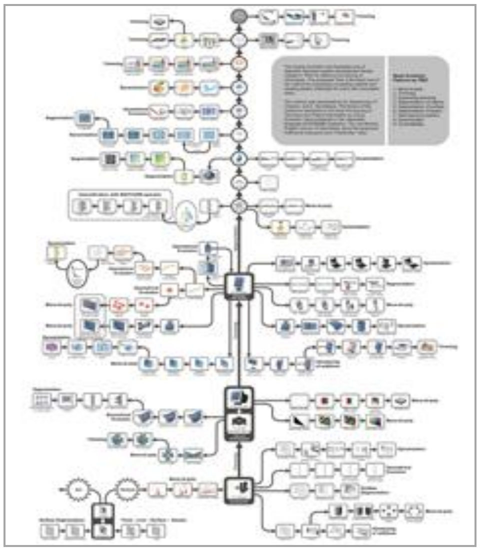


Figure 2. Typical example of evolution tree

Directed evolution suggested by Zlotin & Zusman (2001) provides a full scheme for product development scenarios, which provides researchers to follow reproducible step by step working process. Step by step procedure is really necessary guideline for field working in any instances. But unfortunately it's so hard to understand the finite result at a glance, and it takes so long time even for understanding the result as well as the procedure. In 2005, 2006, SAIT had experiences to evaluate the workability of directed evolution methods for real project, the field engineers responded that it was useful but it was too hard to follow and it took too long time to make. However, its step by step working flow is necessary for novel evolution analysis frame.

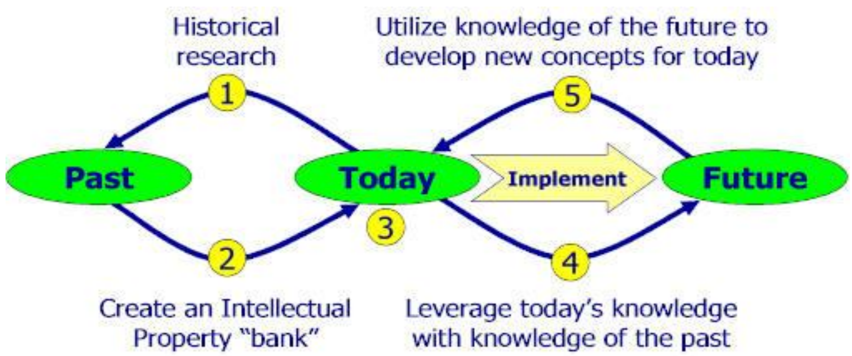


Figure 3. Scheme of Direction Evolution Roadmapping

Mann (2002) provided evolution potential radar chart, which could be used to evaluate specific technical information with evolution metric quasi-quantitatively. It is useful to analyze each patent case by case; however, it has limitation that it's impossible to show off all collection of patent at a glance because of poor structuring scheme. Mann suggested that it is useful to 'predict' direction of evolution as well as diagnose evolution level of specific technology, however, real experience in SAIT generated too many argues which direction could be more promising or not.

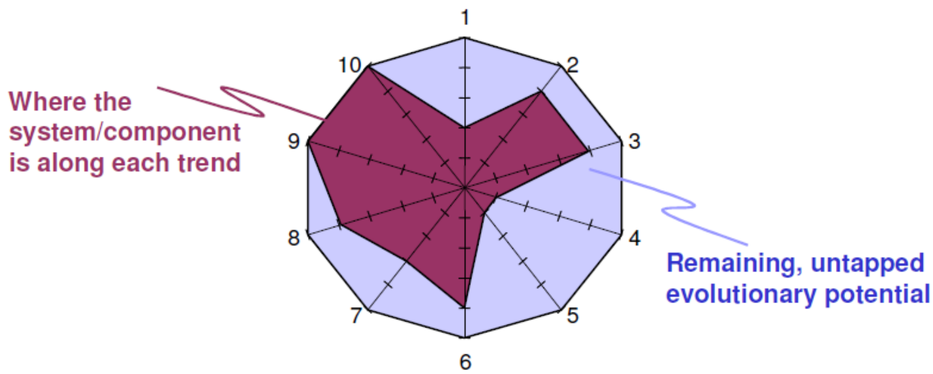


Figure 4. Evolution opportunity potential radar chart

Fey (2005) suggested a macro schema of product development based on classical TRIZ philosophy like the solutions to contradiction and the trends of technical evolutions, whereas Becattini et al. (2009) suggested an information analysis framework and evaluation criterion of technology evolution with definite logical links to the axiomatic schema of evolution theory. Cavallucci (2001) integrated the trends of technical systems evolution into the prediction of the impact of a technical solution.

Rubin (2010) described evolution of operation principle model in his previous work which provides great impacts on R&D point of view. Yang and Chen (2012) applied TRIZ evolution patterns to forecasting the design of eco-products. Yoon and Kim (2012) identified evolutionary status of systems from patents, building on TRIZ evolution trends, which were proposed to be incorporated into the product forecasting process.

Despite the usefulness, executing technical evolution analysis needs the filtering, handling and abstracting of an enormous amount of relevant information covering patents, journal articles, conference proceedings, exhibition reports and other technical reports, which can be a bottleneck for the prediction of evolution. To minimise such burdens, Russo et al. (2009) suggested a framework for information mining and clustering based on TRIZ, which is called a Knowledge

Organizing Module (KOM). Although KOM seems useful for a well-defined target system, it is inevitable for human to look into the whole system especially when the future is unclear.

Su-Field model

TRIZ provides a method of creating a model for technical system as well as non-technical system. The minimum model of technical system could be designated as combination of field (F) and two substances (S_1 and S_2) as a basis of system analysis. Hence this method is called "Su-field Analysis" and the model developed with the concept of field and substances is called the "Su-field model." Since Salamatov (1999) had summarized the whole scheme and standard solution in well-organized form, most engineers had used su-field model and standard solution for understanding and solving problem. Belski (2007) described interaction from S2 via F toward S1 and 5 solving route definitely.

However, it is necessary to discriminate the difference of driving force of S2 and interaction type between S2 and S1. For instance, liquid stop/passing valve of lab on a chip device interacts on the liquid mechanically only nothing else but, valve operating principle are based on various driving force from mechanical to optical. So I modelled the field as driving force of S2 and discriminated it from interaction between S2 and S1.

Rubin (2010) described two types of system model so called ele-field model, which is useful to describe operation principle model of a given system. His suggestion provides a way to see trends of evolution patterns for each element and field, which is useful frame for designing future system schema. But visible frame and step by step working process for such future design should be provided to be adopted for real field project.

This standard minimum system model and its transformation is a generic formulation for a specific problem, which becomes the foundation of standard solutions to solve the problem. A collection of those solutions construct a set of 76 standard solutions that may be utilised when the system model has deficiencies or inadequacies. These solutions or standard transformations are grouped into five classes and can offer highly innovative solutions to previously intractable systems. Though many different models can be used to examine system evolution, this research introduces the Su-field model for analysis both at the macro-level (for main functions) and at the micro-level (for detailed elements), before tracking system evolution. The 76 standard solutions are expected to direct system evolution. Since system evolution occurs mainly by advances in materials ('substances' in TRIZ terms) or changes of energy ('fields' in TRIZ terms) that operate the system, and more commonly by combinations of the two, the su-field model seems to be one of the most simple and realistic models to track the evolution of technical system operation principle.

