International Conference on Systematic Innovation

1st International Conference on Systematic Innovation (ICSI)

Hsinchu, Taiwan, R.O.C, January 22-25, 2010

Proceedings

ISBN 978-986-84919-1-5

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Forward & Executive Report

The organizers of the International Conference on Systematic Innovation (ICSI) in Taiwan are pleased to present the proceedings of the conference, which includes 77 English papers and 32 Chinese Papers accepted for presentation at the conference. The amount of papers to be presented in the conference is about twice as many as any previous TRIZ/SI conferences making this conference the most prolific conference in the history of innovation conferences. About 150 author and non-author participants from 14 countries will interact in the conference. This probably, again, is a record in the field. Credit is due to all participants and organization team. Together, we are making historical records.

This conference is organized by The Society of Systematic Innovation and the Journal of Systematic Innovation (IJoSI) which is an affiliation of the Society. Whether the papers included in the proceedings are work-in-progress or finished products, the conference and proceedings offer their authors an opportunity to disseminate the results of their research and receive early feedback from colleagues, without the long wait associated with publication in peer-reviewed journals. On the other hand, the presentations and the proceedings do not preclude the option of submitting the work in an extended and finished form for publication in a special or general issue of the IJoSI, or another peer-reviewed journal.

The organizers are indebted to a number of people who gave freely of their time to make the conference a reality and to publish these proceedings. The list of organizations and working team who have contributed tremendous amount of time and efforts to create this conference are acknowledged at the end of this program brochure. There are more contributors who are beyond the list.

The conference is intended to be annual and international. The second ICSI conference will be in China in 2011. We welcome proposals for locations of future conferences in various countries. Please submit your proposal to myself. In addition, you are cordially invited to submit scholarly papers to the IJoSI at www.IJoSI.org. The conference and the journal are synergetic and closely related. The journal is intended to be with academic rigor while addressing real-world problems and opportunities. The goal is to be SCI indexed in about 6-8 years.

Since this is a conference regarding innovation, we've got to be innovative. The conference has designed in a few novel measures not seen in the past innovation related conferences including:

- Arranging to have four journals selecting special issue papers from the conference;
- Giving away journal prints in a conference;
- Inviting Managers of world-class major companies to share the success stories and findings on how these companies were able to achieve phenomenal financial benefits and hundreds of patents with introductions of innovation programs;
- Preparing a comprehensive "Visitor's Guides" to provide all related information making visitors' lives easier;
- Providing free scenic and technical tours.

As the host, our team tried our best to provide the best services we possibly can. We hope that you will find the participation in this conference rewarding. However, due to the overwhelming work we need to do, it is quite likely that we overlooked something. If there is anything that you need assistance, please feel free to let the attendant(s) at the service desk know. We are here to serve you.

With best regards,

D. Daniel Sheu, Ph.D., MBA, CMfgE
General Chair & Chair of Organizing Committee
The 1st International Conference on Systematic Innovation
Professor, National Tsing Hua University, Taiwan, R.O.C.
President, the Society of Systematic Innovation
Editor-in-Chief, the International Journal of Systematic Innovation
Director, Education & Training, the Society of Manufacturing Engineers, Taipei Chapter
Editorial Board, Computers & Industrial Engineering, an SCI indexed international journal
Member of the Board, Global Talentrepreneur Innovation & Collaboration Association

Paper List

Full Papers in English

Paper ID: 68

Systematic method for roadmapping disruptive innovation in Fuzzy Front End of NPD

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Abstract

As an effective innovation method, distuptive innovation(DI) can be applied in a new firm to realize leaping-over development. Based on the technology evolution theory, the occurrence conditions of DI is put forward. In order to forecast and realize disruptive technologies during the process of product development, the basic laws and principles of DI are summarized. The paper offers a kind of innovation method of fuzzy front end (FFE) stage in new product development (NPD). The method marks out effective disruptive technologies in the end mostly relays on disruptive innovation and brings it as the final high quality idea of FFE. The adoption of this method makes the object of the initial stage in product development clearer and which is good for improving the effectiveness of innovation, advancing the mission success rate of product development. It especially fits for the new product development process for new enterprise to enter a mature market.

Keywords: Disruptive Innovation, Fuzzy front end (FFE), Systematic method

1. Introduction

Disruptive Innovation (DI) was a technological innovation theory which is put forward by Christensen [1] in 1997, and consummated by him at last[2-4]. DI refers to the product which introduces the product performance that under the product performance finalized the design in the mainstream market, but it has several characteristics used for attracting unimportant consumers or new users. When these products are getting stable gradually not only in the low-end market and in the new market by development, but they can also take the place of the products which finalized the design in the mainstream market, the enterprises that have these products, in other words, radical enterprises will replace current ones so as to achieve DI.

The development of DI product needs bran-new values which can be brought into the existing market. Therefore, the develop process of DI product is an integration of a series of procedures. The integration contains various contents which are from the field selection of initial products to consumer demand analysis, the forecast of disruptive technologies opportunity, the realization of disruptive technologies, the research and development production plan and various contents such as design administration which can ensure each plan be carried out effectively. Sometimes the integration even includes the selling channel in the market for the preparing of new product and the arrangement like generalization and promotion. Product design is included in the process of product development and is made up of each technical activity which accord with market development and commercial operation. It contains the development that in conformity with technical manual requirement which is for conceiving of product, the development of new thinking and blending technological factor in new product.

The initial stage of product innovation is called fuzzy front end (FFE). Recently, the lifecycle of product is shorter and shorter because of fierce market competition, new products come out continuously and take the place of primary products. The mission success rate of product design is demanded to be heightened enormously for adapting to this situation. It is requested that reliable and effective design constraint must be implemented from the front end of the conceptual design of product, the FFE stage, so as to achieve the effective innovation process. The development of DI products answers for this regulation as well. In order to improve the mission success rate of DI process, the stage of FFE of DI process should be studied.

2. Literature Review

Disruptive Technology (DT) is the technology taken in the process of the realization of DI. DT is the technology which doesn't accord with the needs of mainstream consumers of enterprises and the improvement of it doesn't take place on the evolvable track of mainstream capability. DT might be the innovation technology that could not fulfill the needs of mainstream consumers of enterprises transitorily. The incidence and development of DT are usually lower than primary technological product on the mainstream technical performance of product for a short time in the initial stage, it will surpass primary technology before long and replace primary technology. Successful DT can offer extra product characteristic for existing market consumers to meet their uncovered needs. The characteristics of these extra products usually are small, light, cheap, rich in function, easy to use, high reliability, high efficiency and energy saving [5]. To some extent, the process of DI is just the process of forecasting and searching of DT. Therefore, to study the forecasting and searching method of DT gets more important and many other scholars at home and abroad all defined DT in their own way.

Abernathy and Utterback[6](1988) described DT as the technology for creating bran-new technology product—market pattern, DT will bring new concept to the whole world which may be difficult to understood for consumers.

Bower and Christensen[7](1995) believed a kind of technology will be regarded as having the characteristic of disruptive, when some kind of service commodity and entity commodity which are produced by this technology have the capability that was ignored by existing consumers. For instance, when 8-inch rigid disk drives appeared for the first time, consumers couldn’t see the value from its “small volume” on the rigid disk drive market whose mainstream product is 14-inch (for mainframe computer market) in size. And consumers took no account of the attribute of volume size. We can define that the technology for 8-inch drive is right part of DT from the example above.

Walsh and Linton[8](2000) supposed that DT was the combination of existing technologies and some new technologies. These new technologies would lead to momentous reform of product technology pattern or creating a sort of new product when they were used in the problem field or commercial competition.

Lewis, Cosier and Hughes[9](2001) hold the view that the S curve which was the tradition way to study technological evolution could not describe DT any more. They believed that a structural plane of social intention definition should be added, so the DT can be described fully. If the track of technological evolution develops according to the track which is from the beginning to exploring, from exploring to autumn, this technology is DT.

Walsh, Kirchhoff and Newbert[10](2002) thought DT was the technology which didn’t support the fundamental manufacturing operation of existing enterprises, in other words, DT was the technology that didn’t consistent with the fundamental manufacturing technology of existing enterprises.

Kassicieh, Walsh and Cummings etc.[11](2002) brought forward that DT was a kind of discovery of scientific knowledge and this discovery would surpass the capability of common products or technology. DT would become the base of new apotheosis competition, and a change brought by the technology can be used to distinguish DT between common technology. DT would bring changes in three aspects in general: altering science and technology, shifting market structure, changing consumers' benefit.

3. Methodology

3.1 FFE during the process of new product development

Figure 1 is the process model of product innovation process. FFE is its initial stage, the stages afterwards are new product development stages (NPD) which contain conceptual design, detailed design and product manufacturing. The last stage is the businesslike of product. Tan (2008) divided ideas of innovation of stage FFE into three types: raw ideas, possible ideas and high quality ideas. Possible ideas is acquired by the estimate of raw ideas, high quality ideas will be got through the estimate of possible ideas. In the shape of the output of FFE, High quality ideas is just the input of NPD. The idea of the output of FFE turns into product by means of NPD and is put into market from which benefits the enterprises [12].

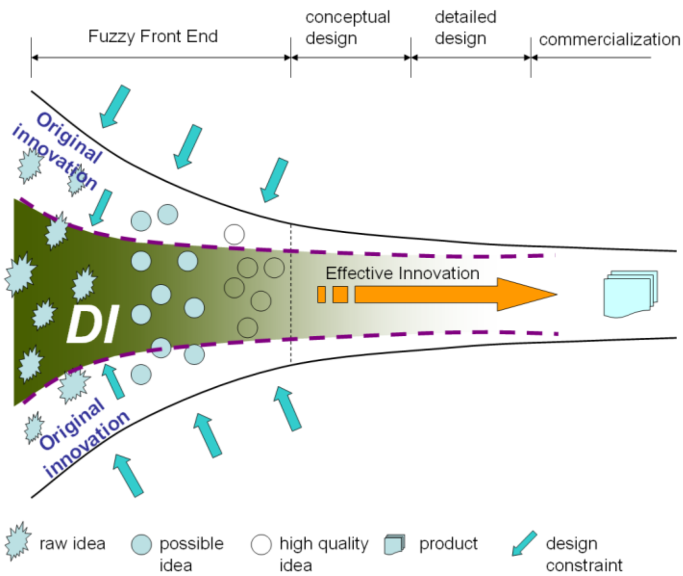

Fig. 1 The process of product innovation

Finding and applying the method of using knowledge in different fields becomes the bridge for designers to produce high quality ideas of stage FFE, through this method, producing just several ideas which contain materials of high quality will be all right. It is unnecessary to form many ideas. As a result, not only the evaluation of idea gets easier but also conquered the obstacle of producing high quality ideas. However, as the original technology innovation is aiming at innovating system knowledge of antetype, high quality idea is hard to be acquired. It is necessary to master a number of knowledge in each field, but to DI or sustaining innovation(SI) process, because the existing of many design constraints that are known, the transpiration extent of FFE falls greatly, so the difficulty of acquiring high quality idea is knocked-down greatly and small FFE area is formed in figure 1.

3.2 The model of DI products development face to FFE

Figure 2 shows the FFE process of DI product development based on TRIZ frame. “TRIZ” is the (Russian) acronym for the ”Theory of Inventive Problem Solving.” G.S. Altshuller and his colleagues in the former U.S.S.R. developed the method between 1946 and 1985. TRIZ is an international science of creativity that relies on the study of the patterns of problems and solutions, not on the spontaneous and intuitive creativity of individuals or groups. More than three million patents have been analyzed to discover the patterns that predict breakthrough solutions to problems.

Firstly, according to the history and actuality of enterprises themselves and the analysis of market condition, choosing a kind of product which is already available in the market to be the object of DI. Using forecasting tool of technology maturity which is supported by TRIZ predicts the technology maturity of target product. If the result of technology maturity prediction is that the technology lies in maturity phase, the main function of product has been evolved fully and has stable, mature market, so it can begin forecasting process of DI. If the result of technology maturity prediction is that the technology lies in decline phase, new substitutable technology should be found and radical innovation process is entered. If the result of technology maturity prediction is that the technology lies in child or growth phase, then incremental innovation is needed because of the evolutive insufficiency of main function of the product. Technology evolution law and technology evolution route and method in TRIZ are needed in searching for DT opportunity then ensuring possible evolutive direction of technical subsystem which is waited to be improved, the state of technology that is on certain evolutive route, after that finding potential state and putting forward innovative idea according to it. Applying the conflict, effect and canonical solution and other tools in TRIZ and analogical method [13] to fix on innovative idea that is for the settlement of field problems as the produce of innovative idea will bring relative field problems. Computer aided innovations (CAIs) offers tools and acts as repository in the process which is showed in Picture 2. That is to say CAIs contains all kinds of TRIZ tools and the corresponding repository, so it can support the produce of product innovative idea expediently.

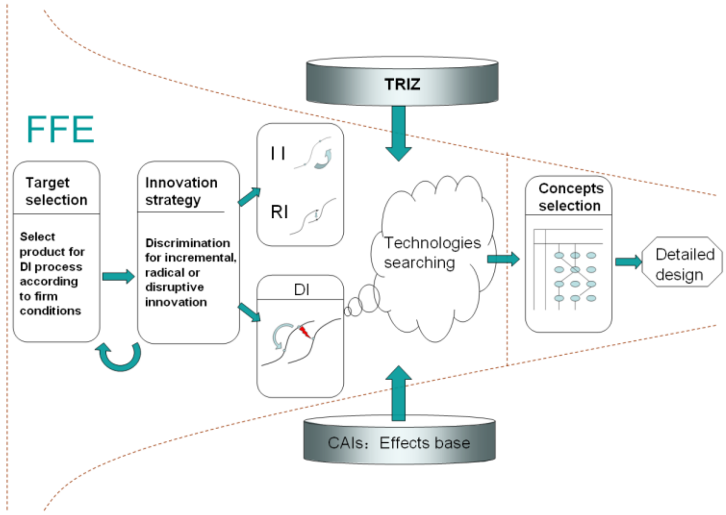

Fig. 2 The model of disruptive product development

3.3 Disruptive technologies forecasting based on technological system evolution theory

Product is a kind of complicated entia which is made up of different subassembly and which has unitary function and comprehensive performance. The technical system which composes the product is built up by each subsystem and it can be analyzed as an integrated technical system. Tree decomposition method as figure 3 shows is usually used in foregone decomposition of system. In order to avoiding the overabundance of the technical system decomposition hierarchy, the least unit of decomposition should be the outsourcing unit when enterprises are manufacturing products. Moreover, design constraint (volume, price, operative accessibility, energy consumption etc.) is also regarded as technical subsystem so as to be convenient for technical system doing analysis and the design constraint is list in all subsystems.

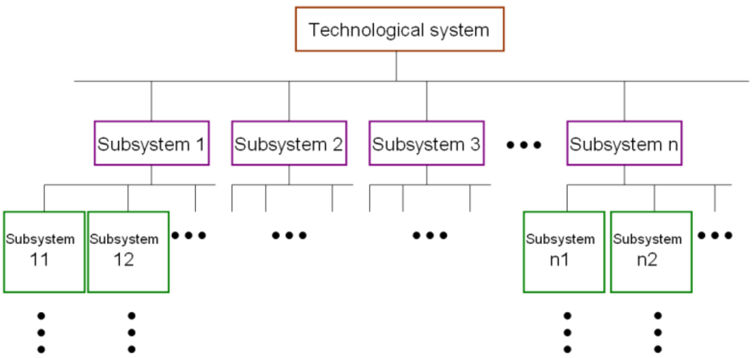

Fig. 3 Hierarchies of technological system

The evolution of product technology is not a single technical evolvable process. On the one hand, the technology which composes of the product turns into many kinds of technologies after it has been broken down and the general technical level of the product is the combination of state of the art of these built-up technologies. On the other hand, there will be user's needs evolution and relative cooperative technology evolution coupled with product evolution. Hence, product evolution appears as evolution of the whole system. Requirement evolution is composed of demand of different user groups.

Requirement evolution is made up of different demands of user groups as is shown in figure 4, the requirement of each technology of products vary to different user groups. Cooperative technology refers to the technology that coevolves with some sub-function, which usually is technology in other field that affects some technology level of product.

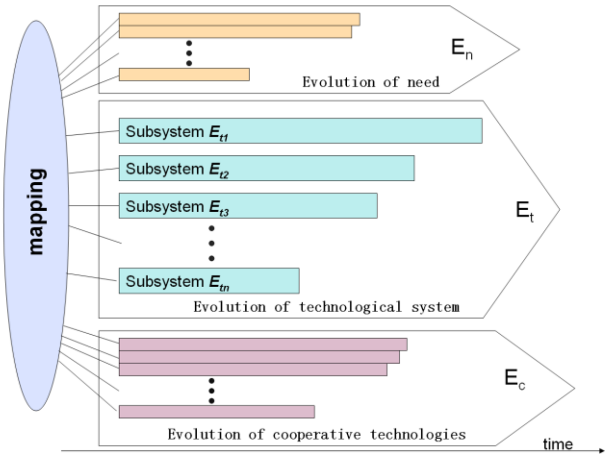

Fig. 4 Technologies system evolution model

Figure 5 shows the development process model of new product based on DT, and it can be divided into the following procedures.

Part 1:

1. Project selection

2. Function analysis

3. IFR definition

4. Decomposing technological system

5. Technological evolution analysis

Part 2:

Before technologies forecasting, there are two judgement problems: Are the customers' needs over satisfied? Is the technological system evolution unbalance? The questions determine the types of innovations, such as low-end DI, new-market DI and SI. After that, according to features of different innovations, latent technologies are forecasted based on TRIZ technological evolution theory.

Part 3:

The Managers need to understand the feasibility of these obtained technologies. To achieve this objective, a robustness evaluation for the obtained technologies will be given. If result is not ideal, the former forecasting process will be carried out anew by selecting a different TRIZ technological evolution path till getting a ideal robustness evaluation. Then, the following 4 steps proceed:

1. Technical design

2. Detailed design

3. Blueprint

4. Put into production

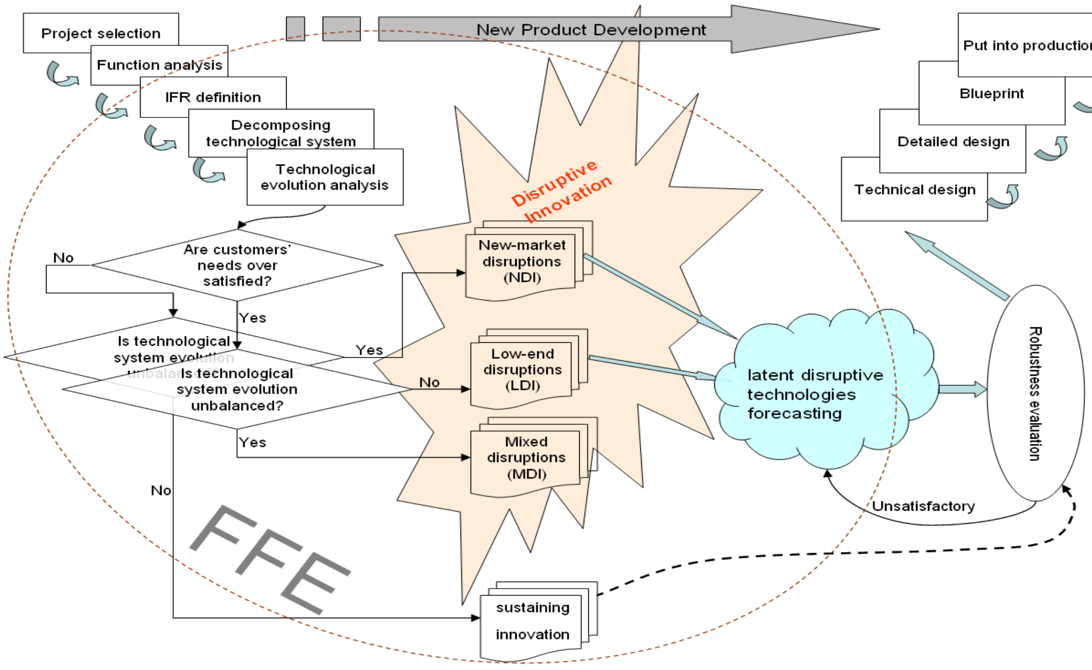

Fig. 5 Model of disruptive technologies roadmapping

4. Results

The innovative ideas of DI includes the raw ideas of DI, possible ideas and high quality ideas. As is shown in figure 6, the produce of the three ideas makes the stage of FFE in product development of DI.