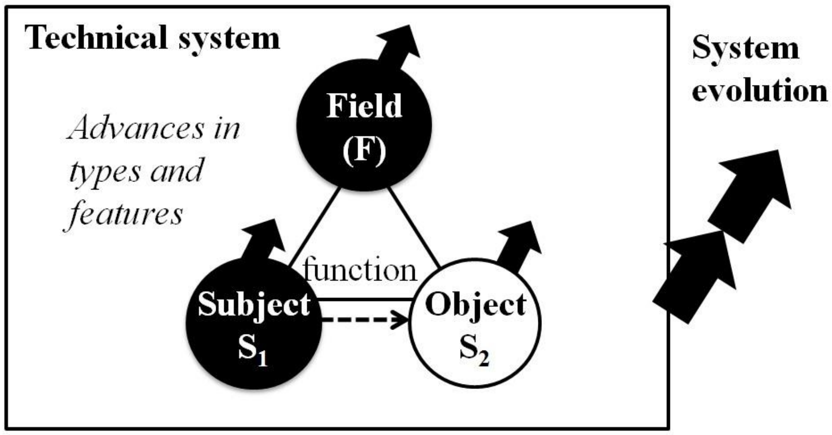


Figure 5. Basic model of technical system operation principle and its evolution analysis

Figure 5 shows a basic model of technical system operation principle and its evolution analysis in this study. In this model, a "S2, subject" and a "field" that constitute a system may produce beneficial, insufficiently beneficial, harmful, or no functions on an "object" in the system. Here, the "S2, subject" is the element performing the functional action whereas the "object" is the element being worked on. The "field" is the driving force to operate S2 to perform interactions between the subject (S2) and the object (S1). Consequently, every function operation principle has the form "Subject (S2) acts on Object (S1)" and "F1 (driving force on S2) and interaction (energy transfer way between S2 and S1)" which can be described as "the active action of a tool, or instrument, on the passive object being worked on." In general, advances of these types and features are observed in field, object and subject to cause the evolution of a system.

In this study, I just adopted S2 and F1 only to minimize the complexity of patent information analysis and designating graphical drawing of evolution map. But in further study, introducing all participants in the operating principle model designated in Figure 5 might be possible and should give the researchers more valuable information of evolution of operating principles of specific technical system.

3. TEOM APPROACH

3.1. Proposed approach

During several years of field experience of TRIZ and evolution study, SAIT managers and researchers had provided me many design points of novel TRIZ evolution techniques. Such voices of customers are summarized in the next table. I should consider the link between TRIZ based evolution method with the technology management system operated in SAIT also.

Table 2. Requirements for technology prediction method

	Top Manager	Researchers	Management System
Mandatory	•Show me something to make decision •Based on industry objective law	•Easy to handle •Reduce time /human resource	•Align with exisiting SAIT R&D management system
Attractive	•Easy to understand and decide something	•Easy to explain the result to the top manager without complicated comments	•Simple SW(e.g. excel, powerpoint) is enough to handle the method •Seamless to SAIT known methods, for example, technology tree, patent map, technology roadmap

Mandatory requirements from top managers were 'something useful to make a decision' based on industry objective law. Usually top managers are so busy persons which mean 'something' should be very easy to understand at a glance. I've got requirements from the researchers who work to make such 'something' with TRIZ technique. They asked me that 'method to make something' should be very clear and consistent with minimal time/human resource with reliability to explain it to top manager as summarized in Table 2. Analyzing existing methods and requirements I defined problem statements to solve as following.

3.2. Problem statements

Problem to be solved of conventional evolution study is as following.

- Poor technology evolution guide based on technical information (e.g. patent)
  - Structure, operation principle design guide is insufficient
- Diagnostic oriented evolution tool
  - New direction creation as well as diagnostic
- Complicated process and result
  - Hard for CEO to make decision
  - Hard for researchers to complete all step during 3~4 weeks planning stage

What the author intended in this study is to provide more concrete technology evolution guide of evolutionary forecasting as well as diagnostic with instinctive/visual result as well as affordable working process. I propose inventive strategy, based on the new matrix of evolution in order to discover new technology opportunities.

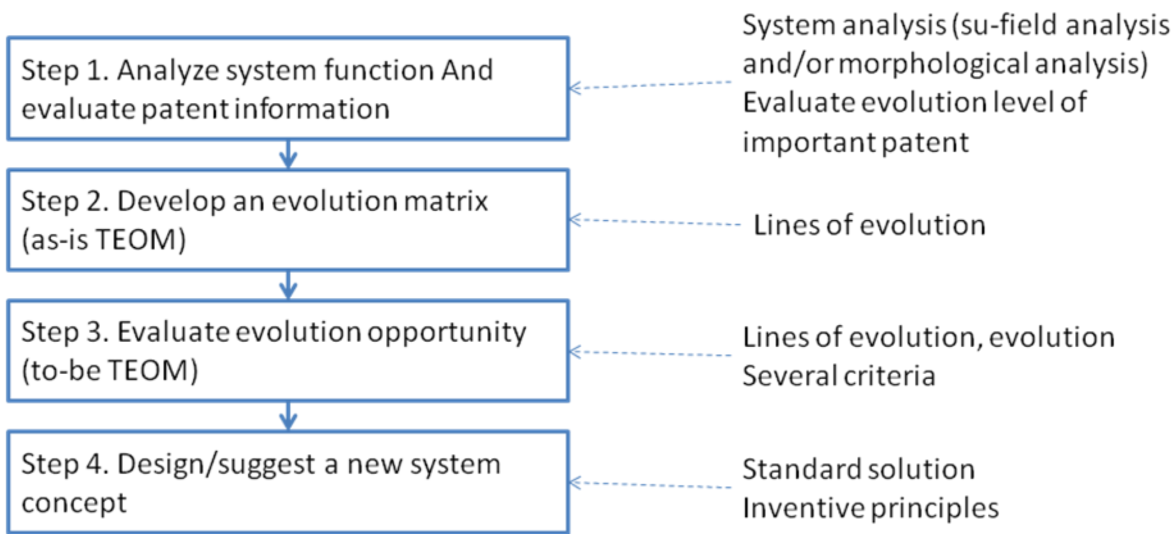


Figure 6. The overall process to identify new technology opportunities

3.2. Detailed procedure of TEOM

This section explains detailed procedures to apply the suggested approach. Whole procedures are described in fiture6. In the first step, the main functions of a target system are analyzed using function analysis techniques such as *Su-field Model*. Su-field model provides the operation principle of tool in the technical system. As itself, it is a representative minimal technical system model also. Its component of su-filed model follows each evolution lines, which are the point I focused. Designating each evolution lines of su-filed model following visible platform, whoever want to understand the evolution trajectory can understand the whole evolution trajectory designated in figure 2 and 7.

To provide high level of reliability of prediction, existing patent information of operating principles gathering and evaluation following evolution levels were conducted also similar to that of Mann (2002). But the analysis level was focused on the operation principles evolution only. Because the function and product type are pre-defined and high level managers asked the researchers to think about novel operation principle for designated function/product type. It is not usual for product manufacturing company, but it is usual for corporate research institute like SAIT case.

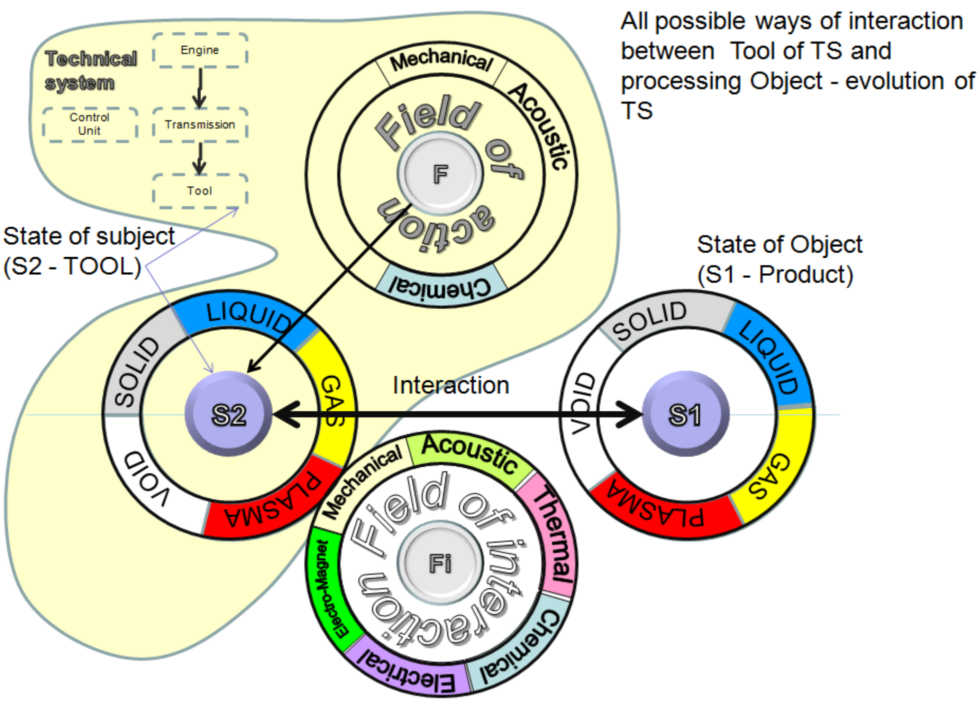


Figure 7. Su-field model of operation principle of tool (S2)

Then, out of the identified functions, two major factors expected to drive innovation in the system are selected to be used in developing an *Evolution Opportunity Map* (TEOM). TEOM is a two-dimensional matrix where the technical evolution patterns of the two factors is described applying the *Lines of Technical Systems Evolution* in Petrov's guidance (2002).

By combining new technical attributes in the evolution paths of S2 and field, it is possible to discover innovation opportunities. The opportunities range from the most advanced to the most similar to the current system. They are evaluated in the third step to determine the one most suitable for a next-generation system. Finally, the last step focuses on designing a system concept model capable of realizing the opportunity. Here, it is usually inevitable to have some technical problems in designing the system. Conventional standard solution and/or conflict resolving principles could help solve the problem, obtaining enabling technologies and feasible solutions to implement the innovative idea.

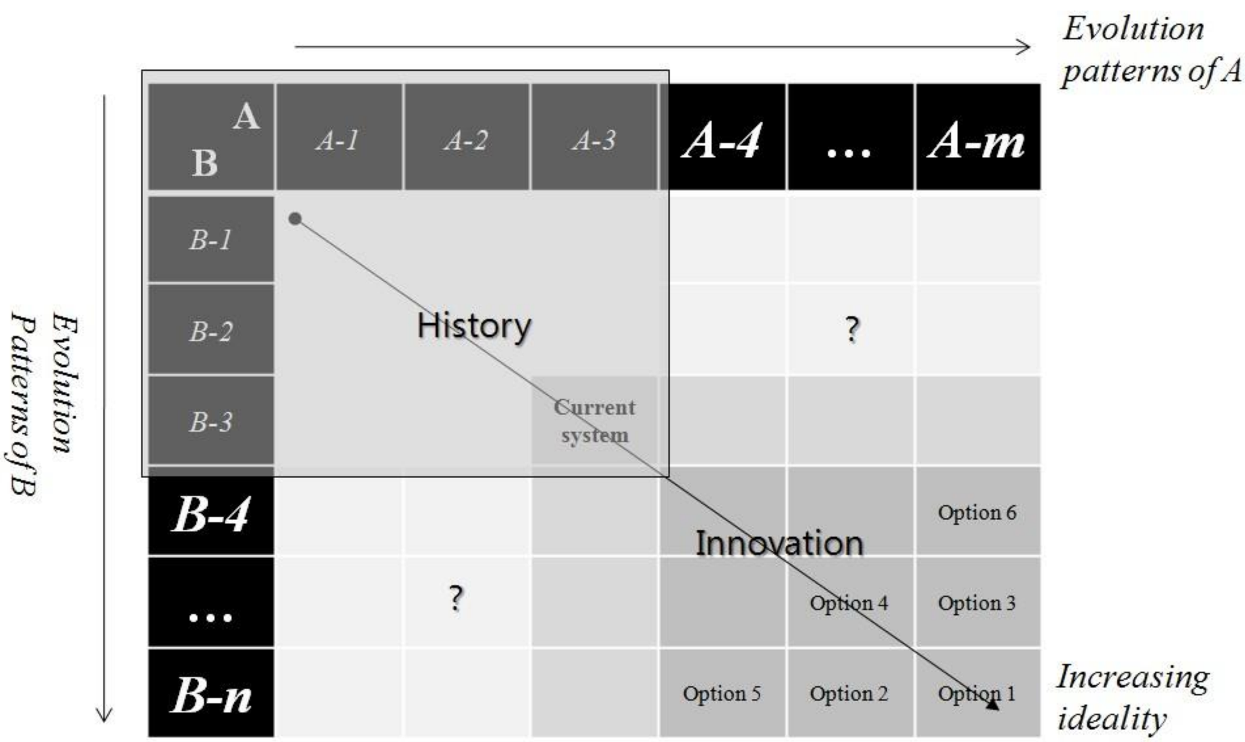


Figure 8. A TEOM developed using evolution patterns in X-Y frame

After the system modeling is completed, two key dimensions are selected and a TEOM is developed for them (see Figure 8). Then, the trends of system evolution is applied to the past evolution patterns of system. In detail, after picking up the most suitable law from the list of system evolution trends that TRIZ suggests for each dimension, its future direction of evolution is predicted. For example, in Figure 8, the trends of system evolution that correspond to A-1, A-2 and A-3 are retrieved and selected from a database, based on which A-4, A-5, … and A-m are predicted for dimension A.

When the TEOM is prepared, m × n ideas can be drawn from the combinations of shapes in two dimensions. Among them, ones that already exist are removed from the candidate list of new ideas, which are then arranged by priority. In this research, we recommend starting from the most advanced candidate. According to TRIZ, a system is evolved to increase ideality, and so a major innovation is most likely to happen in the most advanced condition. But to provide meaningful direction of innovation, it is inevitable to evaluate the feasibility of vacant/prospect blank of the matrix in Figure 8. For example, in Figure 8, the concept derived from the combination of B-n and A-m is a top priority. The final task is to determine the best concept by evaluating the candidates with respect to technical feasibility, internal capability, cost, benefit, and environmental factors. Of course, evaluation criteria should be tailored to innovation purpose, characteristics of the target system, and surrounding conditions.

4. TEOM APPLICATION

4.1. Background of the real project

The suggested approach TEOM has been applied to idea generation at SAIT and verified its feasibility and utility. SAIT is the Samsung Group's central R&D organization, established as an incubator for future cutting-edge technologies, and is in charge of innovation. As a result, innovative idea generation and new technology development are one of the most significant activities in SAIT. To facilitate the activities, SAIT has used TRIZ methods in a variety of ways since 2002 when it first adopted a technical systems evolution approach (see Table 3).