Product design starts in the market and ends in the market too. The first problem of new product development is to decide what to develop, what kind of innovative method should we choose—Incremental Innovation, Radical Innovation or DI? The production process of raw idea of DI product contains the choice of object product and the forecast of innovative opportunity. The contents and time of DI are restricted by means of the choice of object product and the forecast of innovative opportunity. After that, more specific procedures are followed and the evolutive state of product technology system is acquired through technical system decomposition of object product which is chosen. And then making the decision, which one to choose, Low-end DI, New-market DI or Mixed DI by the method which is shown in figure 5 and the survey of market user requirements so as to form possible idea of DI. Afterwards, searching and fixing on the technical measures which should be chosen to realize DI by DI, therefore, high quality ideas of DI is produced. The technical searching of DI relates to technical evolution, conflict theory and other resolvent for many problems.

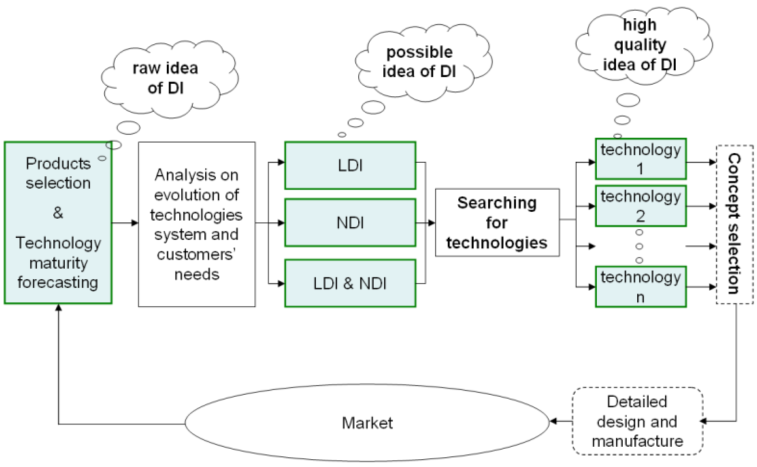

Fig. 6 Raw, possible and high quality ideas during the process of DI

5. Conclusion

Stage FFE is quite important in the process of NPD, the innovative result of this stage decides directly whether the development of new products is successful or not. DI is effective innovation method, the roadmapping of DT is the applied result of DI. DT enables designers to produce high quality idea in stage FFE. With the help of the production process of DI, not only does the imaginative estimate gets easier but the obstacle which is produced in the creation of high quality idea is also be conquered. Relative to original innovative technology, because the existing of vast design constraints which are known, the radiation extent of FFE will be reduced greatly owing to the application of DI. Therefore, mission success rate of product development will increase greatly and new product will be accepted into the market more easily.

6. Acknowledgment

Authors are grateful to the Natural Science Foundation of China (70972050), Doctoral Degree Foundation of Education Ministry (No. 20060080002), Basis of National Science and Technology Work (2008IM030100)，the Natural Science Foundation of Hebei Province (No. E2008000086)for funding this work.

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Paper ID: 70

Computer Aided Innovation – Pro/Innovator

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Abstract

This paper explains what CAI is and how it is applied in new product development and assists R&D staffs in resolving engineering problem by using an engineering problem from industry. TRIZ theory and Pro/Innovator are used to illustrate how to apply software to assist engineers resolve technical problems.

Keywords

TRIZ, Computer Aided Innovation, Axiomatic Design, Contradictions

1 INTRODUCTION

CAI is short for Computer aided innovation and it is a technology developed recently used in various industries for new product development as well as breaking psychological inertia. Pro/Innovator is one of the mostly used CAI software due to its friendly user interface and well designed system structure; in addition, it integrates TRIZ, Ontology, Modern design methodology, natural language technique, root cause analysis, TOC, axiomatic design, functional design, value engineering, Pugh Matrix, and computer software engineering into one single robust system. Combined with over 12000 scientific effects extracted from patents, and patent search module, Pro/Innovator can support all stages of concept design.

New product development usually consists analyze, concept design, detailed design, and verification. There are two problems need to be considered in the concept design stage, “what” and “how”. By analyze the initial situation, it tells us what to do, but, concept design provides us with a guideline of how to do it. Concept design should provide a clear understanding of the core functions of the technical system, as well as a break down structure of each level.

Axiomatic design is a systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables.

Pro/Innovator integrated TRIZ methodology to facilitate the designers and engineers from all kinds of industries, at various stage of designing, to break through the psychological inertia and sharpen the minds.

Below is an example of applying Pro/Innovator to resolve an engineering problem.

2 PROJECT DESCRIPTION：

1. System description
   The system is a length measurement equipment. Wire with a diameter of 0.6 mm winded on a bobbin. The length of the wire can be calculated by the number of rotates on the bobbin. In order to rotate the wire evenly on the bobbin, a guider is introduced into the system. The bobbin and the guide are placed in one box to fix their position. At the front of the box, there is a slot with a folding door to enable the wire move freely in-and-out of the box.
2. Problem
   Because of the slot, dust can flow in and accumulate in the box, thus, it causes the stable of the system decrease and the accuracy of the measure also will be affected.
3. Condition
   Because of the guider is always open, dust can flow in all the time, especially when rotating wire.
4. Reference solutions
   1) Minimize the size of guider. Disadvantage: caused friction increased and wire to bend, decrease accuracy and product life. Cannot completely stop dust flow in.
   2) Use flexible material to block the opening. Disadvantage: the wire will touch flexible material and wears off, cannot stop dust completely.

Structure shown in Figure 1

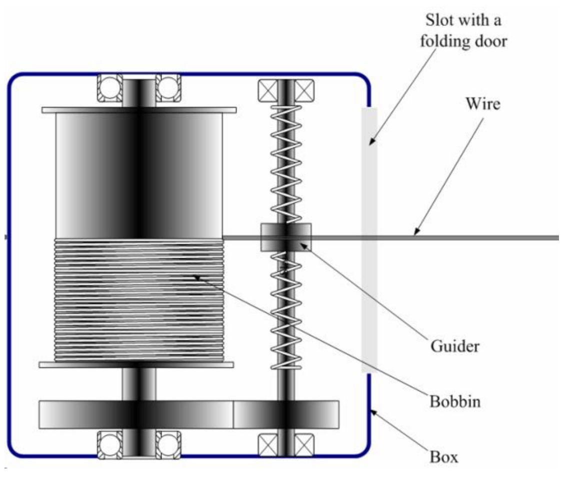


Figure 1: Structure

Pro/Innovator Screenshot shown in Figure 2

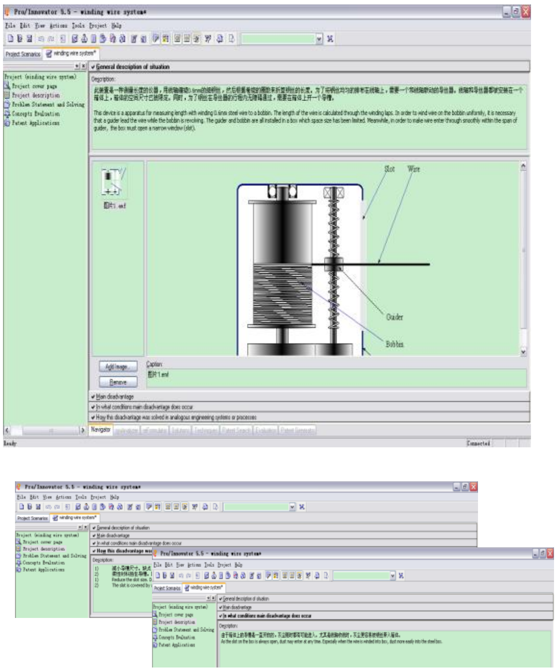


Figure 2: Pro/Innovator Screenshot

The above procedures complete the process for problem analysis.

3 ANALYZING PROBLEM

Since Pahl and Beitz introduced concept design in 1984, modern design methods concentrate on functions vitalization and description, the most used techniques are as below:

(1) Buur introduced "terms of function" expression;
(2) Hansen introduced "verb + noun + adjective phrase" expression;
(3) Kirschman used complete sentence expression;
(4) Input output flow interchange, such as material flow, information flow, and energy flow;
(5) Input output status change;
(6) Schmeke introduced function model building by symbols.

Pro/Innovator integrated all advantages of the above.

When starting a project, express the system as "name of technical system + for + verb + (parameter + of + components)" to clarify the objective of the concept design project. In the above example, the project name is determined to be: wire winding system for measuring length of measured object. It stated the main function of the technical system is measuring length, in addition, this would avoid misinterpret of the problem for the current system.

Pro/Innovator concentrates on "functions", integrated with analysis of components, actions, and functions form System Theory, eventually build function models by using symbols and charts. The concept of flow is also introduced in Pro/Innovator to break down the function of the technical system. Component in Pro/Innovator is usually referred to functional component; it's the minimal units in the technical system. Component could be a combination of several parts, also can be a single part with multiple functions. It matches with the requirements for functions in Axiomatic Design as well as feature modelling concept in CIMS; more over, it satisfied the needs for design automation.

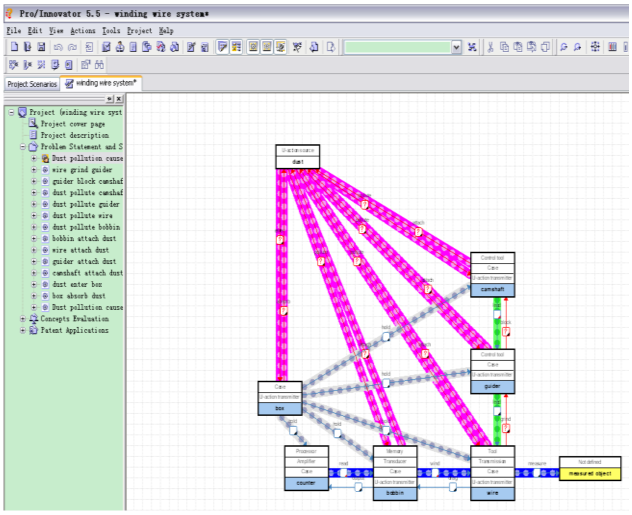


Figure 3: sysAnalyzer

Component role analysis and value engineering help engineers jumped from Qualitative analysis to Quantitative Analysis. Pro/Innovator helps to locate the weak points in the technical system and thus identify the component to be improved.

Components	Function contribution	Problem contribution	Cost contribution		Ideality index	
			Eval	Percentage	Calc	Percentage
wire	28	29	Low	3	0.98360655737	16
bobbin	17	14	Middle	10	1.09090909090	17
counter	8	0	High	33	1.8	28
guider	13	29	Middle	10	0.42857142857	7
camshaft	13	14	High	33	0.675	11
box	21	14	Middle	10	1.36363636363	22

Figure 4: Components Profile

According to components profile, the components with lower ideality index value can be found to analyze in RCA analysis.

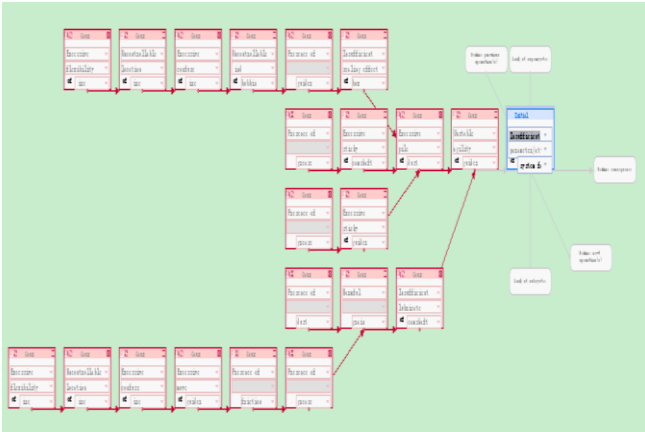


Figure 5: Root Cause Analysis

Root Cause Analysis (RCA) is based on resource analysis and functional analysis. Resource analysis in Pro/Innovator's RCA not only adapted the method for analyzing "material, energy, information, space" in TRIZ methodology, but also developed a three dimensional problem reformulation map can be converted automatically into reformulated problem. The reformulated problem can be used directly for contradiction definition or problem solving in TRIZ techniques module.

According to the minimal requirement for technical system in Axiomatic Design, combined with trimming tools in TRIZ, engineers can eliminate components from the current technical system. Search in Pro/Innovator for "Way of function achievement". Ontology is also built in Pro/Innovator and formed Functional understanding to help engineers design new components. Pro/Innovator has a built in knowledge bas contains more than 12,000 inventive solutions that are extracted from millions of worldwide patents, in addition, Pro/Innovator enables users to search the patent databases over the internet to get the latest updates.

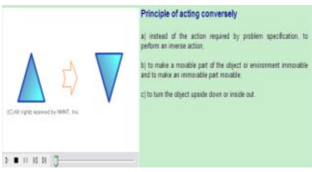
4 FINDING SOLUTIONS

By applying RCA analysis, Pro/Innovator provided the following solution for the above example.

1. Eliminate harmful functions (Eliminate dust)
   ① Eliminate dust →
   ② Block dust →
   ③ Solid lubrication →
2. Improve useful performance (Direct measure)
   ① Manufactory wire with scale on it →
   ② Direct detect the movement of wire →

In the following steps, Pro/Innovator combined TRIZ tools and knowledge base together to help engineering in problem solving.

Use the contradiction matrix to define contradictions and get the inventive principles to resolve the contradiction, and then get the detailed solution for the specific problem.



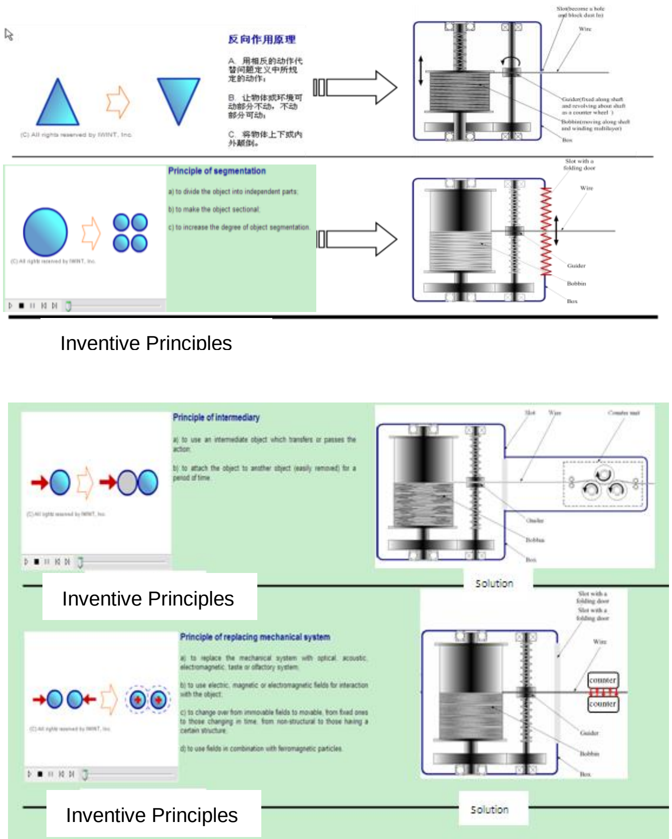
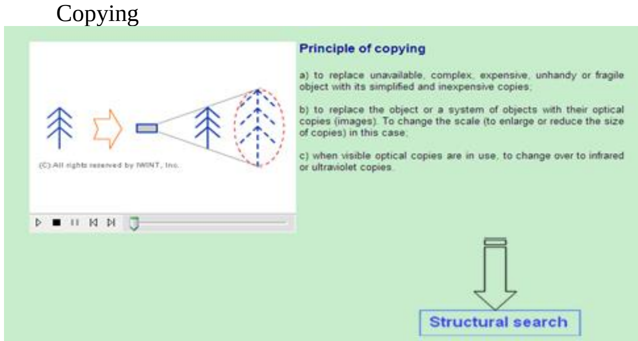
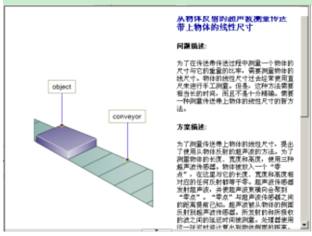


Figure 6: Solutions

Also search in knowledge base and patents; it gives a more realistic solution in addition to inventive principles, for instance:

1. Methods for light(wave) measurement by Principle of Copying





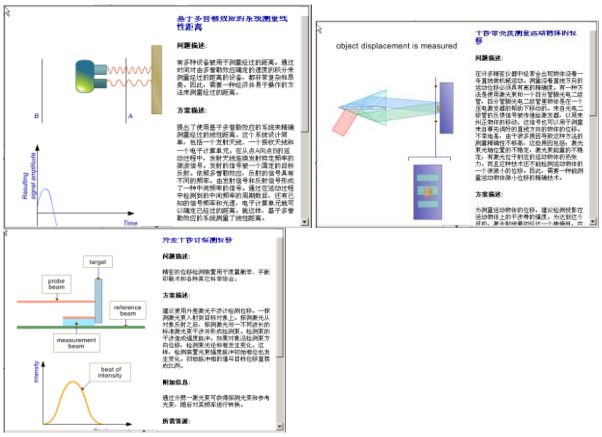


Figure 7: Principle of Copying

2. Solutions for Dust elimination

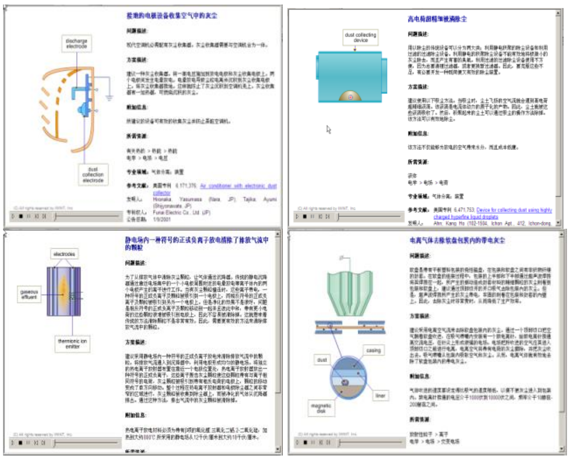


Figure 8: Solutions for Dust elimination

3. Methods for manufacturing magnetic scale on wire (knowledge base and patents)

Figure 9: Methods for manufacturing magnetic scale

4. Solutions for solid lubrication (knowledge base and patents)

Figure 10: Solutions for solid lubrication

Formed relevant solutions,

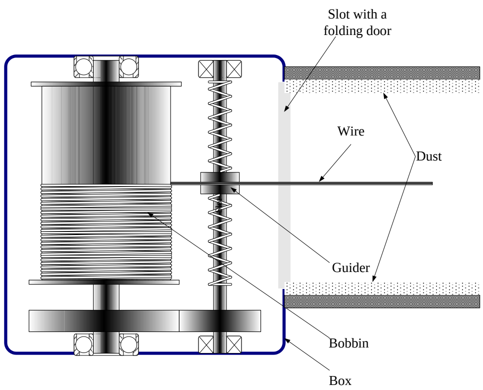


Figure 11: Add dust exit channel

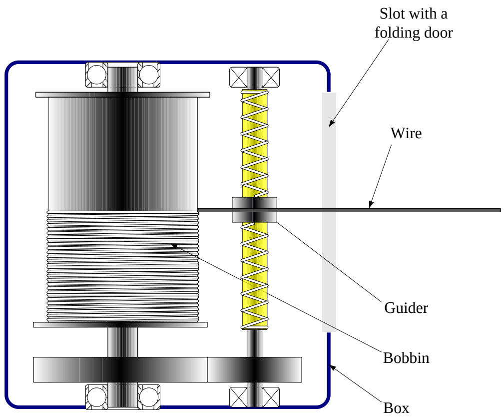


Figure 12: Applying engineering plastic

It shows the process of problem solving by Pro/Innovator through the above example. Also, we have noticed that TRIZ methodology is the core of Pro/Innovator, combined with Philosophy, modern design theory, and effective analysis method, Pro/Innovator provides the foundation for R&D concept design.