Table 3. SAIT's historical approaches on technical systems evolution

Year	Attempt to adopt TRIZ techniques
2002	Introduction of the approach
2003	Internal study of evolution theory
	First trial of the basic evolution tree approach
2006	First trial of the evolution scenario writing
	First trial of 'Su-field model' and 'TEOM' (Success)
2007	Trial of 'TEOM' approach (Success)
	Development of 'Evolution patterns'
2008	Trial of 'TEOM'(Success)
2009	Development of hybrid approach of 'TEOM', 'Ideation' and 'Planning'

Figure 9. Typical operation of LOD

LOD is abbreviation of terminology, Lab on a Disc. Its function is to identify biochemical ingredient of body fluid, especially blood during very short time. Since ʹ06 SAIT Project has been started and its aim of 2006 was to configure novel design scheme of LOD differentiated from competitors (e.g. Abaxis, Gyros). Purpose of TRIZ activity was reading internal evolution lines of LOD core module and suggests high evolution potential design. Most serious problem of LOD was that valve module to deal with small volume of biochemical fluid should perform its function well enough as well as patent differentiation.

Figure 9 shows typical working process of lab on a disc in real medical diagnosis. The TEOM was applied to a micro-liquid handling system for Lab-on-a-Disc (LOD). The pilot test for the new system was successfully conducted in 2009 and the relevant technology is planned to be delivered to Samsung Electronics Division. LOD is a medical diagnostics kit based on a compact disk (CD) which carries sensors and other devices, enabling medics to quickly and automatically analyze saliva, blood, urine and other biological samples. The purpose of the R&D was to develop a real-time and point-of-care testing (POCT) LOD system. Despite the 20.2 billion dollar market expected over the next decade (www.marketresearch.com), LOD has been used only for simple biochemistry analysis because of technical limits. The suggested approach was tried to discover breakthrough technology that can overcome these limits.

4.2. System modeling and information analysis

First, we carried out system function analysis for LOD. The functions required to analyze blood via LOD are as follows: 1) Plasma separation from the blood, 2) Fluidic operation of biochemical reagent, 3) Biochemical reaction, 4) Detection of the result of biochemical reaction (Cho et al., 2007).

Interpretation of signals after detection is also important for commercialization but excluded from this work. It is noted that liquids such as blood are moved by centrifugal forces during fluidic operation and so additional components to deliver the liquids were not needed, which made the system small. The structured function analysis results are summarized in Figure10. This tree type function analysis is called as technology tree in SAIT (Cheong, S.H. 2006), which is widely used for patent/information analysis frame since 2000. Physical operation stage of blood flow is designated in Figure 11.

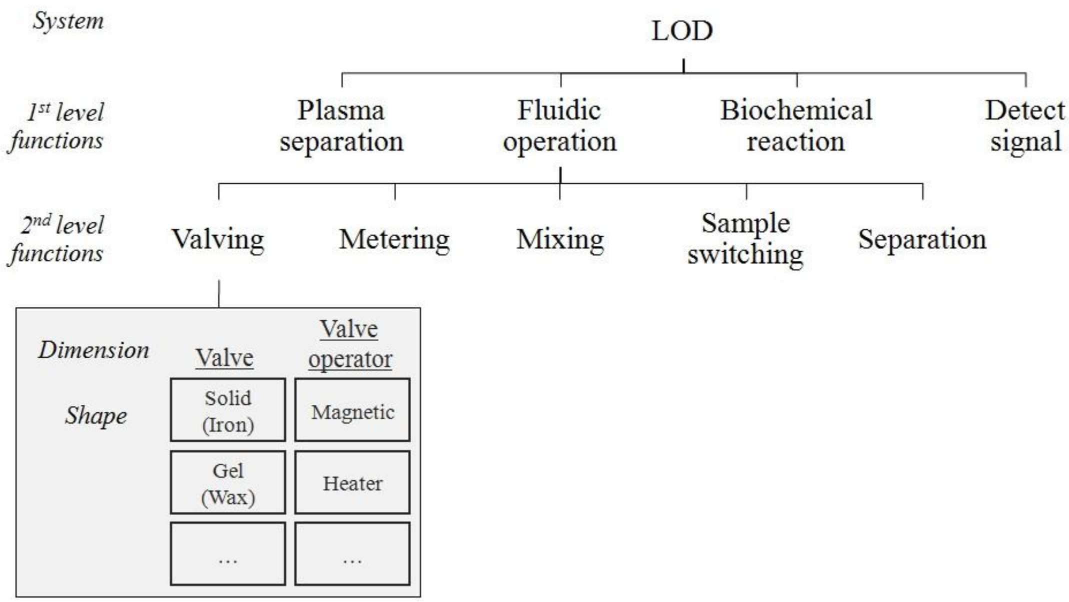


Figure10. Hierarchical structure of LOD system functions

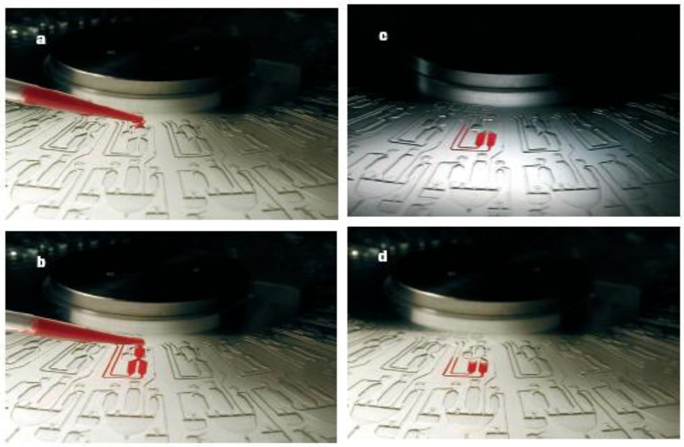


Figure 11. Blood flow of LOD during operation

Out of the four functions at the first level, fluidic operation was the main concern as the use of existing LOD products had been limited due to the absence of technology to control valves separately. It was judged that development of technology related to "valves" and "valve operators" was in urgent need (Park et al., 2007). Therefore, *valving* was selected as the main technology driver and thus a TEOM on a valving system became the goal. For the purpose, a task force (TF) team consisting of TRIZ experts and technology experts in the field was organized, working on the project to analyze the evolutionary path of LOD and its future direction.

Firstly, the TF team created a Su-field Model of valves to examine the fundamental value that the valve should provide in its functions. In the model, three elements – subject, object and field – are defined and functions are expressed in the syntax of "subject-verb-object" where the "verb" signifies the action of the subject to change or preserve the property of the object. The main functions (MFs) of the valving system are expressed in TRIZ syntax. Considering the two functions, the Su-field model of the valving system can be defined as Figure 12.

MF1 : valve – hold – fluid (useful function) when fluid holding is necessary
MF2: valve – pass – fluid (useful function) when fluid passing is necessary

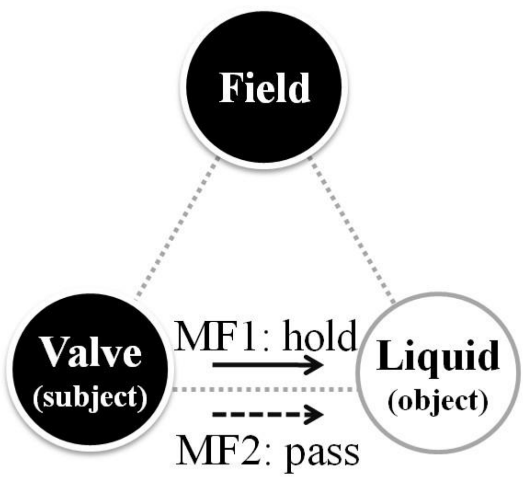


Figure 12. Su-field Model of a valving system

According to the TF team, the *valve* and *valve operator* were the critical dimensions for a valving system. For competitors such as ABAXIS, GYROS, IMTEK, TSST, UCK and Gamera Bioscience, technologies used in their micro fluidic devices were analyzed, especially focusing on the two dimensions. They found that the biggest difference among them was "the composition of substance (S)" for the valve and "the field to operate the valve (F)" for the valve operator. For instance, TSST possess a technology that uses a magnetic valve and strips (S) operated by a magnetic field (F), while Gamera Bioscience has a technology of valves (S) activated by heat (F).