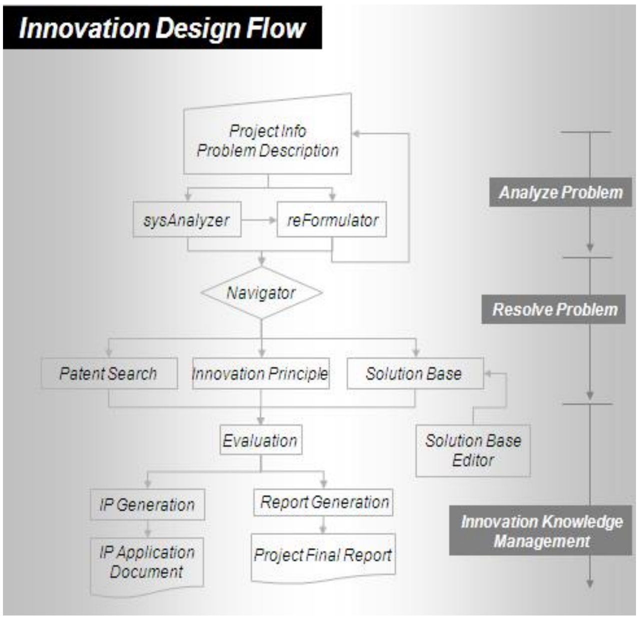


Figure 12: Process of Problem Solving in Pro/Innovator

5 CONCLUSION

We have illustrated an example by using Pro/Innovator and demonstrated how to apply this software to assist engineers resolve technical problems. Pro/Innovator is a knowledge-based, computer aided innovation application. It contains a rich knowledgebase of US – patented solutions of the most acute innovations and TRIZ-based inventive rules to resolve technical and physical contradictions. Pro/Innovator assists engineers in resolving technical problems through technical system analysis, problem formulation, solution search, solution evaluation, creation of the patent applications and reporting. It is a unique computer aided innovation design platform that integrates R&D process and enterprise knowledge management process, this mechanism allows R&D IP and knowledge engineers to cooperate on the same platform.

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Paper ID: 76

Comparison of Absolute Deterioration Factor of 6-th order moment in a Broad Sense

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Abstract

Among many dimensional and dimensionless amplitude parameters, kurtosis (4-th normalized moment of probability density function) is generally regarded as a sensitive good parameter for machine diagnosis. However, higher order moment may be supposed to be much more sensitive. Bicoherence is an absolute deterioration factor whose range is 1 to 0. The theoretical value of n-th moment divided by n-th moment calculated by measured data would behave in the same way. We name this factor as absolute n-th moment deterioration factor. In this paper, a simplified calculation method of this factor is introduced. The concept of absolute deterioration factor of n-th order moment in a broad sense is introduced and the analysis is executed. From the result of comparison, absolute deterioration factor of 6-th order moment in a broad sense is better than other factors in the viewpoint of sensitivity and practical use. Thus, n-th order moment in a broad sense was examined and evaluated, and we obtained practical good results.

Key Words: impact vibration, probability density function, kurtosis, n-th moment

1. Introduction

In mass production firms such as steel making that have big equipments, sudden stops of production processes by machine failure cause severe damages such as shortage of materials to the later processes, delays to the due date and the increasing idling time.

To prevent these troubles, machine diagnosis techniques play important roles. So far, Time Based Maintenance (TBM) technique has constituted the main stream of the machine maintenance, which makes checks for maintenance at previously fixed time. But it has a weak point that it makes checks at scheduled time without taking into account whether the parts are still keeping good conditions or not. On the other hand, Condition Based Maintenance (CBM) makes maintenance checks by watching the condition of machines. Therefore, if the parts are still keeping good condition beyond its expected life, the cost of maintenance may be saved because machines can be used longer than planned. Therefore the use of CBM has become dominant. The latter one needs less cost of parts, less cost of maintenance and leads to lower failure ratio.

However, it is mandatory to catch a symptom of the failure as soon as possible of a transition from TBM to CBM is to be made. Many methods are developed and examined focusing on this subject. In this paper, we propose a method for the early detection of the failure on rotating machines which is the most common theme in machine failure detection field.

So far, many signal processing methods for machine diagnosis have been proposed (Bolleter, 1998; Hoffner, 1991). As for sensitive parameters, Kurtosis, Bicoherence, Impact Deterioration Factor (ID Factor) were examined (Yamazaki, 1977; Maekawa et al.1997; Shao et al.2001; Song et al.1998; Takeyasu, 1989). In this paper we focus our attention on the index parameters of vibration.

Kurtosis is one of the sophisticated inspection parameters which calculates normalized 4-th moment of Probability Density Function (PDF). In the industry, there are cases where quick reactions are required on watching the waveform at the machine site.

In this paper, we consider the case such that impact vibration occurs on the gear when the failure arises. Higher moments would be more sensitive compared with 4-th moment. Kurtosis value is 3.0 under normal condition and when failure increases, the value grows big. Therefore, it is a relative index. On the other hand, Bicoherence is an absolute index which is close to 1.0 under normal condition and tends to be 0 when failure increases.

In this paper, we deal with the generalized n-th moment. When theoretical value of n-th moment is divided by calculated value of n-th moment, it would behave as an absolute index. New index shows that it is 1.0 under normal condition and tends to be 0 when failure increases.

In this paper, we introduce a simplified calculation method to this new index and name this as a simplified absolute index of n-th moment. Furthermore, as Bicoherence can be considered to be a kind of 6-th order moment, several factors concerning absolute deterioration factor of 6-th order moment are compared and evaluated.

Trying several n, we search n which shows the most similar effect to the behavior of Bicoherence. This simplified method enables us to calculate the new index even on a pocketsize calculator and enable us to install it in microcomputer chips. The rest of the paper is organized as follows. We survey each index of deterioration in section 2. Simplified absolute index of n-th moment is proposed in section 3. In section 4, numerical examples are presented which are followed by the remarks of section 5. Section 6 is a summary.

2. Factors for Vibration Calculation

In cyclic movements such as those of bearings and gears, the vibration grows larger whenever the deterioration becomes bigger. Also, it is well known that the vibration grows large when the setting equipment to the ground is unsuitable (Yamazaki, 1977). Let the vibration signal be presented by the function of time $x(t)$. And also assume that it is a stationary time series with mean $\overline{x}$. Denote the probability density function of these time series as $p(x)$. Indices for vibration amplitude are as follows. Here we especially suppose that $\overline{x} = 0$ for the simplicity of description.

$$X_{root} = \left[\int_{-\infty}^{\infty} |x|^{\frac{1}{2}} p(x) dx \right]^2 \tag{1}$$

$$X_{rms} = \left[\int_{-\infty}^{\infty} x^2 p(x) dx \right]^{\frac{1}{2}} \tag{2}$$

$$X_{abs} = \int_{-\infty}^{\infty} |x| p(x) dx \tag{3}$$

$$X_{peak} = \lim_{n \to \infty} \left[\int_{-\infty}^{\infty} x^n p(x) dx \right]^{\frac{1}{n}} \tag{4}$$

These are dimensional indices which are not normalized. They differ by machine sizes or rotation frequencies. Therefore, normalized dimensionless indices are required.

There are four main categories for this purpose.

A. Normalized root mean square value

B. Normalized peak value

C. Normalized moment

D. Normalized correlation among frequency domain

A. Normalized root mean square value

a. Shape Factor : *SF*

$$SF = \frac{X_{rms}}{\overline{X}_{abs}} \tag{5}$$

($\overline{X}_{abs}$: mean of the absolute value of vibration)

B. Normalized peak value

b. Crest Factor : *CrF*

$$CrF = \frac{X_{peak}}{X_{rms}} \tag{6}$$

(X_{peak} : peak value of vibration)

c. Clearance Factor : *ClF*

$$ClF = \frac{X_{peak}}{X_{root}} \tag{7}$$

d. Impulse Factor : *IF*

$$IF = \frac{X_{peak}}{\overline{X}_{abs}} \tag{8}$$

e. Impact Deterioration Factor : ID Factor / *ID*

This is proposed in Maekawa *et al*. (1997).

$$ID = \frac{X_{peak}}{X_c} \tag{9}$$

(X_c : vibration amplitude where the curvature of PDF becomes maximum)

C. Normalized moment

f. Skewness : *SK*

$$SK = \frac{\int_{-\infty}^{\infty} x^3 p(x)dx}{\left[\int_{-\infty}^{\infty} x^2 p(x)dx\right]^{\frac{3}{2}}} \tag{10}$$

g. Kurtosis : KT

$$KT = \frac{\int_{-\infty}^{\infty} x^4 p(x)dx}{\left[\int_{-\infty}^{\infty} x^2 p(x)dx\right]^{2}} \tag{11}$$

D. Normalized correlation in the frequency domain

Bicoherence shows the relationship between two frequencies and is expressed as

$$Bic,_{xxx}(f_1, f_2) = \frac{B_{xxx}(f_1, f_2)}{\sqrt{S_{xx}(f_1)\cdot S_{xx}(f_2)\cdot S_{xx}(f_1 + f_2)}} \tag{12}$$

Here

$$B_{xxx}(f_1, f_2) = \frac{X_T(f_1)\cdot X_T(f_2)\cdot X_T^*(f_1 + f_2)}{T^{\frac{3}{2}}} \tag{13}$$

means Bispectrum and

$$X_T(t) = \begin{cases} x(t) & (0 < t < T) \\ 0 & (else) \end{cases}$$

T : Basic Frequency Interval

$$X_T(f) = \int_{-\infty}^{\infty} X_T(t) e^{-j2\pi ft} dt \tag{14}$$

$$S_{xx}(f) = \frac{1}{T} X_T(f) X_T^*(f) \tag{15}$$

Range of Bicoherence satisfies

$$0 < Bic,_{xxx}(f_1, f_2) < 1 \tag{16}$$

When there exists a significant relationship between frequencies f_1 and f_2 ,Bicoherence is near 1.Otherwise,the value of Bicoherence comes close to 0.

These indices are generally used in combination and machine condition is judged totally. Among them, Kurtosis is known to be one of the superior indices (Noda, 1987) and numerous researches have been conducted on Kurtosis (Maekawa *et al.*,1997; Shao *et al*.,2001; Song *et al*.,1998).

Judging from the experiment we made in the past, we may conclude that Bicoherence is also a sensitive good index (Takeyasu, 1987, 1989).

Eq. (15) is a power spectrum. Power spectrum is a Fourier Transform of Autocorrelation function (Tokumaru *et al.*, 1982). Therefore it is a kind of second order moment in a broad sense. Watching at the denominator of Eq. (12), a square root is taken for the triple products of power spectrum. Normalization is executed by this item. That is, Bicoherence is equivalent to the square root of normalized 6-th order moment in a broad sense. Therefore, Bicoherence can considered to be a kind of an absolute deterioration factor of normalized 6-th order moment in a broad sense.

In Maekawa *et al.*(1997), ID Factor is proposed as a good index. In this paper, focusing on the indices of vibration amplitude, we introduce a simplified calculation method for absolute index of n-th moment and search n by which it makes a similar behavior to those of Bicoherence.

3. SIMPLIFIED ABSOLUTE INDEX OF n-TH MOMENT

3.1 Absolute index of *n*–th moment

Mean value $\bar{x}$ of $x(t)$ is calculated as

$$\bar{x} = \int_{-\infty}^{\infty} x p(x) dx$$

Discrete time series are stated as follows.

$$x_k = x(k\Delta t) \qquad (k = 1,2,\cdots)$$

Where Δt is a sampling time interval. $\bar{x}$ is stated as follows under discrete time series.

$$\bar{x} = \lim_{M \to \infty} \frac{1}{M} \sum_{i=1}^{M} x_i$$

Under the following Gaussian distribution

$$\phi(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2} \tag{17}$$

Its moment is described as follows which is well known (Hino,1977)

$$\overline{x^{(2n-1)}} = 0 \tag{18}$$

$$\overline{x^{(2n)}} = \prod_{k=1}^{n} (2k-1)\sigma^{2n} \tag{19}$$

If we divide Eq. (19) by σ^{2n}, we can obtain normalized moment. In general, normalized n-th moment is stated as follows.

$$Q(n) = \frac{\int_{-\infty}^{\infty} (x-\bar{x})^n p(x)dx}{\left[\int_{-\infty}^{\infty} (x-\bar{x})^2 p(x)dx\right]^{\frac{n}{2}}} \tag{20}$$

In discrete time system, it is described as

$$Q(n) = \lim_{M\to\infty} \frac{\frac{1}{M}\sum_{i=1}^{M} (x_i - \bar{x})^n}{\left\{\frac{1}{M}\sum_{i=1}^{M} (x_i - \bar{x})^2\right\}^{\frac{n}{2}}} \tag{21}$$

We describe $Q(n)$ as $Q_N(n)$ if it is calculated by using N amount of data.

$$Q_N(n) = \frac{\frac{1}{N}\sum_{i=1}^{N} (x_i - \bar{x})^n}{\left\{\frac{1}{N}\sum_{i=1}^{N} (x_i - \bar{x})^2\right\}^{\frac{n}{2}}} \tag{22}$$

Absolute index of n-th moment is described as follows.

$$Z_N(n)=\frac{\prod_{k=1}^{n/2}(2k-1)}{\dfrac{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{x})^n}{\left\{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{x})^2\right\}^{\frac{n}{2}}}} \tag{23}$$

Under the normal condition, $Z_N(n)\to 1(N\to\infty)$, and if failure becomes larger, $Z_N(n)\to 0$.

3.2 Simplified Absolute index of *n*–th moment

When the number of failures on bearings or gears arise, the peak value arise cyclically. In the early stage of the defect, this peak signal usually appears clearly. Generally, defects will injure other bearings or gears by contacting the inner covering surface as time passes.

Assume that we get *N* amount of data and then newly get *L* amount of data. Assume that mean, variance and moment are same with 1~*N* data and *N*+1~*N*+*L* data except for the case where a special peak signals arises. Let mean ,variance and n-th moment calculated by using 1~*N* data state as

$$\bar{x}_N,\ \ \sigma^2{}_N,\ \ M_N(n)$$

And as for *N+1~N+L*, let them state as

$$\bar{x}_{N/l},\ \ \sigma^2{}_{N/l},\ \ M_{N/l}(n)$$

Where

$$M_N(n)=\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{x})^n \tag{24}$$

$$M_{N/l}(n)=\frac{1}{l}\sum_{i=N+1}^{N+l}(x_i-\bar{x})^n \tag{25}$$

Therefore, Eq. (22) is stated as

$$Q_N(n)=\frac{M_N(n)}{\sigma^n{}_N} \tag{26}$$

Assume that the peak signal which has S times impact from normal signals arises in each *m* times samplings. As for determining the sampling interval, the sampling theorem which is well known can be used (Tokumaru *et al.*,1982). But in this paper, we do not pay much attention on this point in order to focus on the proposed theme.

Let $\sigma^2{}_{N/l}$ and $M_{N/l}$ of this case, of $N + 1 \sim N + l$ be $\bar{\sigma}^2{}_{N/l}$, $\overline{M}_{N/l}$, then we get

$$\begin{aligned}\bar{\sigma}^2{}_{N/l} &= \frac{1}{l}\sum_{i=N1}^{N+l}(x_i - \bar{x})^2 \\ &\cong \frac{l - \frac{l}{m}}{l}\sigma^2{}_N + \frac{\frac{l}{m}}{l}S^2\sigma^2{}_N \\ &= \sigma^2{}_N\left(1 + \frac{S^2 - 1}{m}\right)\end{aligned} \tag{27}$$

$$\begin{aligned}\overline{M}_{N/l}(n) &= \frac{1}{l}\sum_{i=N+1}^{N+l}(x_i - \bar{x})^n \\ &\cong \frac{l - \frac{l}{m}}{l}M_{N/l}(n) + \frac{\frac{l}{m}}{l}S^n M_{N/l} \\ &= \left(1 + \frac{S^n - 1}{m}\right)M_{N/l}(n)\end{aligned} \tag{28}$$

From these equations, we obtain $\overline{Q}_{N+l}(n)$ as $Q_{N+l}(n)$ of the above case

$$\begin{aligned}\overline{Q}_{N+l}(n) &\cong \frac{\frac{N}{N+l}M_N(n) + \frac{l}{N+l}\left(1 + \frac{S^n - 1}{m}\right)M_N(n)}{\left\{\frac{N}{N+l}\sigma^2{}_N + \frac{l}{N+l}\sigma^2{}_N\left(1 + \frac{S^2 - 1}{m}\right)\right\}^{\frac{n}{2}}} \\ &= \frac{1 + \frac{l}{N+l}\cdot\frac{S^n - 1}{m}}{\left(1 + \frac{l}{N+l}\cdot\frac{S^2 - 1}{m}\right)^{\frac{n}{2}}}\cdot\frac{M_N(n)}{\sigma^2{}_N} \\ &= \frac{1 + \frac{l}{N+l}\cdot\frac{S^n - 1}{m}}{\left(1 + \frac{l}{N+l}\cdot\frac{S^2 - 1}{m}\right)^{\frac{n}{2}}}Q_N(n)\end{aligned} \tag{29}$$

While $Q_{N+l}(n)$ is Kurtosis when $n=4$,

$$Q_N(4)=KT$$

We assume that time series are stationary as is stated before in 2. Therefore, even if sample pass may differ, mean and variance are naturally supposed to be the same when the signal is obtained from the same data occurrence point of the same machine.

We consider such case when the impact vibration occurs. Except for the impact vibration, other signals are assumed to be stationary and have the same means and variances. Under this assumption, we can derive the simplified calculation method for machine diagnosis which is a very practical one.

From the above equation, we obtain $\overline{KT_{N+l}}$ in the following way.

$$\overline{KT} \cong \frac{1+\frac{l}{N+l}\cdot\frac{S^4-1}{m}}{\left(1+\frac{l}{N+l}\cdot\frac{S^2-1}{m}\right)^2}\times 3.0 \tag{30}$$

Consequently, we obtain $\bar{Z}_{N+l}(n)$ as of Eq. (23) as

$$\begin{aligned}\bar{Z}_{N+l}(n) &\cong \frac{\prod_{k=1}^{n/2}(2k-1)}{Q_{N+l}(n)} \\ &= \frac{\prod_{k=1}^{n/2}(2k-1)}{\dfrac{1+\frac{l}{N+l}\cdot\frac{S^n-1}{m}}{\left(1+\frac{l}{N+l}\cdot\frac{S^2-1}{m}\right)^{\frac{n}{2}}}Q_N(n)}\end{aligned} \tag{31}$$

Under the normal condition,

$$Q_N(n) \cong \prod_{k=1}^{n/2}(2k-1) \tag{32}$$

Therefore, we get

$$\bar{Z}_{N+l}(n) \cong \frac{\left(1+\frac{l}{N+l}\cdot\frac{S^2-1}{m}\right)^{\frac{n}{2}}}{1+\frac{l}{N+l}\cdot\frac{S^n-1}{m}} \tag{33}$$

Here we introduce the following number. Each index is compared with the normal index as follows.

$$F_a(P_{abn}) = \frac{P_{abn}}{P_{nor}} \tag{34}$$

p_{nor} : Index at normal condition

p_{abn} : Index at abnormal condition

In Eq. (29), F_a becomes

$$F_a\left(\bar{Q}_{N+l}(n)\right) \cong \frac{1+\frac{l}{N+l}\cdot\frac{S^n-1}{m}}{\left(1+\frac{l}{N+l}\cdot\frac{S^2-1}{m}\right)^{\frac{n}{2}}} \tag{35}$$

Correlation between $\bar{Z}_{N+l}(n)$ and F_a is as follows.

$$\bar{Z}_{N+l}(n) \cong \frac{1}{F_a\left(\bar{Q}_{N+l}(n)\right)} \tag{36}$$

4. Numerical Example

If the system is under normal condition, we may suppose $p(x)$ becomes a normal distribution function. Under this condition, $Q(n)$ is as follows theoretically when $n = 4,6,8$

$Q(4) = 3.0$
$Q(6) = 15.0$
$Q(8) = 105.0$

Under the assumption of 3.2, let $m = 12$. Considering the case $S = 2,4,6$ for3.2, and setting $N \to 0, l \to N$, we obtain table1.

Table 1. $\bar{Q}, \bar{Z}, F_a$ **by the variation of** S

<table>
<tr><td></td><td colspan="2">S</td><td>1</td><td>2</td><td>4</td><td>6</td></tr>
<tr><td rowspan="9">n</td><td rowspan="3">4</td><td>$\bar{Q}$</td><td>3.0</td><td>4.32</td><td>13.2</td><td>21.3</td></tr>
<tr><td>F_a</td><td>1.0</td><td>1.44</td><td>4.40</td><td>7.10</td></tr>
<tr><td>$\bar{Z}$</td><td>1.0</td><td>0.69</td><td>0.23</td><td>0.14</td></tr>
<tr><td rowspan="3">6</td><td>$\bar{Q}$</td><td>15.0</td><td>48.65</td><td>450.71</td><td>970.89</td></tr>
<tr><td>F_a</td><td>1.0</td><td>3.24</td><td>30.05</td><td>64.73</td></tr>
<tr><td>$\bar{Z}$</td><td>1.0</td><td>0.31</td><td>0.03</td><td>0.02(0.016)</td></tr>
<tr><td rowspan="3">8</td><td>$\bar{Q}$</td><td>105.0</td><td>956.93</td><td>22378.44</td><td>62453.16</td></tr>
<tr><td>F_a</td><td>1.0</td><td>9.11</td><td>213.13</td><td>594.79</td></tr>
<tr><td>$\bar{Z}$</td><td>1.0</td><td>0.11</td><td>0.0047</td><td>0.0017</td></tr>
</table>

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As a matter of course, when n grows large, the value of $\bar{Q}, F_a$ increase. Therefore, the sensitivity of the failure detection becomes good.