Before developing a TEOM for LOD, the features of an ideal system stemming from the limitations of MF1 and MF2 in existing valves were discussed to set a development target for SAIT's LOD (see Table 4).

Table 4. SAIT's development target of LOD

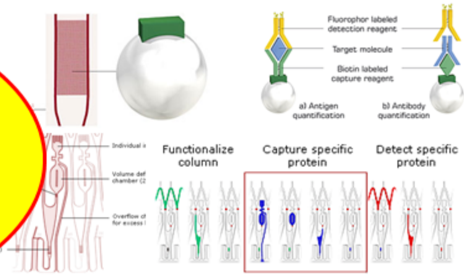
Categories	Limitations of the existing valves	Characteristics of an ideal valve
MF1	Difficult to charge liquids Water leak under high pressure	Easy to charge liquids Available under high pressure
MF2	Slow response Unable to control multiple chambers Inference between chambers Variants in the amount of liquid and position	Quick response Able to control multiple chambers No inference between chambers The right amount of liquid at the right spot
Others	Expensive and unique materials Complex structure Complicated manufacturing process High unit cost	Common materials Simple structure Simple manufacturing process Low unit cost

Keeping those requirements in mind, the evolution patterns of critical dimensions towards an ideal valve system were identified. Actually, several patterns are applicable to the evolution process of valve (*substance*) and valve operator (*field*) but only one dominant pattern was selected for each dimension to facilitate visual thinking in two-dimensional space.

The Trends of Technical Systems Evolution that was matched to the evolution patterns of valve and valve operators were collected from the works by TRIZ experts (Fey 2005; Mann 1999; Petrov 2002; Shpakovsky 2006; Zlotin and Zusman 2006). First, from the comparison between the trends and the features of a valve, it was concluded that "*transition from macro to micro level*," particularly "*changes of aggregate states*," was most suitable to explain the dominant pattern of evolution. According to the law, technical systems tend to evolve by transforming the physical and chemical states of an object from a solid to a liquid, a liquid to a gas, a gas to a plasma, a plasma to a low-density or vacuum state, a vacuum to a mixture of solid, liquid, gas and plasma (e.g. bubble, spray, dust, or carbon dioxide gas), and the mixture to a field. On the assumption that the composition of valves follows the law, many different concepts for advanced valves can be created. On the other hand, we selected "*changes of fields*" for valve operators. The law says that technical systems have a tendency towards using more controllable and flexible fields to provide system functions in a more ideal way. Supposing that a valve operation mechanism will be developed that changes mechanical fields to acoustic/pneumatic, thermodynamic, chemical, physicochemical, electric, magnetic, or electromagnetic fields, researchers can develop concepts for the advanced mechanism of valve operation.

According to the evolution axis of substance and field, I classified evolution stage of each competitive technology found from patent pools as following figure 13. Designating the evolution status of substance and field according to evolution lines, evolution stage could be evaluated quasi-quantitatively.

Title	Hydrophobic valve			No.	6010554
Date	1997-06-23	Assignee	Gyros	Country	US
Substance keyword	No substance		Field keyword	hydrophobic	
104 sandwich type < 50 min sample automatic intert • Complicate procedure to bri • high rpm for operation • Hard to bring multi chamber • Liquid pre-fill is impossible					
Target	blood		Spec.		



			high	medium	low
Key Funtcion contribution	①	Response time	■	□	□
	②	cost	□	■	□
	③	Simple structure	■	□	□
	④	Manufacturing easiness	■	□	□
	⑤	patentability	■	□	□

Figure 13. Evolution status analysis frame for real technical information

4.3. Development of a TEOM

Gathering the evolution analysis results for every important technical patent denoted in figure 13, I could suggest a layout to show off evolution status of LOD valve as following. The two main evolution drivers were used for the x-axis and y-axis to develop a TEOM for LOD (see Figure 14).

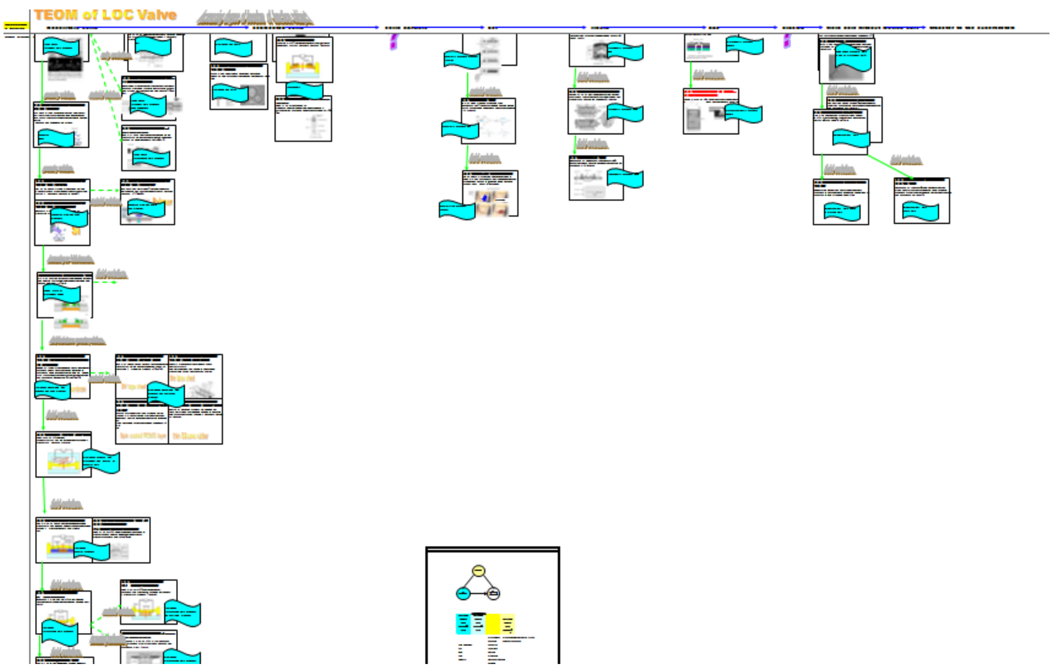


Figure 14. Whole TEOM diagram for LOD valve operation principle

Until now, most valves are in a *solid* form and *mechanical*, *thermal*, *chemical*, *physico-chemical* and *magnetic* fields have been used to operate them. Using a solid is at the very early stage of evolution, which creates a lot of room to improve. Figure 15 highlights the focused area of detailed TEOM in figure 14.