In Maekawa *et al.*(1997), the waveform is simulated in three cases as (a) normal condition, (b) small defect condition (maximum vibration is two times compared with (a)), (c) big defect condition (maximum vibration is six times compared with (a)). They showed the result of F_a and Kurtosis in these cases. We showed the relations between those results and $\bar{Q}$ (in detail see Takeyasu *et al.* (2003)). Subsequently, we examine Bicoherence. We made experiment in the past (Takeyasu(1987),Takeyasu(1989)). Summary of the experiment is as follows. Pitching defects are pressed on the gears of small testing machine.

Small defect condition	Pitching defects pressed on 1/3 gears of the total gear.
Middle defect condition	Pitching defects pressed on 2/3 gears of the total gear.
Big defect condition	Pitching defects pressed on whole gears of the total gear.

We examined several cases for the f_1, f_2 in Eq. (12). We got best-fit result in the following case.

$$\begin{cases} f_1 \ : \text{peak frequency of power spectrum among principal vibration} \\ f_2 \ : 2\, f_1 \end{cases}$$

We obtained the following Bicoherence values in this case (Table2).

Table 2. Tranition of Bicoherence value

Condition	Normal	Small defect	Middle defect	Big defect
Bicoherence	0.99	0.38	0.09	0.02

Thus, Bicoherence proved to be a very sensitive good index. These results can be taken into account, though the definition of defect size does not necessarily coincide. Bicoherence is an absolute index of which range is 1 to 0.   Therefore it can be said that it is a universal index.

Now, we compare this index with proposed simplified absolute index of n-th moment. The proposed method is an absolute index of which range is from 1 to 0 similarly as Bicoherence. As for sensitivity, the case of $n=6$ is quite similar to Bicoherence, but the proposed one is slightly much more sensitive. The value is already 0.31 at small defect condition and 0.03 at middle defect condition which show quite sensitive behavior. It is suitable for especially early stage failure detection.

Sensitivity is better in $n=6$ than that of $n=4$. Sensitivity is much better in $n=8$, but the value falls too fast therefore the judgment becomes hard. Therefore the case $n=6$ is good for the practical use. As Bicoherence is one of the kind of 6-th order moment in a broad sense, these deterioration factors of 6-th order moment in a broad sense found to be sensitive and practical indicies.

This calculation method is simple enough to execute even on a pocketsize calculator as is shown in Eq. (33). Compared with Bicoherence which has to be calculated by Eq. (12)~(15), proposed method is by far a simple one and easy to handle on the field defection.

5. Remarks

Here, we introduced firstly an absolute index of n-th moment and then a simplified calculation method for a simplified absolute index of n-th moment. We compared proposed method with Bicoherence and Kurtosis. The result of this simplified calculation method is a reasonable one compared with the results obtained so far.

The steps for the failure detection by this method are as follows.

1. Prepare a standard $\overline{Z}$ Table for each normal or abnormal level
2. Measure peak values by signal data and compare the peak ratio to the normal data
3. Calculate $\overline{Z}$ by Eq. (33)
4. Judge the failure level by the score of $\overline{Z}$

Generally, it is said that machine is under small defect condition when $S = 2$. By precise diagnosis utilizing deterioration index such as Bicoherence or Eq. (33), much more detailed machine condition can be estimated.

How to set the abnormal level of the machine depends upon the level of control. If the machine is very important and they must be maintained carefully, subtle change of deterioration index should not be neglected. They have to make maintenance at a rather small change of deterioration index. If not, maintenance may be executed at a rather big value of index (This is a case that big value of index means increasing damages).

Preparing standard Table of $\overline{Z}$ for each normal and abnormal level, we can easily judge the failure level only by taking ratio of the peak value to the normal level and calculating $\overline{Z}$ by Eq. (33). This method is simple enough to be carried out even on a pocketsize calculator and is very practical at the factory of maintenance site. This can be installed in microcomputer chips and utilized as the tool for early stage detection of the failure.

6. Conclusions

We proposed a simplified calculation method for an absolute index of n-th moment and named this as simplified absolute index of n-th moment. Compared with the results obtained so far, the results of numerical examples of this paper are reasonable. Judging from these results, our method is properly considered to be effective for especially early stage failure detection. This calculation method is simple enough to be executed even on a pocketsize calculator and is very practical at the factory of maintenance site. The effectiveness of this method should be examined in various cases.

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Paper ID: 77

IDENTIFICATION OF BRAND TRANSITION MATRIX IN THE CASE OF NEW BRAND ENTRY

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Abstract

It is often observed that consumers select the upper class brand when they buy the next time. Suppose that the former buying data and the current buying data are gathered. Also suppose that the upper brand is located upper in the variable array. Then the transition matrix becomes an upper triangle matrix under the supposition that the former buying variables are set input and the current buying variables are set output. Using the data of former buying data and the current buying data, the transition matrix is calculated by the least square method. But when the new products are selected in the current data, there are no former buying data concerning the new products. Therefore the transition matrix can not be calculated by using the least square method because determinant of matrix becomes 0 and the inverse of matrix can not be calculated. There may often arises such case that new products come into the market. How to cope with this is a big issue. In this paper, a new identification method is introduced for the case when new products come into the market. The new method is traced by simple numerical examples. Thus, this proposed approach enables to handle the case that new products come into the market and spread the width of the approach proposed so far.

Key Words: brand selection, matrix structure, brand position, new products

1. Introduction

It is often observed that consumers select upper class brand when they buy next time after they are bored to use current brand.

Suppose that former buying data and current buying data are gathered. Also suppose that upper brand is located upper in the variable array. Then transition matrix becomes upper triangular matrix under the supposition that former buying variables are set input and current buying variables are set output. If the top brand were selected from lower brand skipping intermediate brands, corresponding part in upper triangular matrix would be 0. Using the data of former buying data and the current buying data, the transition matrix is calculated by the least square method. But when the new products are selected in the current data, there are no former buying data concerning the new products. Therefore the transition matrix can not be calculated by using the least square method because determinant of matrix become 0 and the inverse of matrix can not be calculated. There may often arises such case that new products come into the market. How to cope with this is a big issue. If transition matrix is identified, s-step forecasting can be executed. Unless planners for products notice its brand position whether it is upper or lower than other products, matrix structure makes it possible to identify those by calculating consumers' activities for brand selection. Thus, this proposed approach makes it effective to execute marketing plan and/or establish new brand.

Quantitative analysis concerning brand selection has been executed by Yamanaka[5], Takahashi et al.[4]. Yamanaka[5] examined purchasing process by Markov Transition Probability with the input of advertising expense. Takahashi et al.[4] made analysis by the Brand Selection Probability model using logistics distribution. Such research is quite a new one.

2. Brand Selection and Its Matrix Structure

In cyclic movements such as those of bearings and gears, the vibration grows larger whenever the deterioration becomes bigger. Also, it is well known that the vibration grows large when the setting equipment to the ground is unsuitable (Yamazaki, 1977). Let the vibration signal be presented by the function of time $x(t)$. And also assume that it is a stationary time series with mean $\overline{x}$. Denote the probability density function of these time series as $p(x)$. Indices for vibration amplitude are as follows. Here we especially suppose that $\overline{x} = 0$ for the simplicity of description.

2.1 Upper Shift of Brand Selection

The next level of heading is boldface with upper and lower case letters. The heading is flushed left with the left margin. It is often observed that consumers select the upper class brand when they buy the next time. Now, suppose that x is the most upper class brand, y is the second upper brand, and z is the lowest brand. Consumer's behavior of selecting brand would be $z \to y$, $y \to x$, $z \to x$ etc. $x \to z$ might be few.

Suppose that x is the current buying variable, and x_b is the previous buying variable. Shift to x is executed from x_b, y_b, or z_b. Therefore, x is stated in the following equation.

$$x = a_{11}x_b + a_{12}y_b + a_{13}z_b$$

Similarly,

$$y = a_{22}y_b + a_{23}z_b$$

And

$$z = a_{33}z_b$$

These are re-written as follows.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{pmatrix} \begin{pmatrix} x_b \\ y_b \\ z_b \end{pmatrix} \tag{1}$$

Set :

$$\mathbf{X} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}, \quad \mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{pmatrix}, \quad \mathbf{X_b} = \begin{pmatrix} x_b \\ y_b \\ z_b \end{pmatrix}$$

then, $\mathbf{X}$ is represented as follows.

$$\mathbf{X} = \mathbf{AX_b} \tag{2}$$

Here,

$$\mathbf{X} \in \mathbf{R}^3, \mathbf{A} \in \mathbf{R}^{3\times 3}, \mathbf{X_b} \in \mathbf{R}^3$$

$\mathbf{A}$ is an upper triangular matrix. To examine this, generating the following data, which are all consisted by the upper brand shift data.

$$\mathbf{X^i} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad \cdots \qquad \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \tag{3}$$

$$\mathbf{X_b^i} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad \cdots \qquad \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \tag{4}$$

$$i = 1, \qquad 2, \qquad \cdots \qquad N$$

parameter can be estimated using least square method. Suppose

$$\mathbf{X}^i = \mathbf{A}\mathbf{X}_\mathbf{b}^i + \boldsymbol{\varepsilon}^i \tag{5}$$

Where

$$\varepsilon^i = \begin{pmatrix} \varepsilon_1^i \\ \varepsilon_2^i \\ \varepsilon_3^i \end{pmatrix} \qquad i = 1,2,\cdots,N$$

And

$$J = \sum_{i=1}^{N} \boldsymbol{\varepsilon}^{iT} \boldsymbol{\varepsilon}^i \rightarrow Min \tag{6}$$

$\hat{\mathbf{A}}$ which is an estimated value of $\mathbf{A}$ is obtained as follows.

$$\hat{\mathbf{A}} = \left(\sum_{i=1}^{N} \mathbf{X}^i \mathbf{X}_\mathbf{b}^{iT} \right) \left(\sum_{i=1}^{N} \mathbf{X}_\mathbf{b}^i \mathbf{X}_\mathbf{b}^{iT} \right)^{-1} \tag{7}$$

In the data group of the upper shift brand, estimated value $\hat{\mathbf{A}}$ should be an upper triangular matrix. If the following data, that have the lower shift brand, are added only a few in equation (3) and (4),

$$\mathbf{X}^i = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \qquad \mathbf{X}_{\mathbf{b}}^i = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \tag{2}$$

$\hat{\mathbf{A}}$ would contain minute items in the lower part triangle.

2.2 Sorting Brand Ranking by Re-arranging Row

In a general data, variables may not be in order as x, y, z. In that case, large and small value lie scattered in $\hat{\mathbf{A}}$. But re-arranging this, we can set in order by shifting row. The large value parts are gathered in an upper triangular matrix, and the small value parts are gathered in a lower triangular matrix.

$$\begin{array}{cc} & \hat{\mathbf{A}} \\ \begin{pmatrix} x \\ y \\ z \end{pmatrix} & \begin{pmatrix} \bigcirc & \bigcirc & \bigcirc \\ \varepsilon & \bigcirc & \bigcirc \\ \varepsilon & \varepsilon & \bigcirc \end{pmatrix} \end{array} \quad \overset{\text{Shifting}}{\Longleftarrow} \quad \begin{array}{cc} & \hat{\mathbf{A}} \\ \begin{pmatrix} z \\ x \\ y \end{pmatrix} & \begin{pmatrix} \varepsilon & \varepsilon & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \varepsilon & \bigcirc & \bigcirc \end{pmatrix} \end{array} \tag{8}$$

2.3 Matrix Structure Under the Case Skipping Intermediate Class Brand in Skipped

Judging from the experiment we made in the past, we may conclude that Bicoherence is also a sensitive good index (Takeyasu, 1987, 1989).

It is often observed that some consumers select the most upper class brand from the most lower class brand and skip selecting the middle class brand. We suppose v, w, x, y, z brands (suppose they are laid from the upper position to the lower position as $v > w > x > y > z$). In the above case, the selection shifts would be

$$v \leftarrow z, \qquad v \leftarrow y$$

Suppose there is no shift from z to y, corresponding part of the transition matrix is 0 (i.e. a_{45}=0). Similarly, if there is no shift from z to y, from z to w, from y to x, form y to w, from x to w, then the matrix structure would be as follows.

$$\begin{pmatrix} v \\ w \\ x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ 0 & a_{22} & 0 & 0 & 0 \\ 0 & 0 & a_{33} & 0 & 0 \\ 0 & 0 & 0 & a_{44} & 0 \\ 0 & 0 & 0 & 0 & a_{55} \end{pmatrix} \begin{pmatrix} v_b \\ w_b \\ x_b \\ y_b \\ z_b \end{pmatrix} \tag{9}$$

3. Variables Handling Method in Matrix Structure

3.1 In the Case There is No Shift to Lower Brand

If we divide Eq. (19) by σ^{2n}, we can obtain normalized moment. In general, normalized n-th moment is stated as follows.

We consider the case that brand selection shifts to the same class or upper classes. As above-referenced, coefficient matrix must be upper triangular matrix. Suppose following events occur.

Vector $\mathbf{X}, \mathbf{X_b}$ in these cases are expressed as follows.

1. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$

2. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

3. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

4. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$

5. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$

6. $\mathbf{X} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$ $\quad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

Substituting these to equation (7), we obtain

$$\hat{\mathbf{A}} = \begin{pmatrix} 6 & 5 & 3 \\ 0 & 4 & 4 \\ 0 & 0 & 3 \end{pmatrix} \begin{pmatrix} 6 & 0 & 0 \\ 0 & 9 & 0 \\ 0 & 0 & 10 \end{pmatrix}^{-1} = \begin{pmatrix} 1 & \frac{5}{9} & \frac{3}{10} \\ 0 & \frac{4}{9} & \frac{4}{10} \\ 0 & 0 & \frac{3}{10} \end{pmatrix}$$

This makes upper triangular matrix as is supposed.

3.2 In the Case There is Event to Shift to Lower Brand

Next, we examine the case that there is one event included which shift to lower brand. Estimated matrix should include minute items in the lower part of triangle. Add one event as follows.

7. Shift from upper brand to middle brand 1 event

7. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$

Then $\hat{\mathbf{A}}$ is estimated as

$$\hat{\mathbf{A}} = \begin{pmatrix} 6 & 5 & 3 \\ 1 & 4 & 4 \\ 0 & 0 & 3 \end{pmatrix} \begin{pmatrix} 7 & 0 & 0 \\ 0 & 9 & 0 \\ 0 & 0 & 10 \end{pmatrix}^{-1} = \begin{pmatrix} \frac{6}{7} & \frac{5}{9} & \frac{3}{10} \\ \frac{1}{7} & \frac{4}{9} & \frac{4}{10} \\ 0 & 0 & \frac{3}{10} \end{pmatrix}$$

We find minute item in the lower part of triangle as is supposed.

3.3 In the Case There Arise Jumps in Brand Selection

Expressing these in Block Matrix form, it becomes as follow.

Next, we examine the case that brand selection is executed to most upper class. We generate data such that brand shift is executed more than 2 level upper than it is located. We suppose 5 brands and rank them as 1st ranked brand to 5th ranked brand. As above-referenced, the corresponding part which is skipped is 0 in upper triangular matrix.

We suppose following cases.

1.	jump from 5^{th} rank to 1^{st} rank	5 event
2.	jump from 4^{th} rank to 1^{st} rank	1 events
3.	jump from 3^{rd} rank to 1^{st} rank	1 event
4.	stay at 1^{st} rank	1 events
5.	jump from 5^{th} rank to 2^{nd} rank	5 events
6.	jump from 4^{th} rank to 2^{nd} rank	1 events
7.	stay at 2^{nd} rank	1 events
8.	jump from 5^{th} rank to 3^{rd} rank	2 events
9.	stay at 3^{rd} rank	1 events
10.	stay at 4^{th} rank	1 events
11.	stay at 5^{th} rank	3 events

For these cases, $\mathbf{X}, \mathbf{X_b}$ are as follows.

1. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$

2. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}$

3. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$

4. $\mathbf{X} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$

5. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$

6. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}$

7. $\mathbf{X} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$

8. $\mathbf{X} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$

9. $\mathbf{X} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$

10. $\mathbf{X} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}$ $\mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}$

11. $\mathbf{X} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \qquad \mathbf{X_b} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$

Substituting these to equation (7), we get following estimated matrix.

$$\hat{\mathbf{A}} = \begin{pmatrix} 1 & 1 & 1 & 1 & 5 \\ 0 & 1 & 1 & 1 & 5 \\ 0 & 0 & 2 & 0 & 2 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 3 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 15 \end{pmatrix}^{-1} = \begin{pmatrix} 1 & \frac{1}{2} & \frac{1}{4} & \frac{1}{3} & \frac{1}{3} \\ 0 & \frac{1}{2} & \frac{1}{4} & \frac{1}{3} & \frac{1}{3} \\ 0 & 0 & \frac{1}{2} & 0 & \frac{2}{15} \\ 0 & 0 & 0 & \frac{1}{3} & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{5} \end{pmatrix}$$

We can confirm that the corresponding part of jump is 0.

3.4 In the Case There is No Former Buying Data

We suppose v, w, x, y, z brands (suppose there are laid from upper position to lower position as $v > w > x > y > z$) similarly as is stated in 2(3). For example, set v as a new product and suppose following events occur.

$z_b \to z$	1	event
$z_b \to y$	2	events
$z_b \to x$	1	event
$y_b \to y$	2	events
$y_b \to x$	2	events
$y_b \to w$	1	event
$y_b \to v$	1	event
$x_b \to x$	3	events
$x_b \to w$	2	events
$w_b \to w$	2	events
$w_b \to v$	1	event

Substituting these to equation (7), we obtain

$$
\hat{\mathbf{A}} = \begin{pmatrix} 0 & 1 & 0 & 1 & 0 \\ 0 & 2 & 2 & 1 & 0 \\ 0 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 2 & 2 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 \\ 0 & 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 0 & 4 \end{pmatrix}^{-1} \tag{10}
$$

But as a matter of fact, we can not calculate Eq.(10) because of the following reason.

Set

$$
\mathbf{B} = \sum_{i=1}^{N} \mathbf{X}^i \mathbf{X}_b^{iT} \tag{11}
$$

$$
\mathbf{C} = \sum_{i=1}^{N} \mathbf{X}_b^i \mathbf{X}_b^{iT} \tag{12}
$$

As v is a new product, determinant of $\mathbf{C}$ is 0. Therefore we can not calculate the inverse of this matrix. If we set

$v_b \rightarrow v$ $\qquad\qquad$ ε events

Then Eq.(10) becomes as follows.

$$
\hat{\mathbf{A}} = \begin{pmatrix} \varepsilon & 1 & 0 & 1 & 0 \\ 0 & 2 & 2 & 1 & 0 \\ 0 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 3 & 2 \\ 0 & 0 & 0 & 0 & 2 \end{pmatrix} \begin{pmatrix} \varepsilon & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 \\ 0 & 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 0 & 4 \end{pmatrix}^{-1}
= \begin{pmatrix} 1 & \frac{1}{3} & 0 & \frac{1}{6} & 0 \\ 0 & \frac{2}{3} & \frac{2}{5} & \frac{1}{6} & 0 \\ 0 & 0 & \frac{2}{5} & \frac{1}{3} & \frac{1}{4} \\ 0 & 0 & 0 & \frac{1}{3} & \frac{1}{2} \\ 0 & 0 & 0 & 0 & \frac{1}{4} \end{pmatrix}
$$

Setting $\varepsilon \rightarrow 0$, the result of Eq.(14) does not change. This holds true for the case there is no data concerning the variable of in Eq.(2) for the case there is no data as well as the case of new products. This suggests that we can handle the case by calculating the inverse matrix under the assumption that there is a shift to the same variable from before data to current data when there is no before data to the variable concerning $\mathbf{X}_b$ in Eq.(12). Even if we can calculate the inverse matrix by this operation, item of transition matrix becomes

$$a_{ij} = 1$$

When the variable which has no before data is $\mathbf{X}_i$. Therefore brand transition stops there. It does not make upper shift of lower shift. We examine the above case by putting new product to middle or lowest brand position in the next section.

4. Numerical Example

In 3.4, we examined the case there is no former buying data at the top brand. In this section, we examine the case that new product is put in the middle brand position in 4.1 and the case that new product is put in the lowest brand position in 4.2.

4.1 Case1 : In the case new product is put in the middle brand position

Suppose following events occur where x is a new product.

$$\begin{array}{ll} z_b \to z & 2 \quad \text{events} \\ z_b \to y & 1 \quad \text{event} \\ z_b \to v & 1 \quad \text{event} \\ z_b \to w & 1 \quad \text{event} \\ y_b \to y & 1 \quad \text{event} \\ y_b \to w & 1 \quad \text{event} \\ y_b \to v & 1 \quad \text{event} \\ w_b \to w & 3 \quad \text{events} \\ w_b \to v & 2 \quad \text{events} \\ v_b \to v & 3 \quad \text{events} \end{array} \tag{15}$$

Substituting these to Eq.(7), we obtain.

$$\hat{\mathbf{A}} = \begin{pmatrix} 3 & 2 & 0 & 1 & 1 \\ 0 & 3 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 2 \end{pmatrix} \begin{pmatrix} 3 & 0 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 5 \end{pmatrix}^{-1} \tag{16}$$

$\hat{\mathbf{A}}$ can be obtained by setting

$x_b \to x$ ε events

Similarly in 3.4

$$\begin{aligned} \hat{\mathbf{A}} &= \begin{pmatrix} 3 & 2 & 0 & 1 & 1 \\ 0 & 3 & 0 & 0 & 1 \\ 0 & 0 & \varepsilon & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 2 \end{pmatrix} \begin{pmatrix} 3 & 0 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & \varepsilon & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 5 \end{pmatrix}^{-1} \\ &= \begin{pmatrix} 1 & \frac{2}{5} & 0 & \frac{1}{3} & \frac{1}{5} \\ 0 & \frac{3}{5} & 0 & 0 & \frac{1}{5} \\ 0 & 0 & 1 & \frac{1}{3} & 0 \\ 0 & 0 & 0 & \frac{1}{3} & \frac{1}{5} \\ 0 & 0 & 0 & 0 & \frac{2}{5} \end{pmatrix} \end{aligned} \tag{17}$$

This is a convenient method when there is no before data tothe variable. When there is no before data to the variable. Infact, it does not stay on that position forever. If the following data would occur,

$x_b \to v$ 1 event

$\hat{\mathbf{A}}$ is calculated as follows.

$$\hat{\mathbf{A}} = \begin{pmatrix} 3 & 2 & 1 & 1 & 1 \\ 0 & 3 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 2 \end{pmatrix} \begin{pmatrix} 3 & 0 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 5 \end{pmatrix}^{-1}$$

$$= \begin{pmatrix} 1 & \frac{2}{5} & 1 & \frac{1}{3} & \frac{1}{5} \\ 0 & \frac{3}{5} & 0 & 0 & \frac{1}{5} \\ 0 & 0 & 0 & \frac{1}{3} & 0 \\ 0 & 0 & 0 & \frac{1}{3} & \frac{1}{5} \\ 0 & 0 & 0 & 0 & \frac{2}{5} \end{pmatrix} \tag{18}$$

4.2 Case2 : In the case new product is put in the lowest brand position

Suppose following events occur where z is a new product.

$y_b \to z$	1	event
$y_b \to y$	1	event
$y_b \to x$	1	event
$x_b \to x$	2	events
$x_b \to w$	1	event
$x_b \to v$	2	events
$w_b \to w$	3	events
$w_b \to v$	1	event
$v_b \to v$	2	events

Substituting these to Eq.(7), we obtain

$$\hat{\mathbf{A}} = \begin{pmatrix} 2 & 1 & 2 & 0 & 0 \\ 0 & 3 & 1 & 0 & 0 \\ 0 & 0 & 2 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 2 & 0 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}^{-1} \tag{20}$$

$\hat{\mathbf{A}}$ can be obtained by setting

$z_b \to z$	ε	events

Similarly in 3.4

$$\hat{\mathbf{A}} = \begin{pmatrix} 2 & 1 & 2 & 0 & 0 \\ 0 & 3 & 1 & 0 & 0 \\ 0 & 0 & 2 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & \varepsilon \end{pmatrix} \begin{pmatrix} 2 & 0 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & \varepsilon \end{pmatrix}^{-1}$$

$$= \begin{pmatrix} 1 & \frac{1}{4} & \frac{2}{5} & 0 & 0 \\ 0 & \frac{3}{4} & \frac{1}{5} & 0 & 0 \\ 0 & 0 & \frac{2}{5} & \frac{1}{3} & 0 \\ 0 & 0 & 0 & \frac{1}{3} & 0 \\ 0 & 0 & 0 & \frac{1}{3} & 1 \end{pmatrix} \tag{21}$$

5. Remarks

As is examined in 4., we can handle the case by calculating the inverse matrix under the assumption that there is as shift to the same variable from before data to current data when there is no before data to the variable concerning $\mathbf{X}_b$ in Eq.(12). Even if we can calculate the inverse matrix by this operation,

$$a_{ij} = 1$$

therefore it stops there. a_{11} is a top brand level and it does not make problem at all but when the variable is located at the middle or the lower level, it stops there and does not make upper shift. Therefore we examined such cases in 4. As a result, it can also be handle in the same way and $\hat{\mathbf{A}}$ is calculated by setting

$$a_{ij} = 1$$

where i-th order variable is supposed to have non before data. But brand transition steps there. When there arises following event (Where $\mathbf{X}_b$ is supposed to be the corresponding variable of a_{ij})

$$x_b \to u \qquad 1 \quad \text{event}$$

and reflecting this to the calculation of $\hat{\mathbf{A}}$, $\hat{\mathbf{A}}$ becomes to have upper shift item then it works ordinary without stopping at the middle brand position.

6. Application of This Method

Consumers' behavior may converge by repeating forecast with above method and total sales of all brands may be reduced. Therefore, the analysis results suggest when and what to put new brand into the market which contribute the expansion of the market.

There may arise following case. Consumers and producers do not recognize brand position clearly. But analysis of consumers' behavior let them know their brand position in the market. In such a case, strategic marketing guidance to select brand would be introduced. Setting in order the brand position of various goods and taking suitable marketing policy, enhancement of sales would be enabled. Setting higher ranked brand, consumption would be promoted.

7. Conclusion

It is often observed that consumers select the upper class brand when they buy the next time. Suppose that the former buying data and the current buying data are gathered. Also suppose that the upper brand is located upper in the variable array. Then the transition matrix becomes an upper triangle matrix under the supposition that the former buying variables are set input and the current buying variables are set output. Using the data of former buying data and the current buying data, the transition matrix is calculated by the least square method. But when the new products are selected in the current data, there are no former buying data concerning the new products. Therefore the transition matrix can not be calculated by using the least square method because determinant of matrix becomes 0 and the inverse of matrix can not be calculated. There may often arises such case that new products come into the market. How to cope with this is a big issue. In this paper, a new identification method is introduced for the case when new products come into the market. The new method is traced by simple numerical examples. Thus, this proposed approach enables to handle the case that new products come into the market and spread the width of the approach proposed so far. Such research should be confirmed by the concrete theme in the near future to verify obtained results.

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Paper ID: 78

AN ANALYSIS OF THE QUESTIONNAIRE INVESTIGATION FOR PARTNERSHIP - Multivariate Analysis and Key Graph Analysis -

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Abstract

It is assumed that having partner has a good influence on their spiritual stability, relief and efficiency of study/works. Here, "partner" means the person who trusts and understands himself/herself who is another person of the partner. A sweetheart, an intimate friend and husband/wife are examples of a partner.

In this paper, a questionnaire investigation is executed concerning partner. This is analyzed using the Key Graph method and the Multivariate analysis such as the Multi Correspondence analysis method, Quantification Method Ⅱ and the Factor analysis. Some interesting and instructive results are obtained. These are utilized for building a good relation with partner.

Key Words: partnership, questionnaire investigation, Key Graph, Multivariate analysis, Multi Correspondence analysis, Quantification Method Ⅱ

1. INTRODUCTION

Existence of a partner may have a big influence on himself/herself. It will help them their spiritual stability, relief and efficiency of study/work. Here, we define "partner" as the person who trusts and understands himself/herself. A sweetheart, an intimate friend and husband/wife are examples of a partner.

We can confirm some related papers on this theme. Reynolds F.D. et al. (1977)

analyzed the profile and modern feminine life style based upon marriage life. Which would prefer traditional life style or modern life style is discussed and analyzed. Nakamura (2002) analyzed the influence of mother's attitude towards children. That children's fullness of life largely depends upon the mother's attitude toward children is discussed and analyzed. Osawa et al. (2003) analyzed communication of members using Key Graph. The analysis result shows that whether the leadership exists or not influences the communication characteristics. Although these are some related papers concerning on this theme, we intend to make analysis about partnership using Key Graph analysis and other analyzing method, which is not executed before.

In this paper, a questionnaire investigation is executed concerning partner in order to get instructions for thinking about partner. Furthermore, effect and necessity are analyzed in detail. Through this analysis, we aim to obtain useful instruction concerning the partnership in social life and team work in organization. These are analyzed by using the Key Graph method and the Multivariate analysis such as the Multi Corresponding analysis method, Quantification Method Ⅱ and the Factor analysis. As mentioned above, the analysis was executed by using the Key Graph method, that enabled us to visualize the relationship among the chance, the events and the surroundings, as the tool of the decision making support by data mining about the questionnaire survey that was originally executed it in recent years. Some interesting and instructive results are obtained. These are utilized for building a good relation with partner and a much more effective and useful team work in the company.

The rest of the paper is organized as follows. Outline of questionnaire research is stated in section 2. In section 3, an analysis is executed which is followed by the remarks in section 4. Section 5 is a summary.

2. OUTLINE OF QUESTIONNAIRE RESEARCH

2.1. Outline of Questionnaire Research

Outline of questionnaire research is as follows.

(1)Scope of investigation: Students, Company Employees, Officers, Independents and Housewives, Japan

(2)Period : October 2008～November 2008

(3)Method : Mail and self writing

(4)Collection : Number of distribution 500, Number of collection 165

(Collection rate 33.0%)

2.2. Analysis methods

Analysis methods are as follows. Questionnaire results are analyzed in five methods. First, summary by single variable is explained in 3.1 in order to examine the pattern of responding about each item. Second, analysis by Multi Corresponding analysis is executed in 3.2 in order to visualize the relationship among the items. Third, analysis by Factor analysis is executed in 3.3 in order to clarify the viewpoints of important factors. Fourth, analysis by Quantification Method Ⅱ is executed in 3.4 in order to grasp the contribution to efficacy and necessity of having partner. Fifth, analysis by using the Key Graph method is executed in 3.5 in order to visualize total structure among items as showed in Table 1.

Table 2.1. The systematic approach on efficient analysis

Step	Aim of analysis	Used Method
①	Examining the pattern of responding about items	"Single Variable Analysis" :
②	Examine the relationship among questionnaire items about important factors	"Multi Correspondence analysis" : (Positioning)
③	Clarifying the viewpoints and axes for the important factors	"Factor Analysis": (Extracting)
④	Grasp the contribution to efficacy and necessity of having partner	"Quantification Method Ⅱ" : (Contribution)
⑤	Visualize the total structure among questions systematically	"Key Graph Analysis" : (Text mining)

3. ANALYSIS OF QUESTIONNAIRE RESULTS

3.1. Summary by single variable

Summary by single variable is as follows.

3.1.1. Outline of examinees

Q1. Sex

①Male : 45%

②Female : 55%

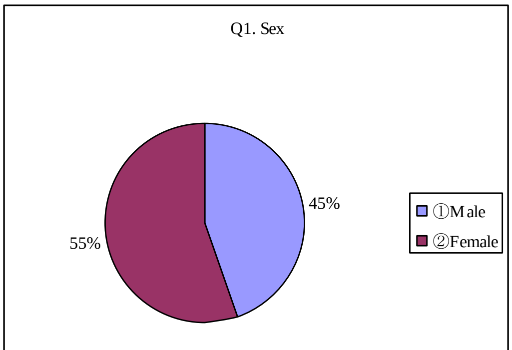


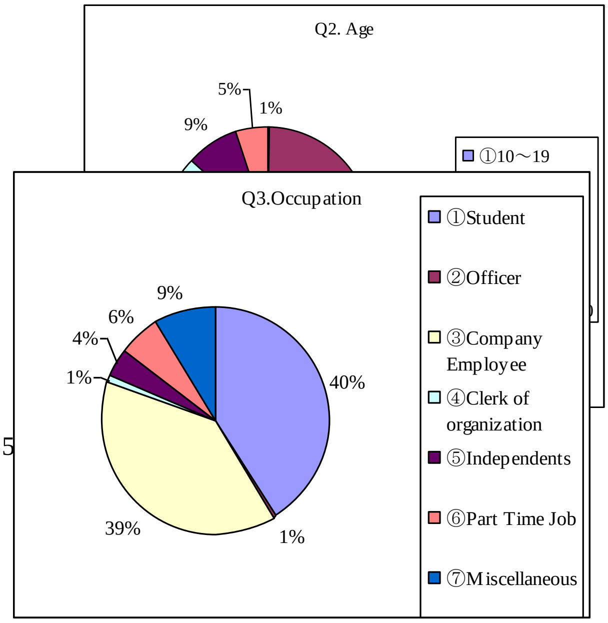
Fig.3.1 Sex

Q2. Age

①10～19 : 1%

②20～29 : 51%

③30～39 : 24%



④40～49 : 10%

⑤50～59 : 9%

⑥More than 60 : 5%

Q3.Occupation

①Student : 40%

②Officer : 1%

③Company Employee : 39%

④Clerk of organization : 1%

⑤Independents : 4%

⑥Part Time Job : 6%

⑦Miscellaneous : 9%

Q4.Official Position

①President : 7%

②Executive : 3%

③General manager : 3%

④Section Chief : 3%

⑤Chief : 1%

⑥Office employee : 20%

⑦Miscellaneous : 61%

Q5. Annual Income

①0～3million yen : 65%

②～5million yen : 16%

③～7.5million yen : 6%

④～10million yen : 6%

⑤～15million yen : 6%

⑥More than 15 million yen : 1%

Q6. Address

① Osaka : 57%

② Hyogo : 13%

③ Kagawa : 11%

④ Shizuoka : 3%

⑤ Miscellaneous : 16%

Q7.Blood Type

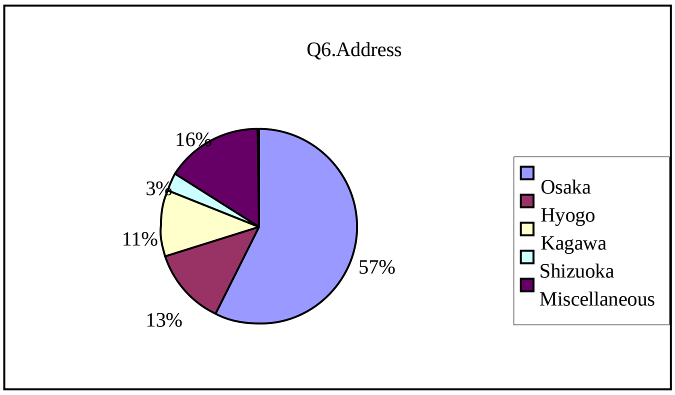


Fig.3.3 Occupation

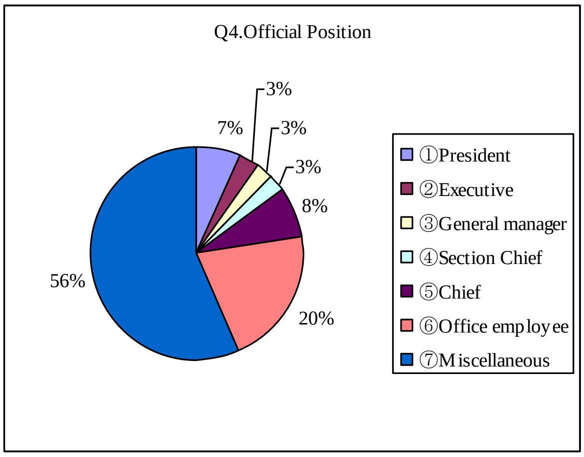


Fig.3.4 Official Position

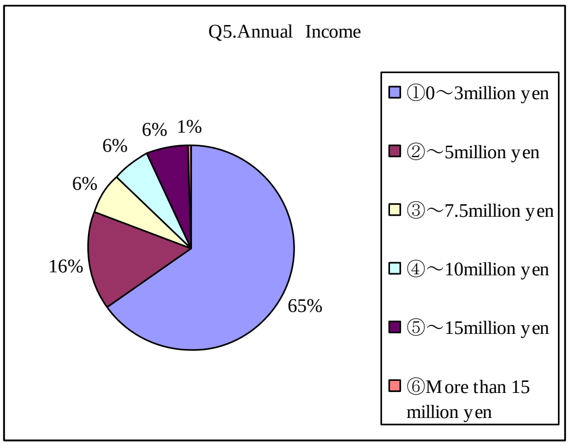


Fig.3.5 Annual Income

①A Type : 43%
②B Type : 18%
③O Type : 29%
④AB Type : 8%
⑤Unknown : 2%

Q8.Are you married?

①Single : 61%
②Married : 39%

Fig.3.6 Address

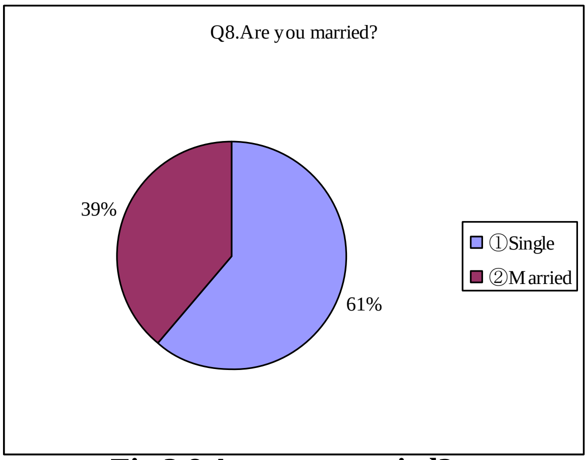


Fig.3.8 Are you married?

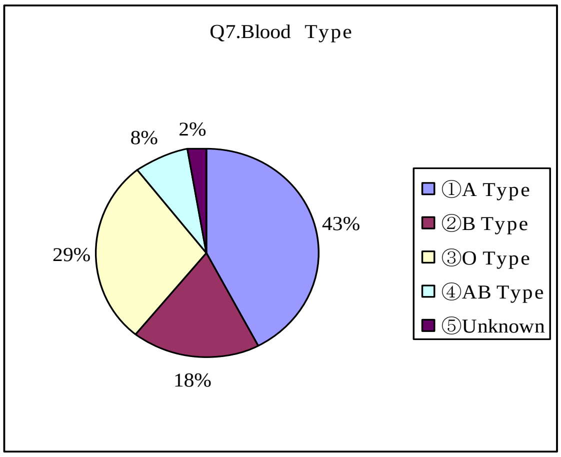


Fig.3.7 Blood Type

Q9.How many children do you have?

①One child : 12%
②Two Children : 14%
③Three Children : 7%

④Four children : 0%
⑤None : 67%

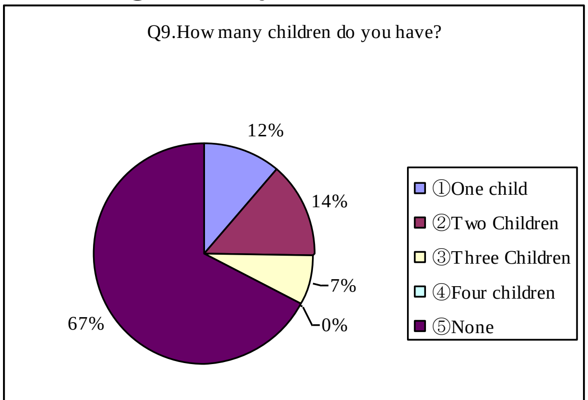


Fig.3.9 How many children do you have?

Q10. Are you positive to do anything?

The share of "Positive" is 41%, and it is dominant.

Q11. Do you like to be alone?

"Like very much"(16 %),and "Rather like"(36%) take half of the share.