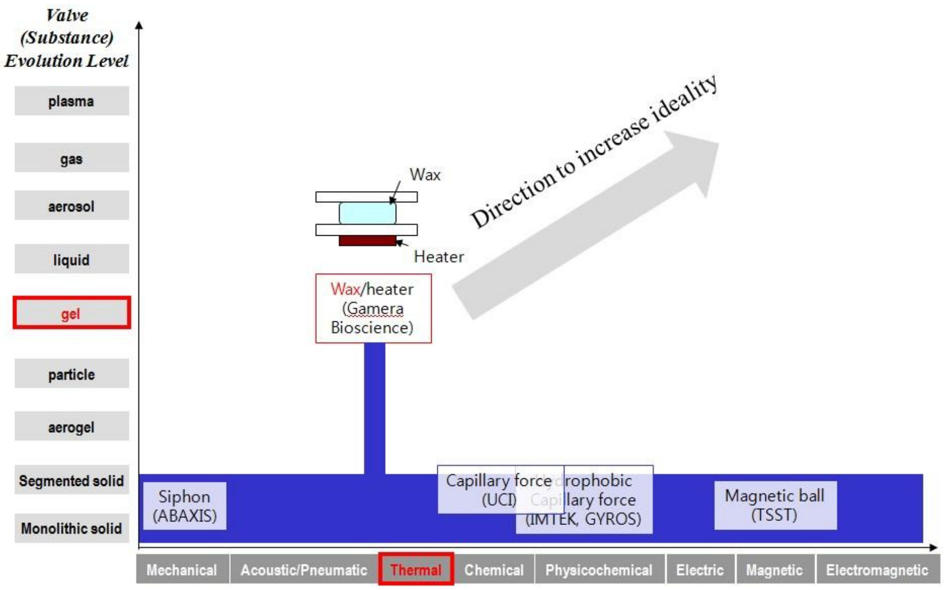


Figure 15. Position of the existing products

4.4. Opportunity analysiss and concept design

Since ideality increases in the upper-right direction of the map, the TF team started to create system concepts from the combinations of valves and valve operators from the upper-right side to the lower-left side. Then, the concepts were assessed with respect to technical feasibility and market profitability (see Figure 16).

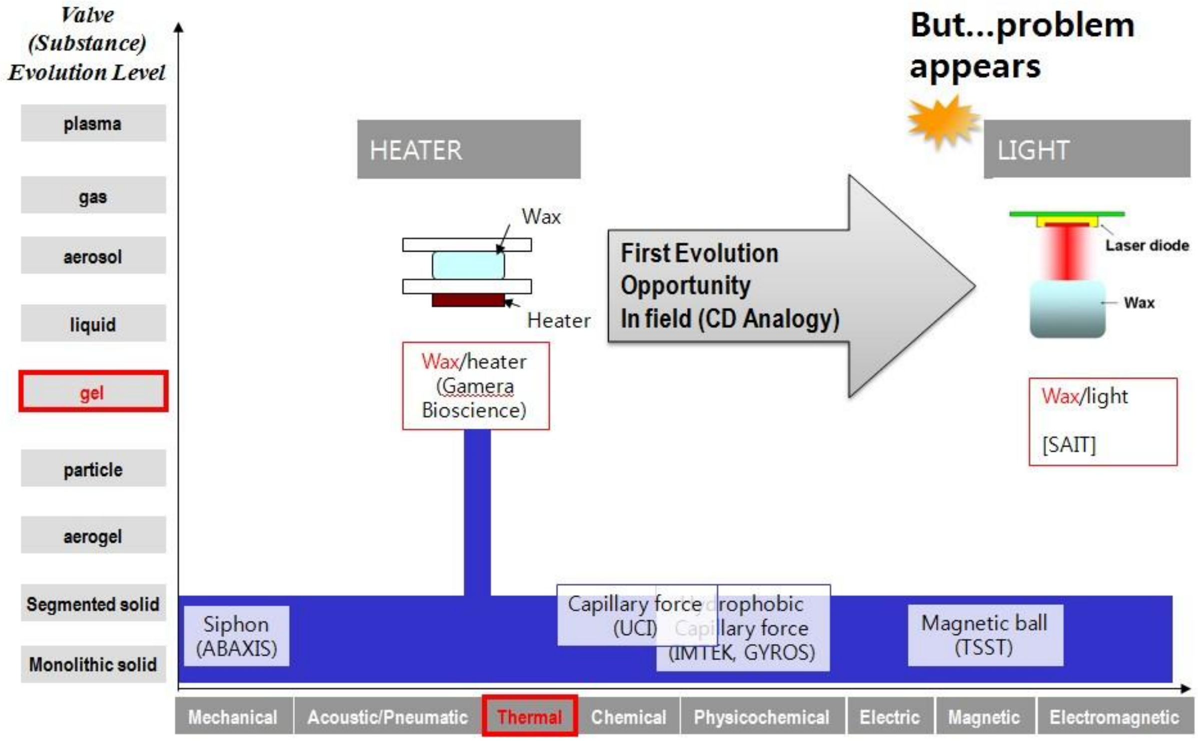


Figure 16. Development of feasible and promising concept

Although a new system concept was successfully developed by TEOM, the initial system still had some problems to be overcome, which are called barriers of innovation. The classic TRIZ tools were used to get over these barriers. I tried to solve the problems by applying *Standard Solutions* to the *Su-field Model.* The LOD by Gamera Bioscience has a wax-based valve system (USP 6063589, 2000) whose underlying principle is similar to the new concept. A valve, which is made of wax and is solid at room temperature, blocks the flow of blood (or other liquids) before a test begins. However, when a test begins the wax is heated, which will cause it to melt and open the valve. Then the blood can move by centrifugal force to a tester, which is located at the edge of a CD, and a test reaction starts. If the heat stops, the melted wax is solidified and will block the flow of blood until the next test begins. This system works well, because the valve both passes and restricts liquid well, and can be turned on or off in 10 seconds. But with all its advantages, the largest drawback is a limitation that a thermal field generator complicates an LOD system. Using an *electromagnetic* field, specifically *light*, as a valve operator, simplifies the system greatly. However, in testing the team members faced the problem that it takes too much time (more than 30 minutes) for light to melt the wax, even though the electromagnetic field is the most advanced one in the evolutionary path of fields according to the trends of evolution.

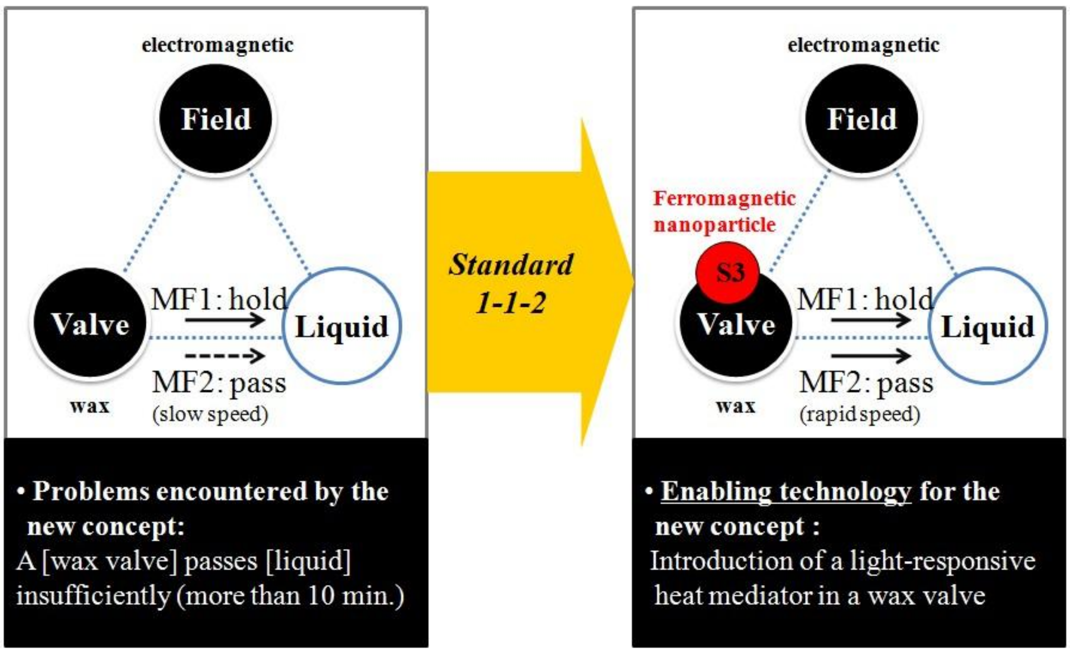


Figure 17. Advanced solution for evolutionary problem drawn from TEOM

To find a solution to the problem, the Su-field Model in left part of Figure 17 was adopted again to describe the problem. In the problem model, a valving system can be described with two main substances (valves and liquids) and one field (valve operator). The technical problem here is that the valve fails to pass liquid well because it takes too much time for the laser to melt wax. The 76 standard solutions for su-field analysis proposed that the following *standard 1-1-2* could be applied to the problem. The solution is recommended when insufficient effects (passing liquid) should be improved with little or no change of object (valve) and adding a new substance or field is possible as in this case. Following the solution, ferromagnetic nanoparticle irradiated by laser was added to the wax and the initial concept was transformed to a more advanced one where the ferromagnetic nanoparticle is activated by light. This reduced the response time from 30 minutes to less than 0.5 seconds (original spec).