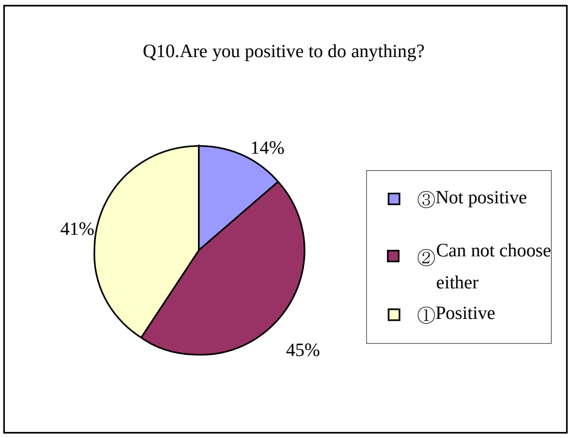


Fig.3.10 Are you positive to do anything

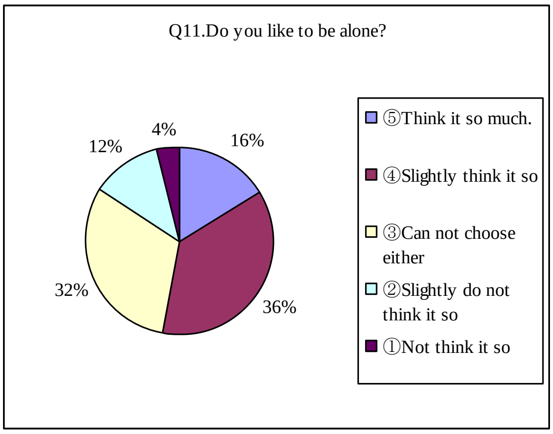


Fig.3.11 Do you like to be alone

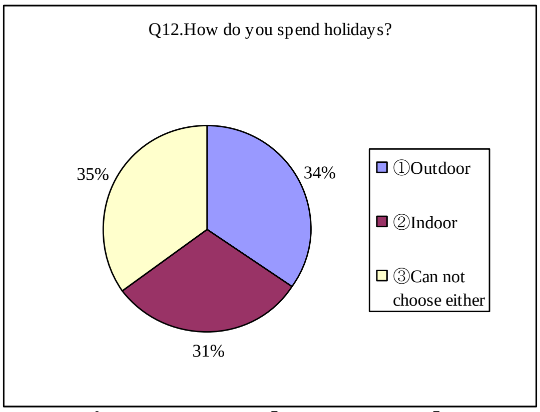


Fig.3.12 How do you spend holidays.

Q12. How do you spend holidays?

Three cases have the share nearly for 1/3 for each.

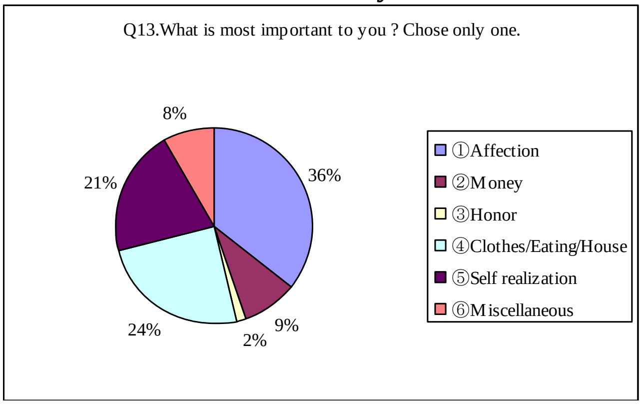


Fig.3.13 What is the most important to you?

Q13.What is the most important to you? （Chose only one.）

"Affection" (36%) is the most and "Clothes/Eating/House" (24%),"Self Realization" (21%) follow. Spiritual elements are esteemed.

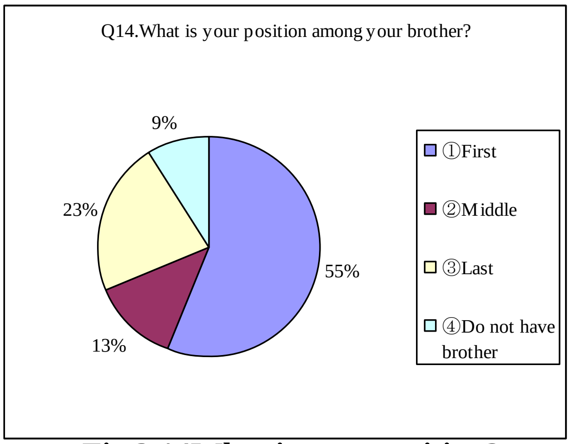


Fig.3.14What is your position?

Q14.What is your position among your brother?

①First :55%
②Middle :13%
③Last :23%
④Do not have brother :9%

Q15.Do you have "partner" now? Who is he/she?

"Husband/Wife" (33%) is the most and "Intimate friend" (22%), "Sweetheart" (20%) follow. "None" consists of 18%.

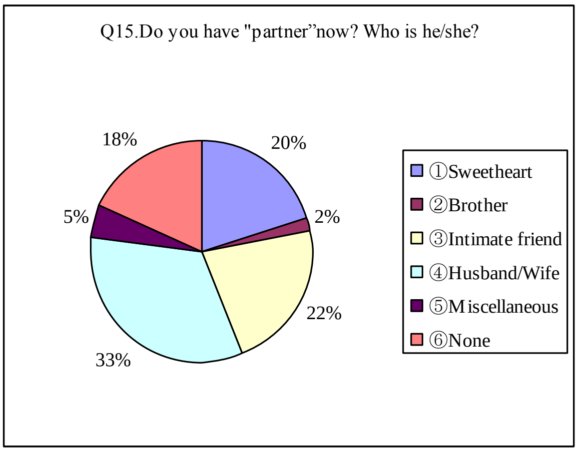


Fig.3.15 Do you have "partner" now?

Q16.How long have you been with your partner?

"More than 10 years" was 50%.

It might be because there were many "Husband/Wife" and "Intimate friend".

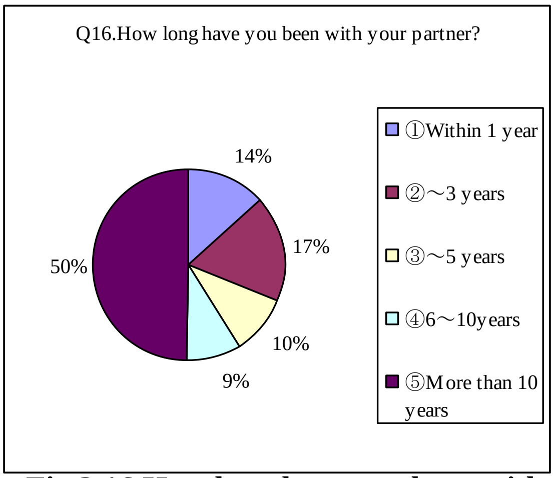


Fig.3.16 How long have you been with your partner?

Q17-Q20

In Q17 (Physical condition), "Very good" (16%), "Rather good" (22%) and "Ordinary level" (46%) take the dominant share.

In Q18 (Work or Study),"Very good" (9%),"Rather good" (23%) and "Ordinary level" (49%) take the dominant share.

In Q19 (Living a full life) and Q20 (Confident in yourself), trend of share is said to be similar on the whole.

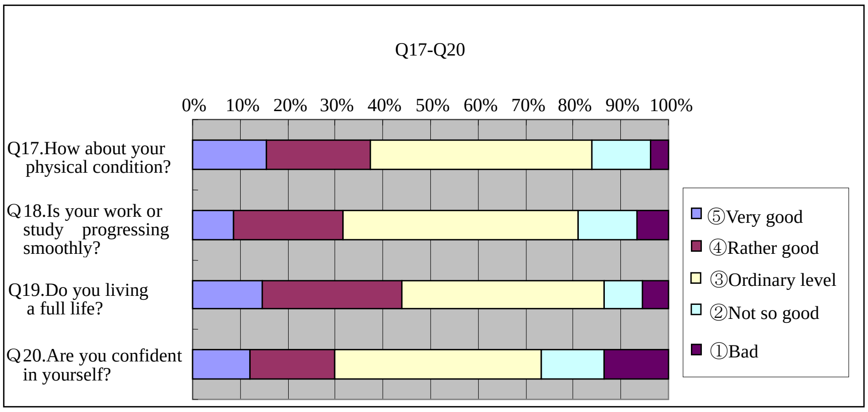


Fig.3.17 Q17-Q20

3.1.2. About partner

Q21.When did you meet with your partner first?

Generally, they have a rather long time connection.

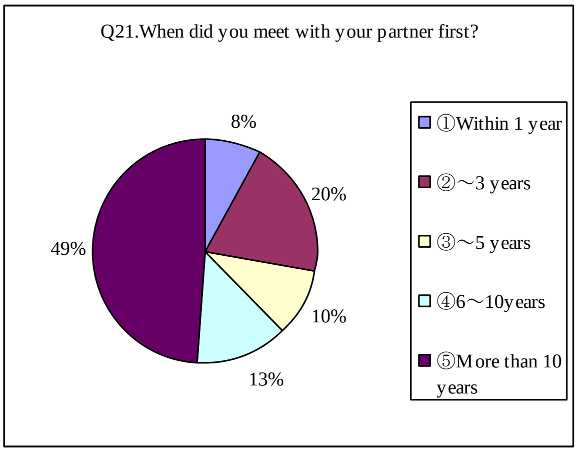


Fig.3.18 When did you meet with your partner?

Q22.How often do you meet with your partner?

Occurrence to meet with partner is said to be rather frequent.

Q23.How do you make a contact?

"Face to face" (41%) is dominant.

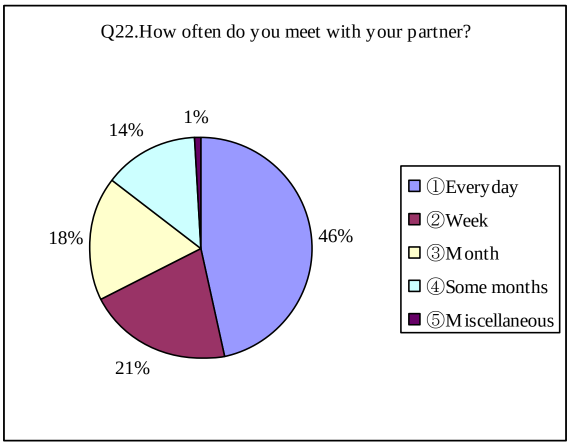


Fig.3.19 How often do you meet with your partner?

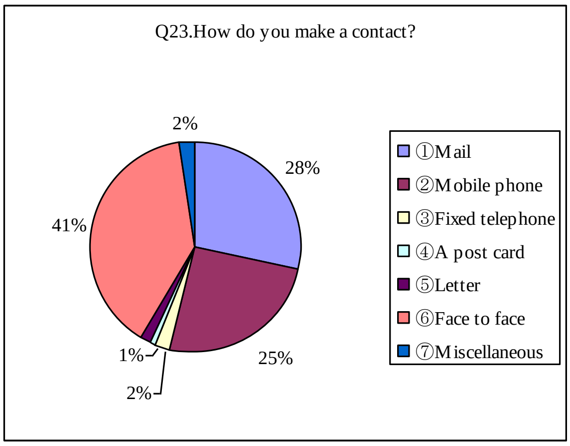


Fig.3.20 How do you make a contact?

Q24.Age

"20th" (43%) occupies nearly half of the share.

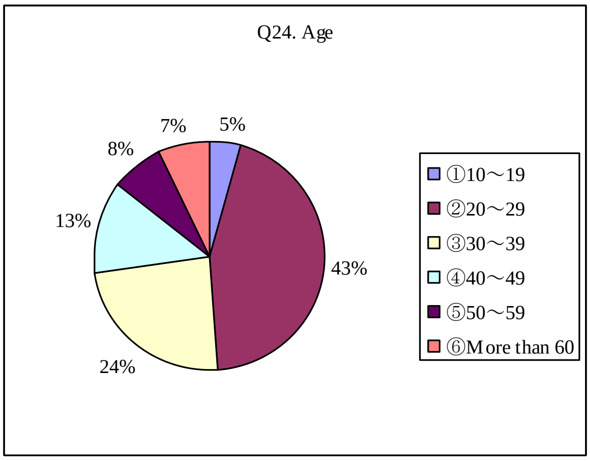


Fig.3.21 Age

Q25.Sex of partner

"The other sex" (69%) is dominant for the partner.

Q26.Occupation

"Student" (39%) and "Company Employee"
(30%) are the main answerers.

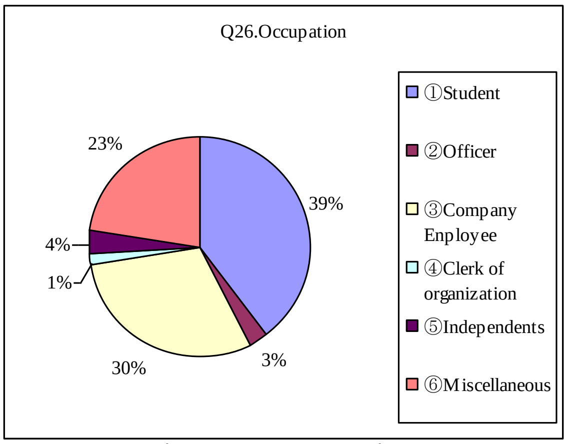


Fig.3.23 Occupation

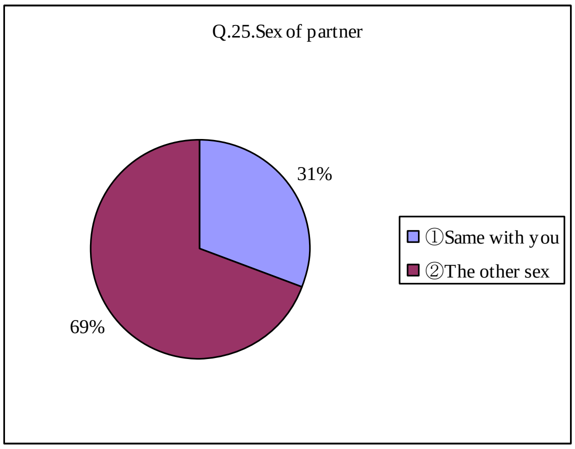


Fig.3.22 Sex of partner

Q27.Official Position

"Miscellaneous" (62%) has a big share

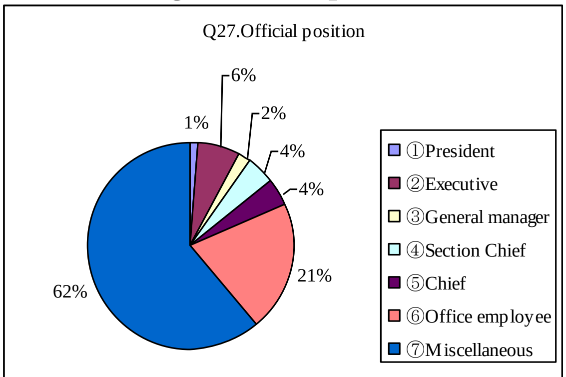


Fig.3.24 Official Position

because there are many student answerers.

Q28.Address

① Osaka：52%

② Hyogo：15%

③ Kagawa：11%

④ Tokyo　：3%

⑤ Miscellaneous：19%

Q29.Blood　Type

"A type" is 37%, "O type" is 23%, and "B type" is 17%, which is nearly the same with the average in Japan.

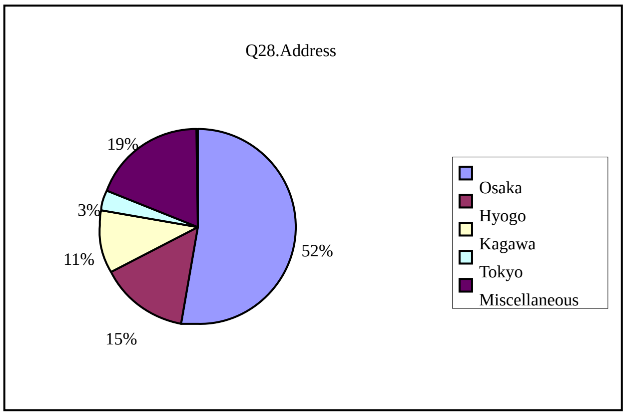


Fig.3.25 Address

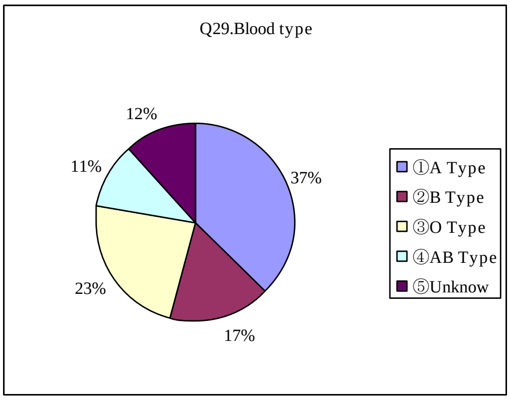


Fig.3.26 Blood Type

Q30.What is your partner's position among his/her brothers?

"First" (43%) takes the dominant share, which is followed by "Last" (33%).

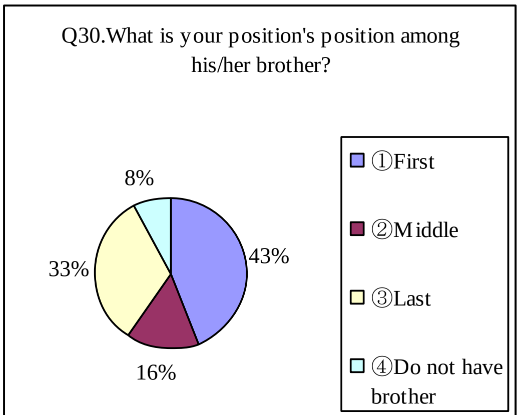


Fig.3.27 Partner's Position

3.1.3 About the relation with your partner Q31.-33

In Q31 (The way of thinking), "Slightly similar" takes the 44% share.

InQ32(The character), "Slightly similar"(31%), "Can not choose either" (26%), and "Slightly not so similar"(27%) have nearly the same share and these are dominant.

InQ33(The opinion), "Very instructive "(37%), and "Slightly instructive"(44%) take the dominant share.

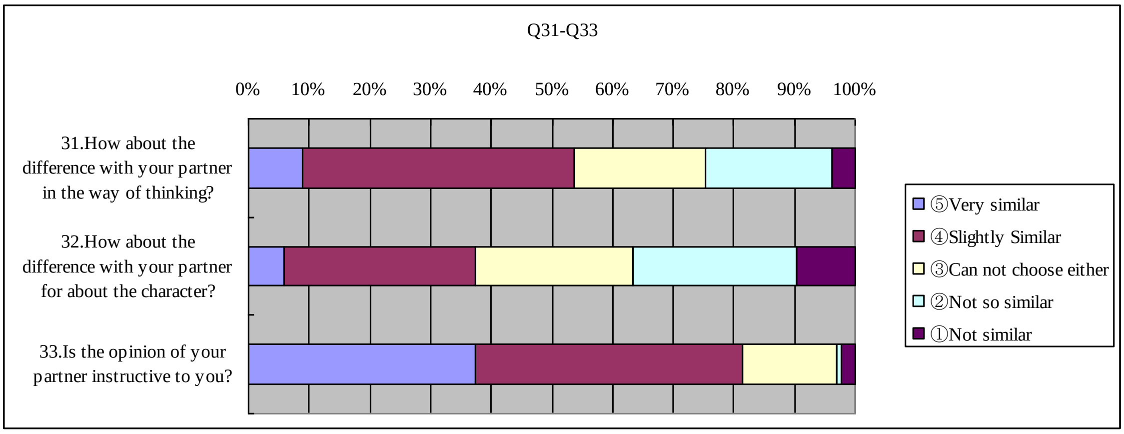


Fig.3.28 Q31-33

3.1.4. Please answer your views concerning partner.

Q34. Is it a good thing for you to have a partner?

"Think it very good"(64%) and "Slightly think it good"(25%) have dominant share.

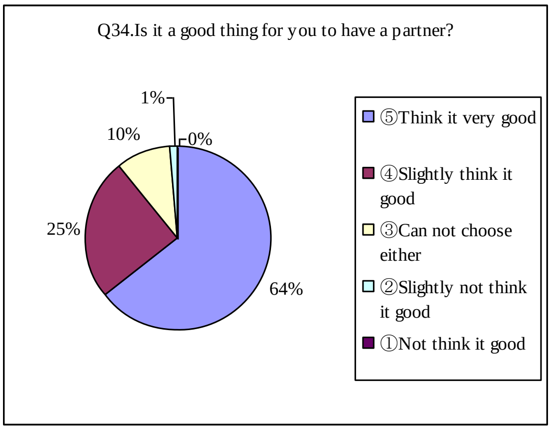


Fig.3.29 Is it a good thing to have a partner?

(1)What is good for?

Q35.-Q45.

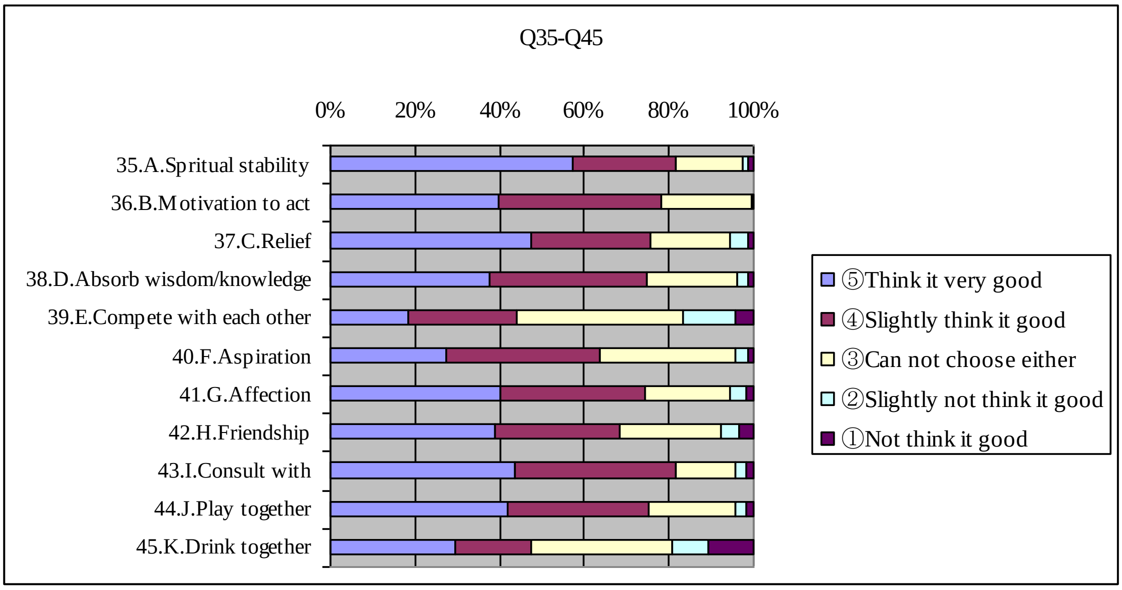


Fig.3.30 Q35-45

Watching the answer for "Think it very good", the most one is "Spiritual stability" and then, "Relief", "Consult with", "Play together" and "Affection" follow. They esteem spiritual ties.

3.1.5 Which item is most important?

Q47. Which item is most important?

"Spiritual stability" (36%) has the dominant share.

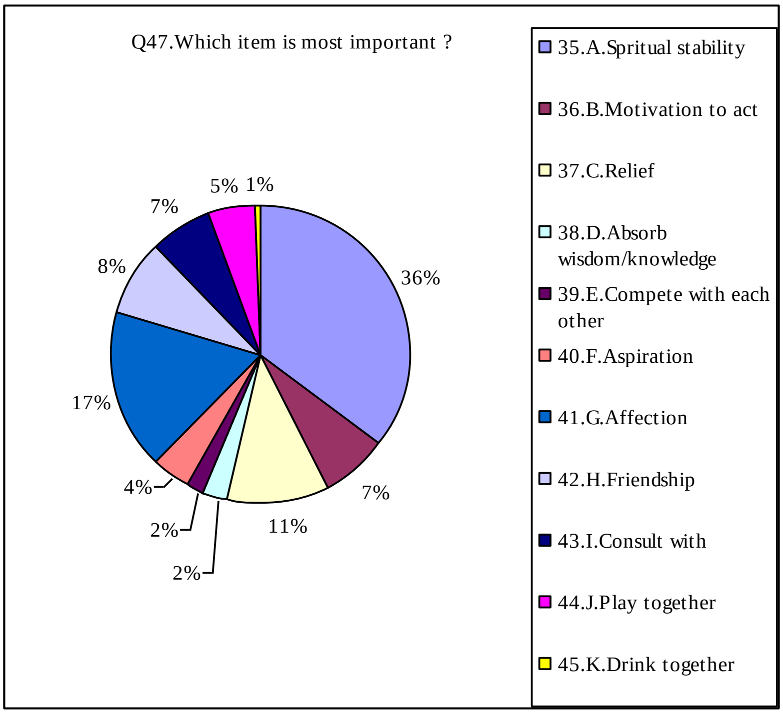


Fig.3.31 Which item is most important?

Q48.-61.

Watching the answer for "Think it necessary", the most one is "Can trust" and then "Can associate without reserve" follows, which exceed 60% share for each of them.

Following items are "Partner listens to me what I say", "Can consult with anything", "Can respect" and "Can rely upon", and these exceed 40% share for each of them.

These answers suggest that "Can trust" is an essential item to build partnership.

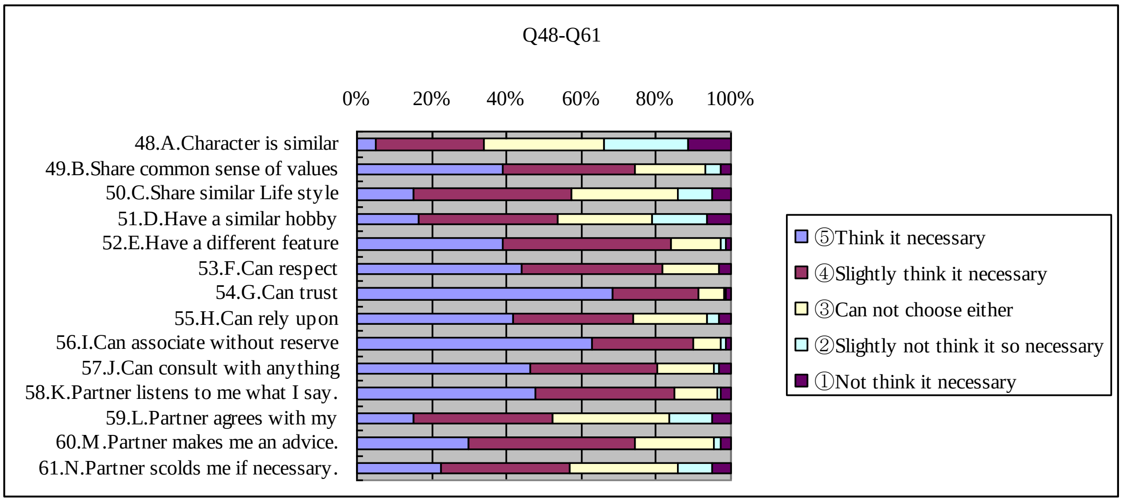


Fig.3.32 Q48-61

3.1.6. Most important item

Q63. Which item is most important?

Most important item is "Can trust" (26%), then "Share common sense of values" (22%), and "Can associate without reserve" (20%) follow.

Q64. Is partner necessary to you?

"Think it very necessary" (68%), "Slightly think it necessary" (24%) occupy the dominant share.

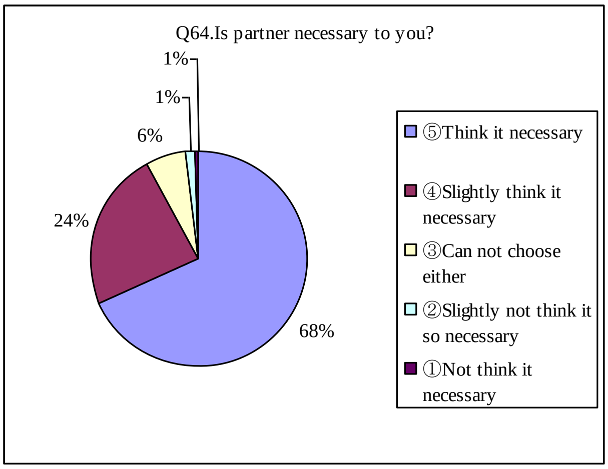


Fig.3.33 Which item is most important?

3.2. Multivariate Analysis

3.2.1. Multi Correspondence Analysis

(1) Q35-45 : Effect of Partner

We can observe 3 clusters from Fig.3.35.

First one is spiritual items such as "Spiritual stability", "Relief", "Absorb wisdom/knowledge" and "Affection".

Second one is items concerning communication such as "Aspiration" and "Drink together".

Third one is items concerning activity such as "Play together" and "Friendship".

On the other hand, such items as "Compete with each

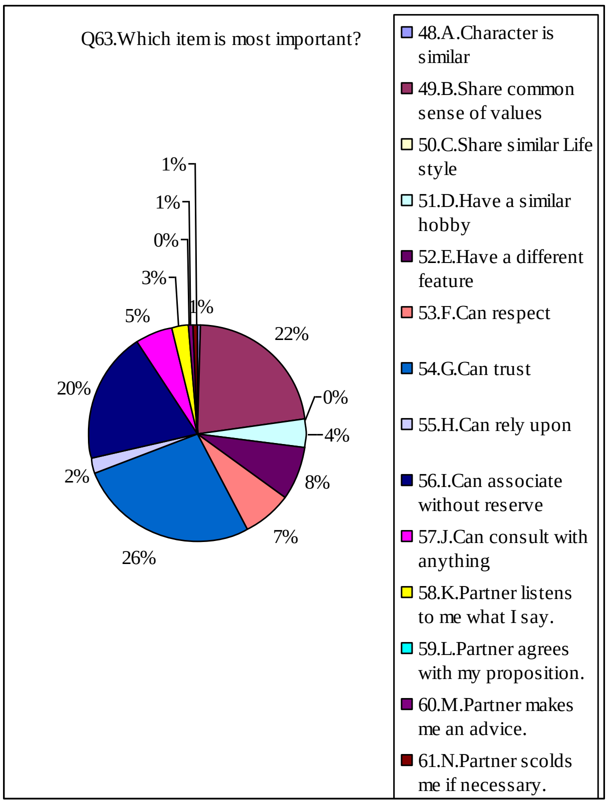


Fig.3.34 Is partner necessary to you?

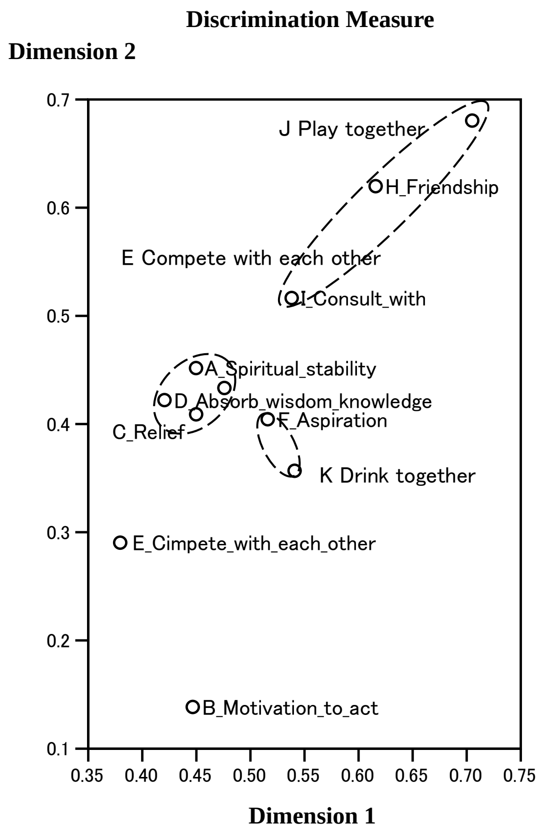


Fig.3.35 Effect of partner

other", "Motivation to act" are separated from the above stated clusters.

（2） Q48-61 : Necessa Condition as a Partner

We can observe 4 clusters from Fig.3.36.

First one is the group which indicates having small stress such as "Can rely upon" and "Can associate without reserve".

Second one is the items concerning reliable relation such as "Partner agrees with my proposition", "Have a different feature".

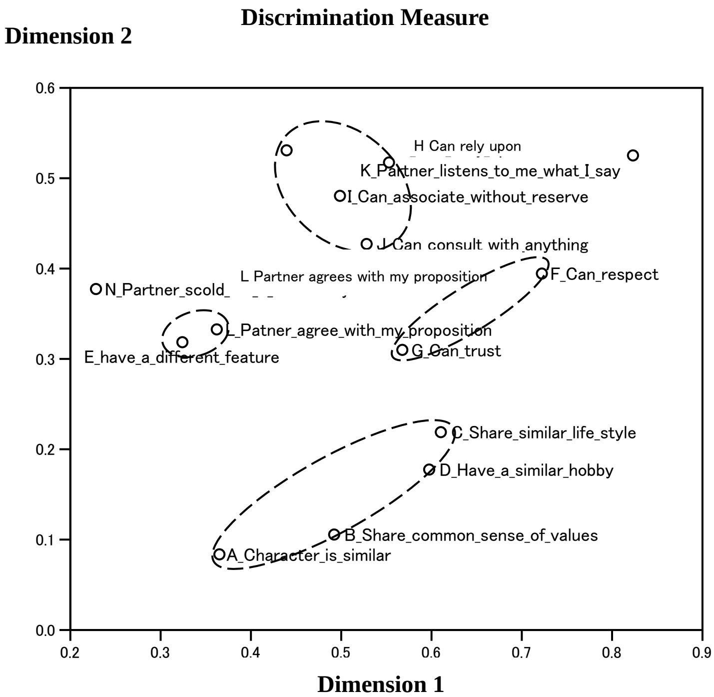


Fig.3.36 Necessary condition as a Partner

Third one is the group which indicates having similar thinking such as "Character is similar", "Share common sense of values", "Have a similar hobby" and "Share similar life style"

Forth one is the group which indicates high consciousness of reliability such as "Can respect" and "Can trust".

3.2.2. The analysis by the Factor Analysis

Factor analysis is executed so as to extract viewpoints or axes for the appraisal stated above. As for the extraction method of the factor, "the principal axis factoring" is adopted , and as for the rolling-method, "The varimax rotation which is accompanied by the normalization of Kaiser as orthogonal rotation " is adopted. Also, we confirmed the validity of the KMO(Kaiser-Meyer-Olkin) specimen validity measure.

(1) Q35-45 : Effect of Partner

KMO is 0.854 and we can confirm an appropriate common factor.

From the factor matrix after rotation, we can extract 2 meaningful axes. We can see that the 1st axis is the factor concerning action based upon such items as "Compete with each other ", "Aspiration " , "Play together" and "Drink together"

The 2nd axis is the axis concerning spiritual feeling such as "Relief", "Spiritual stability" , "Affection" , "Friendship" and "Consult with"

Table 3.1 Factor Matrix after Rotation about Effect of Partner

	Factor	
	1	2
A Spiritual stability	.150	.734
B Motivation to act	.435	.424
C Relief	.134	.826
D Absorb wisdom knowledge	.453	.332
E Compete with each other	.702	.034
F Aspiration	.785	.161
G Affection	.232	.617
H Friendship	.575	.468
I Consult with	.453	.543
J Play together	.624	.510
K Drink together	.626	.298

（2） Q48-61 ： Necessity of Partner

KMO is 0.873 and we can confirm an appropriate common factor.

From the factor matrix after rotation, we can see that the 1st axis is the factor which indicates having small stress such as “Can consult with anything”, “Can associate without reserve” and “Partner listens to me what I say”.

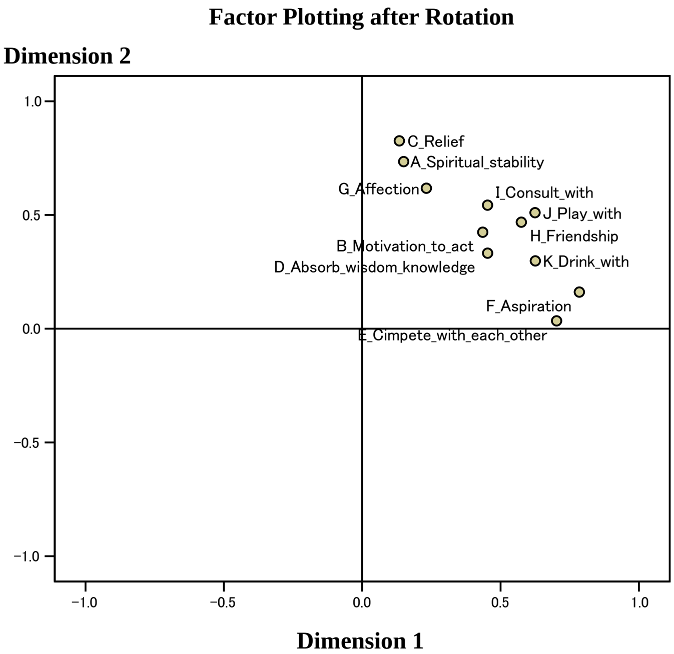


Fig.3.37 Factor Plotting after rotation about Effective of Partner

The 2nd axis is the factor which indicates high consciousness of reliability such as “Can respect”, “Can trust” and “Can rely upon”. The 3rd axis is the factor which indicates having similar thinking such as “Character is similar”, “Share common sense of values”, “Have a similar hobby” and “Share similar life style”.

These results are similar to those of Multi Corresponding Analysis.

Table 3.2 Factor Matrix after Rotation about Necessity of Partner

	Factor		
	1	2	3
A Character is similar	.147	.089	.647
B Share common sense of values	.026	.340	.527
C Share similar life style	.123	.202	.666
D Have a similar hobby	.303	.007	.560

E Have a different feature	.123	.684	.075
F Can respect	.290	.627	.232
G Can trust	.221	.626	.253
H Can rely upon	.483	.485	.175
I Can associate without reserve	.515	.307	.275
J Can consult with anything	.914	.196	.120
K Partner listens to me what I say	.633	.341	.341
L Partner agrees with my proposition	.400	.181	.349
M Partner makes me an advice	.433	.524	.203
N Partner scold me if necessary	.355	.375	.036

Factor Plotting after Rotation

回転後の因子空間の因子ﾌﾟﾛｯﾄ

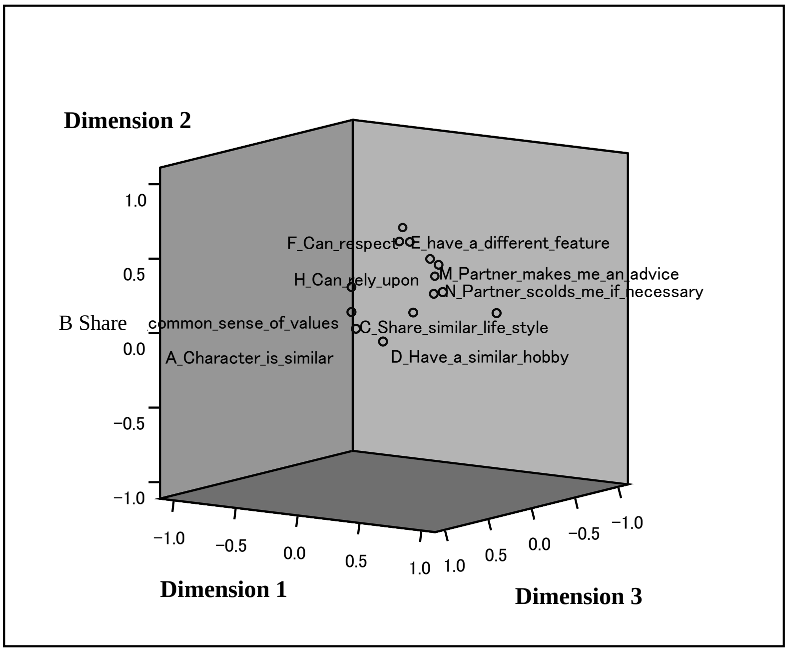


Fig.3.38 Factor Plotting after rotation about Necessity of Partner

3.2.3. Analysis by the Quantification Method Ⅱ

Considering the data volume and the characteristics of the analysis that it is a kind of physiological theme, analysis is executed by converting 5 answer level division to 3 level division, i.e., 5, 4 to 3, 3 to 2, 2,1 to 1.

（1）Q35-45：Effect of Partner

Table 3.3 shows that most influential factor is “Consult with”, and then, “Spiritual stability”, “Affection” follow.

Table 3.3 Structure Matrix Effect of Partner

	Function	
	1	2
I Consult with	.727(*)	.260

A Spiritual stability	.636(*)	-.106
G Affection	.635(*)	.238
F Aspiration	.433(*)	.250
J Play together	.433(*)	.343
B Motivation to act	.421(*)	-.374
C Relief	.412(*)	.103
D Absorb wisdom knowledge	.391(*)	-.158
E Compete with each other	.348(*)	.258
H Friendship	.344(*)	.045
K Drink together	.237	.305(*)

Utilizing the results of Table 3.4, discrimination equation of outer criteria (1. Bad, 2.Can not choose either, 3.Good) can be stated as follows.

$$Z_1 = -7.364 + 0.654A + 0.259B - 0.386C + 0.127D + 0.275E + 0.072F + 0.465G - 0.057H + 0.781I - 0.129J - 0.319K \quad (3.1)$$

$$Z_2 = 1.619 - 0.192A - 1.248B + 0.222C - 0.495D + 0.111E + 0.309F + 0.368G - 0.445H - 0.055I + 0.652J + 0.504K \quad (3.2)$$

Table 3.4 Coefficient of Canonical Discrimination Function

	Function	
	1	2
A Spiritual stability	.654	-.192
B Motivation to act	.259	-1.248
C Relief	-.386	.222
D Absorb wisdom knowledge	.127	-.495
E Compete with each other	.275	.111
F Aspiration	.072	.309
G Affection	.465	.368
H Friendship	-.057	-.445
I Consult with	.781	-.055
J Play together	-.129	.652
K Drink together	-.319	.504
(constant)	-7.364	1.619

(Un-standardization coefficient)

The discriminate hitting ratio is 81.3%. It is good in this case.