4.5. Results and discussions of LOD project

Using the suggested approach, the TF team developed the world's first ferrowax-based LOD, winning SAIT's Frontier Award and Breakthrough Award in 2007. As the new concept of using electromagnetic fields enables a compact LOD design, it will help extend the application areas of LOD. At the same time, technical performance was greatly improved with the valve response time less than 0.1 second and the testing cost less than 0.01 cents. A number of technical solutions were produced during the concept development process when Su-field Analysis was repeatedly applied. They contributed a lot to the innovation of LOD, some of which were published in a cover story of the best journal in the relevant field, resulting in 39 international patent applications. Performance of valve enhanced dramatically of which open time from 1800s to less than 0.1 second. Figure 18 represents final version that I and team members suggested in this project.

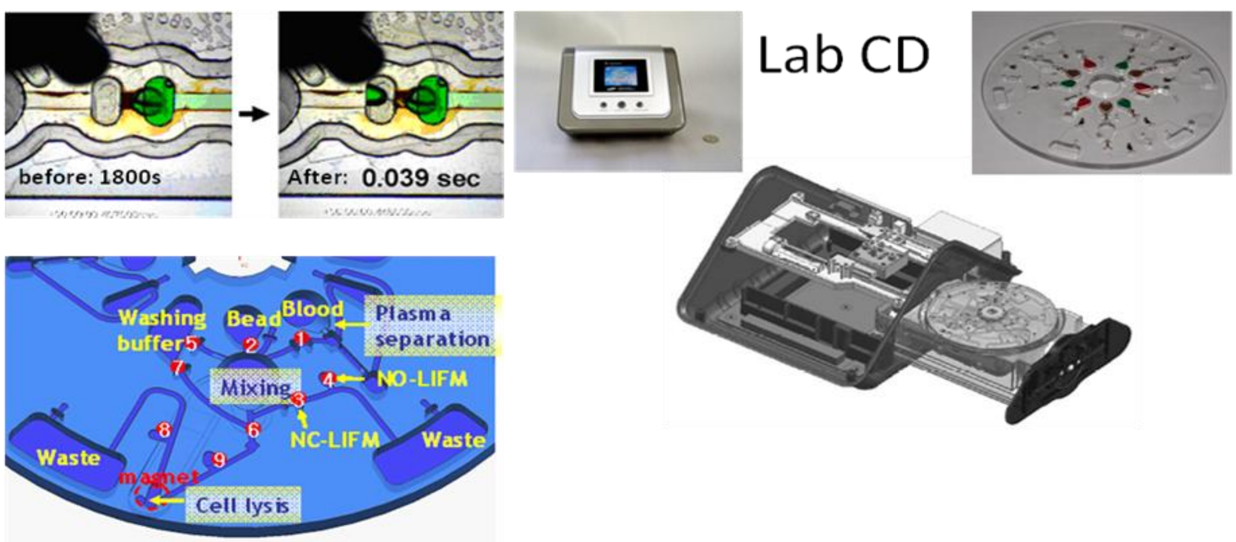


Figure 18. Final version of LOD with valve improvement

This LOD project ensures that the proposed approach is feasible and effective, meaning that TRIZ tools can contribute a lot to the technology innovation process. In particular, the suggested approach is distinguished compared to the other tools in that it starts with defining the conditions of the ideal state and then designs a concept to meet the conditions, whereas most of the other tools try to devise a new system by way of analyzing the existing system to improve. And so, disruptive innovation can happen with the suggested approach. However, in order to get the most benefit from the suggested approach, it is critical to both select the main drivers of system evolution, and to apply a proper evolution theory to the trend of drivers. Therefore, not only TRIZ experts but also experts with domain knowledge should participate in the concept generation process. Finally, the suggested approach is isolated from the other planning techniques such as technology roadmap and QFD in SAIT up to now, but can be more powerful if integrated with them.

5. SUMMARY

5.1. Scientific Novelty of the Work

First in the world, this work introduces Su-Field analysis, patent analysis as unified form for practical prediction of technology evolution. It is the world first [tangible] guide for operational technology configuration as well as product/ function design with evolution line as a ruler of axis and su-field model as technology operation principle schema based on real patent information evaluation. It is a new methodology for patent analysis with using Su-Field model and lines of technology evolution. First in the world, this work provides the R&D researchers as well as top mangers clear opportunities map of technology evolution.

5.2. Practical impact/value of work

Implementation of results of this research had been proved useful for all R&D work because suggested methodology takes in consideration not only abstract categories but real conditions of each technological principles. It is based on bibliographical information as well as evolution theory, therefore it can provide the researchers and decision makers to have bigger confidence comparing to just bibliographical data only or evolution theory only.

TEOM provides step-by-step guideline for each activity, which minimize the mistakes to apply evolution lines toward real technical system. TEOM forecast future direction very clearly based on the vector of evolution axis so, which indicates innovation direction with minimal ambiguity Usually conventional management tools such as QFD can provide only functional or very abstract level of design scheme but TEOM can provide tangible technological operation scheme design, so field engineers shows great friendliness for TEOM after patent analysis work for their own project planning as well as novel patent drafting.

If the operation principle is abstracted as a su-field model, non-technical operation principle evolution can be deployed following same procedure for prediction. Since 2006, 6 years pilot runs of TEOM have been conducted in SAIT and showed successful result for especially very early stage of R&D projects. The suggested approach has been applied to the concept generation process in SAIT several times, which verified its feasibility and utility.

5.3. Further development

In the methodological perspectives, the suggested approach, which indicates the direction of evolution, is different from the previous approaches that identify technology opportunities with trial-and-error. Moreover, it tries to facilitate disruptive innovation by designing a new and ideal system rather than extending existing systems. In the practical perspective, this paper describes a methodology that has been used for several years in practice. Also, the real project application of TRIZ, which is frequently mentioned as a useful tool for technology innovation but lacks detailed guidelines on how to apply it to a new technology planning process is provided and thus will ensure the practicality of TRIZ.

This research will be developed following several liens of *evolution*: Firstly, the suggested approach focuses on only two dimensions in developing a TEOM and identifying new concepts, since it addresses only the functions with the most important technical operation principle that are the keys toward innovation. An extended version of TEOM will have multiple analysis axes for complex system with the aid of information analysis software.

Secondly, this research is descriptive in nature and needs to be more systematized in its procedures, being combined with other frequently used techniques of technology planning. For example, it will be helpful to develop guidelines for matching the evolutionary patterns to the features of innovation drivers. Future research should address such issues as how to select the main drivers and how to analyze technological opportunities in a TEOM more rigorously.

Finally, this research introduces only one case, and more cases are needed to have external validity. More case studies should be conducted to define the technical fields or the characteristics of technical problems suitable for the approach.

The development of logic with sophisticated software systems will be developed for comprehensive evolution analysis and disruptive systems evolution.

5.4. Final Remarks on this research

The Author impresses the sincere acknowledgement to all of my TRIZ teachers and my colleagues who are Korean or foreign (Russian and other countries). Without their friendly helps, this research hardly has ever been done.

6. CONCLUSION

6.1. A unified approach composed of system operation principle modeling, patent information analyzing, evolution direction analyzing, future technological concept design method is provided with the name of TEOM (technology evolution opportunity matrix). These methods are complement and practical application way of the Theory of Evolution of Matter and Models (TEMM) as part of TRIZ.

6.2. Unified approach of TEOM consists of 4 step working process: step 1. Analyze system function and evaluating patent information, step 2. Develop and evolution matrix, step 3. Evaluate evolution opportunity, step 4. Design/suggest a new system concept with innovative operation principle

6.3. Source for TEOM comes from published bibliographical information for instance, patent, journal articles, conference proceedings to enhance reliability of the based information. Bibliographical information is evaluated by evolution lines before TEOM layout.

6.4. Output of TEOM is the evolutionary opportunity map with clear direction for further innovation of technical principles.

6.5. Su-field model can be used for analyzing operation principle to designated evolution axis of operation principle as well as morphological analysis, function model etc.

6.6. Evolution lines matching component of substance and field might be selected and used to designate each evolution axis.

7. LIST OF LITERATURE

Becattini, N., Cascini, G., & Rotini, F. (2009). Network of evolutionary trends and maturity assessment through contradictions analysis. *5th TRIZ symposium.* Japan, Tokyo, Sept 10-12, 2009.

Belaziz, M., Bouras, A., & Brun, J.M. (2000). Morphological analysis for product design. *Computer-Aided Design, 32,* 377-88.

Bonnardel, N., & Zenasni, F. (2010). The impact of technology on creativity in design: An enhancement? *Creativity and Innovation Management, 19(2),* 180–191.

Burkhardt, J., & Lubart, T. (2010). Creativity in the age of emerging technology: Some issues and perspectives in 2010. *Creativity and Innovation Management, 19(2),* 160–166.

Cavallucci, D. (2001). Integrating Altshuller's development trends for technical systems into the design process. *CIRP Annals-Manufacturing Technology, 50(1),* 115-120.

Chen, K., & Feng, X. (2009). A Gene-engineering-based design method for the innovation of manufactured Products. *Journal of Engineering Design, 20(2),* 175-193.

Cheong, S.H. (2006). MOT by using scientific methodology in Samsung R&D. *PICMET 2006* (pp. xlv-lxxxi), 8-13 July, 2006.

Cho, Y.K., Lee, J.G., Park, J.M., Lee, B.S., Lee, Y., & Ko, C. (2007). One-step pathogen specific DNA extraction from whole blood on a centrifugal microfluidic device. *Lab Chip, 7,* 565-573.

Chuksin, P., & Shpakovsky, N. (2006). Information analysis and presentation in forecasting. *TRIZ-journal, March*.

Cohen, L. (1995). *Quality function deployment*. Prentice Hall.

Fey, V., & Rivin, E. (2005). *Innovation on demand, new product development using TRIZ.* New York: Cambridge University Press.

Heiss, M., & Jankowsky, J. (2001). The technology tree concept - An evolutionary approach to technology management in a rapidly changing market. *IEMC01 Proceedings* (pp. 37-43).

Huckvale, M., & Fang, A.C. (2002). Using phonologically-constrained morphological analysis in continuous speech recognition. *Computer Speech and Language, 16,* 165-181.

Huertas-Garcia, R., & Consolacion-Segura, C. (2009). A framework for designing new products and services. *International Journal of Market Research, 51(6),* 819-840.

Iouri Belski (2007). Improve Your Thinking: Substance-field Analysis, TRIZ4U

Isaksen, S., & Ekvall, G. (2010). Managing for innovation: The two faces of tension in creative climates. *Creativity and Innovation Management, 19(2),* 73–88.

Ishihama, M. (2003). Training students on the TRIZ method using a patent database. *International Journal of Technology Management, 25(6-7),* 568-578.

Jiang, J., Sun, P., & Shie, A. (2011). Six cognitive gaps by using TRIZ and tools for service system design. *Expert Systems with Applications, 38(12),* 14751-14759.

Kano, N., Seraku, N., Takahashi, F., & Tsuji, S. (1984). Attractive quality and must be quality. *Quality, 14(2),* 39–48.

Kaufman, J., & Jerry, C. (1977). FAST- a thinking discipline. *1977 SAVE Proceedings* (p. 221).

Li, T., & Huang, H. (2009). Applying TRIZ and Fuzzy AHP to develop innovative design for automated manufacturing systems. *Expert Systems with Applications, 36(4),* 8302-8312.

Mann, D., Dewulf, S., Zlotin, B., & Zusman, A. (2003). *Matrix 2003: Updating the TRIZ contradiction matrix*. CREAX Press.

Mann, D.L. (1999). Using s-curves and trends of evolution in R&D strategy planning. *TRIZ-Journal, July*.

Mann, D.L. , Dewulf, S., (2002). Evolutionary-PotentialÔ in Technical and Business Systems, TRIZ-Journal, July.

MarketResearch.com (2008) The worldwide market for in vitro diagnostic tests [WWW document]. http://www.marketresearch.com.

Moehrle, M.G. (2005). How combinations of TRIZ tools are used in companies – Results of a cluster analysis. *R&D Management, 35(3),* 285-296.

Park, J.M., Cho, Y.K., Lee, B.S., Lee, J.G., & Ko, C. (2007). Multifunctional microvalves control by optical illumination on nanoheaters and its application in centrifugal microfluidic devices. *Lab Chip, 7,* 557-564.

Petrov, V. (2002). The laws of system evolution. *TRIZ-journal, March*.

Pidd, M. (1996). *Tools for thinking – Modelling in management science*. London: Wiley.

Ritchey, T., & Zwicky, F. (1998). 'Morphologie' and policy analysis. *16th Euro Conference on Operational Analysis*, Brussels.

Russo, D., Rizzi, C., & Montecchi, T. (2009). Interconnectivity and white-space opportunity: Bringing together forecasting and scenario planning to find innovative opportunities. *5th TRIZ Symposium in Japan*, Sept 10-12, 2009, Tokyo.

Rubin, M.S., Trend of Operation Principle Performance Completeness, TRIZ Developers Summit July 2010 http://www.triz-summit.ru/file.php/id/f5094/name/9.rubin.pdf

Yang, C., & Chen, J. (2012). Forecasting the design of eco-products by integrating TRIZ evolution patterns with CBR and simple LCA methods. *Expert Systems with Applications*, *39(3)*, 2884-2892.

Yoon, B., & Park, Y. (2007). Development of new technology forecasting algorithm: Hybrid approach for morphology analysis and conjoint analysis of patent information. *IEEE Transactions on Engineering Management, 54(3),* 588-599.

Yoon, J., & Kim, K. (2012). TrendPerceptor: A property–function based technology intelligence system for identifying technology trends from patents. *Expert Systems with Applications, 39(3),* 2927-2938.

Zlotin, B., & Zusman, A. (2006). Patterns of evolution: Recent findings on structure and origin. *TRIZ Journal, September*.

Zwicky, F. (1969). *Discovery, invention, research – Through the morphological approach*. New York: Macmillan Company.