(2) Q48-61 : Necessity of Partner

From the Table 3.5, we can see that most influential factor is “Partner listens to me what I say”, and then, “character is similar” and “Can consult with anything” follow. These results coincide with those of Factor Analysis.

Table 3.5 Structure Matrix- Necessity of Partner

	Function	
	1	2
K Partner listens to me what I say	.729(*)	.126

A Character is similar	.671(*)	.187
J Can consult with anything	.625(*)	.100
H Can rely upon	.538(*)	-.082
G Cant rust	.505(*)	-.245
I Can associate without reserve	.464(*)	.253
L Partner agrees with my proposition	.412(*)	-.241
C Share similar life style	.360(*)	.351
B Share common sense of values	.329(*)	.212
F Can respect	.315(*)	.096
M Partner makes me an advice	.312(*)	.216
E Have a different feature	.236(*)	.171
N Partner scolds me if necessary	.287	.393(*)
D Have a similar hobby	.250	.260(*)

Utilizing the results of Table 3.6, discrimination equation outer criteria （1.Bad, 2.Can not choose either, 3.Good） can be stated as follows.

$$Z_1 = -5.200 + 0.585A - 0.071B + 0.065C - 0.203D + 0.187E - 0.272F + 0.331G + 0.148H - 0.092I + 0.438J + 0.553K + 0.046L - 0.390M + 0.029N \quad (3.3)$$

$$Z_2 = -0.834 + 0.087A + 0.135B + 0.456C + 0.242D + 0.386E - 0.016F - 1.071G - 0.052H + 0.131 + 0.038J + 0.087K - 0.710L + 0.132M + 0.540N \quad (3.4)$$

Table 3.6 Coefficient of Canonical Discrimination function-Necessity of Partner

	Function	
	1	2
A Character is similar	.585	.087
B Share common sense of values	-.071	.135
C Share similar life style	.065	.456
D Have a similar hobby	-.203	.242
E Have a different feature	.187	.386
F Can respect	-.272	-.016
G Can trust	.331	-1.071
H Can rely upon	.148	-.052
I Can associate without reserve	-.092	.131
J Can consult with anything	.438	.038
K Partner listens to me what I say	.553	.087
L Partner agree with my proposition	.046	-.710
M Partner makes me an advice	-.390	.132
N Partner scolds me if necessary	.029	.540
(constant)	-5.200	-.834

(Un-standardization coefficient)

The discriminate hitting ratio is 83.0%. It is good in this case.

3.3. Analysis using Key Graph

Key Graph is a method to visualize the data structure using key words. Data occurrences at the same period of the time are exhibited by the link of Key Graph. Jaccard coefficient is utilized for the analysis of co-appearance rate.

3.3.1. Q1-5, 7-16, 34 Correlation between Attribute and Effect of Partner

From Fig.3.39, we can find high co-occurrence rate between "Think it very good (for having partner)" (i.e. Effect of partner) and "Single ", "0〜3miliion yen" , "Male". Watching them as a cluster , items among "highly effective for having partner" , "Single " "0〜3miliion yen" , "Student" , "20〜29" , "Female", and "Male" have high co-occurrence rate. We can see that young men think highly of having a partner.

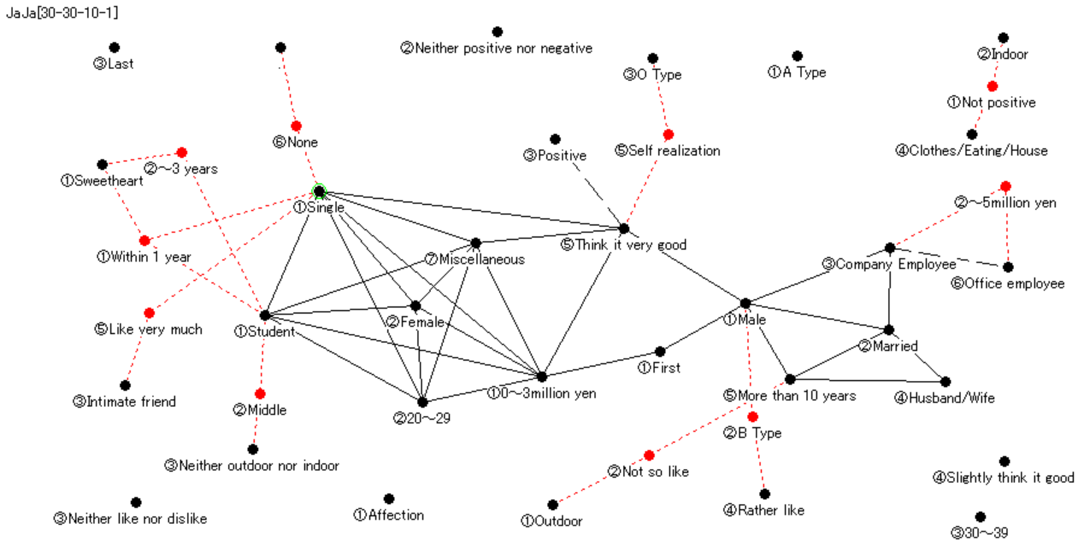


Fig.3.39 Correlation between Attribute and Effect of Partner

3.3.2. Q1-5, 7-16, 34 Correlation between Attribute and Necessity of Partner

From Fig.3.40, we can see high co-occurrence rate between "Think it necessary" and "Single " "0〜3miliion yen" , "More than 10 years", and "First" . We can observe that single young men especially need partner. Another cluster is consisted by "Male" , "Married" , "Husband/Wife" , "More than 10 years" , "Company employee", and "First". From these, we can see that even "Male" of "Married" think it important to have a partner.

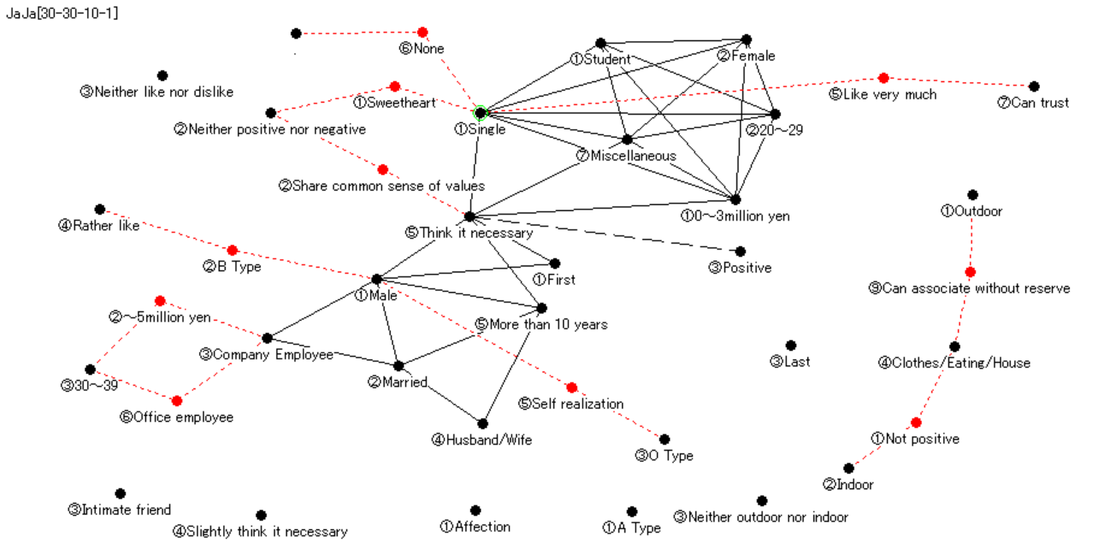


Fig. 3.40 Correlation between Attribute and Necessity of Partner

3.3.3. Q21-27, 29-34 Attribute of Partner and Effect of Partner

Watching the co-occurrence rate between “Attribute of Partner” and “Effect of Partner”, we can observe following characteristics. High co-occurrence rate items with “Effect of Partner” are “The other sex” “meet everyday”, and “Face to face”, which implies that “married” think highly of the effect of partner.

On the other hand , “Student” of “20～29” has high co-occurrence rate with “Same sex” , which implies that they raise “intimate friend” as an effect of partner

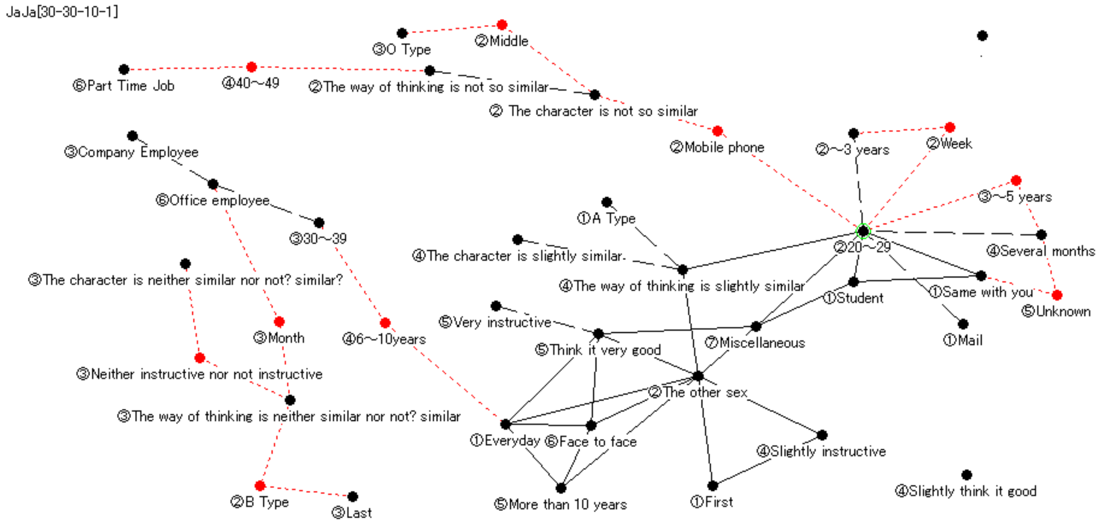


Fig.3.41 Attribute of Partner and Effect of Partner

3.3.4. Q1-5, 7-16, 34･47, Q63･64 Attribute of Partner and Effect of Partner･Necessity of Partner

Watching Fig.3.42, we can find that “Effect of Partner” and “Necessity of Partner” have high co-occurrence rate. High co-occurrence rate items with “Effect of Partner” are “Single” , “Male” , and “0～3miliion yen”, which implies that especially young men highly think of the effect of partner , while female does not think so much on this.

On the other hand, high co-occurrence rate items with “Necessity of Partner” are Single”, “Male”, “0～3miliion yen”, and “More than 10 years, while female does not think so much on this in the same way. Items among “”Male”, “Married”, “Husband/Wife”, and “More than 10 years” have high co-occurrence rate.

Considering these results, these are similar to those of Single Variable Analysis and Multivariate Analysis.

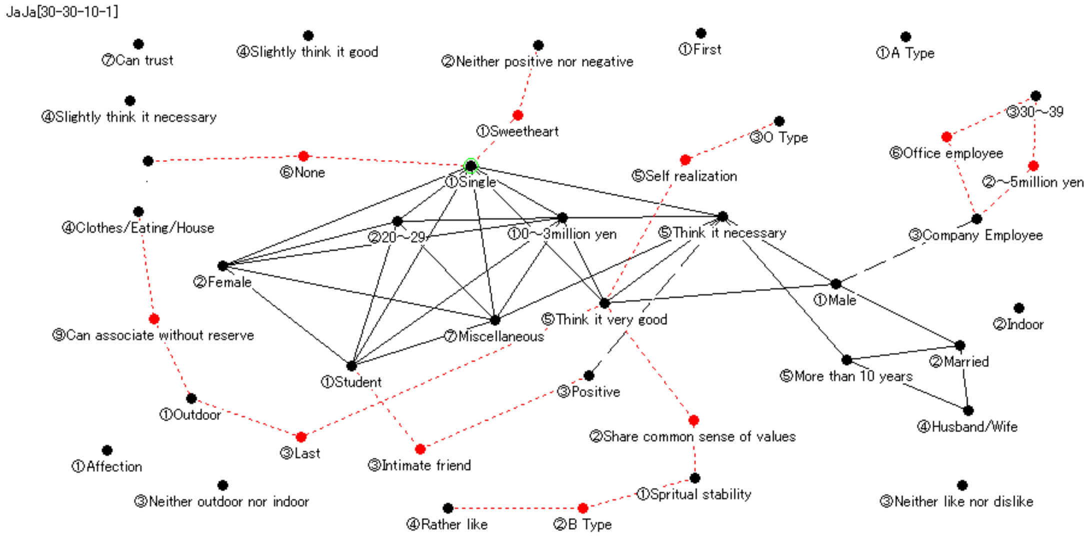


Fig.3.42 Attribute of Partner and Effect of Partner・Necessity of Partner

3.3.5. Q34･47, Q63･64 Effect of Partner･Necessity of Partner and Important Items

Watching Fig.3.43, we can confirm that “Effect of Partner” and “Necessity of Partner” have a high co-occurrence rate in the same way as before.

High co-occurrence items with “Effect of Partner” are “Spiritual stability”, “Affection”, “Share common sense of values”, “Can trust”, ”Can associate without reserve”.

When considering partner, such items as “Spiritual stability”, “Affection”, “Share common sense of values”, “Can trust”, “Can associate without reserve” seems to be very important. Item of “Can associate without reserve” has a high co-occurrence rate with “Relief” and this item may be a fundamental one.

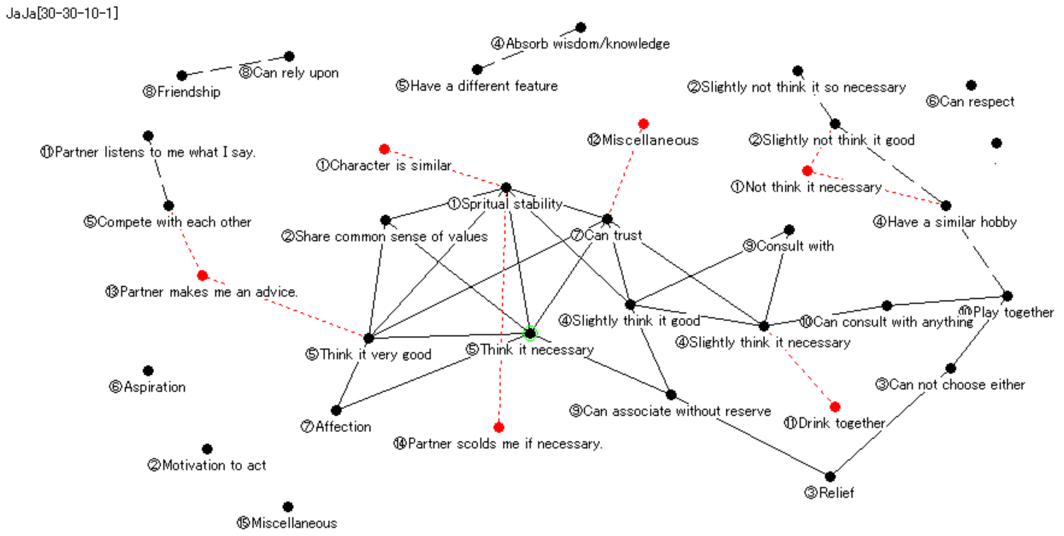


Fig.3.43 Effect of Partner・Necessity of Partner and Important Items

3.3.6. Q34･47 Effect of Partner and Important Items

Watching Fig.3.44, we can confirm that “Think it very good” for the effect of partner has a high co-occurrence rate with “Spiritual stability”, “Motivation to act”, “Relief”, “Compete with each other”, “Aspiration”, “Affection”, “Friendship”, “Consult with”, and “Play together”. Among these items, “Motivation to act” and “Aspiration” have rather high co-occurrence rates with “Slightly not think it good”, which is a negative item for the effect of partner.

Considering these facts, these results are similar to those of Single Variable Analysis and Multivariate Analysis.

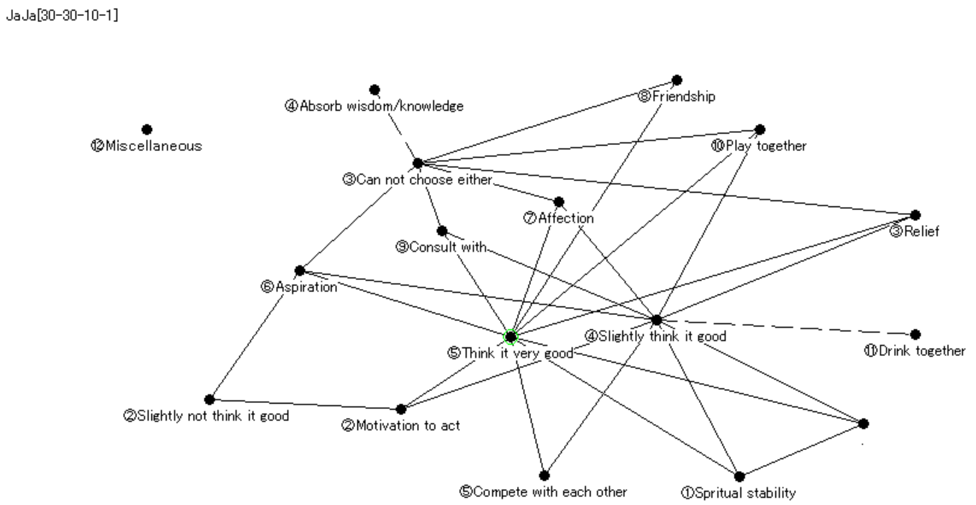


Fig. 3.44 Effect of Partner Important Items

3.3.7. Q63･64　Necessity of Partner and Important Items

Watching Fig.3.45, we can observe that "Think it necessary" for the necessity of partner has a high co-occurrence rate with “Share common sense of values” , “Have a similar hobby” , “Can respect” , “Can trust” , “Can associate without reserve” , “Have a different feature”, and “Can consult with anything”.

On the contrary, items among “Character is similar”, “Partner scolds me if necessary” do not have so much co-occurrence and the relation among these items is low.

These results coincide with those of Single Variable Analysis Multivariate Analysis.

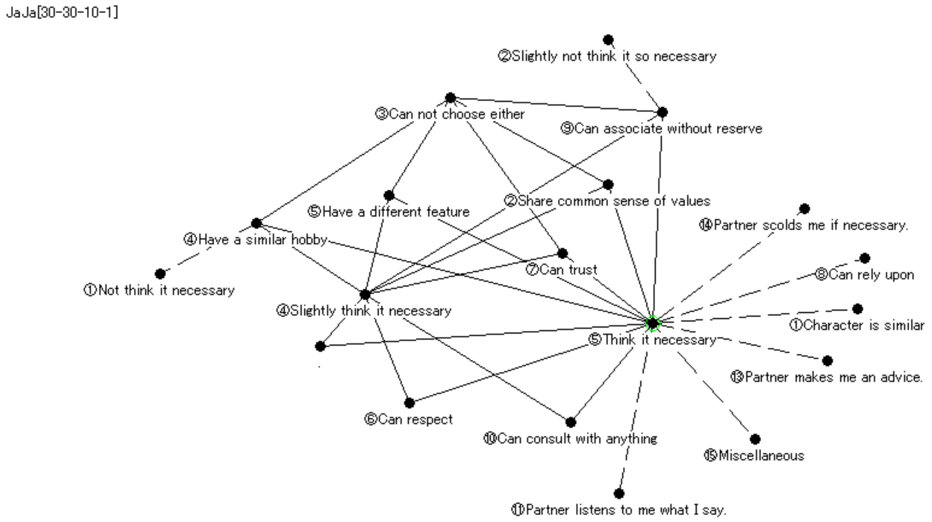


Fig.3.45 Necessity of Partner and Important Items

4. REMARKS

Analysis was executed concerning partnership for their effect, necessity, relation with attribute, and the correlation among them.

Analysis by Single Variable shows that nearly 90% people notice the effect of partner. More than 80% people esteem such items as “Spiritual stability”, and “Can consult with”. As for necessity, such items as “Can rely upon”, “Can respect”, “Can consult with anything”, “Have a similar hobby”, “Can associate without reserve” exceed 80% which implies that having a similar character and having a same kind of thinking are not necessarily essential. Looking over the analysis results totally, we can confirm following issues.

The most influential element for the effect of partner is the existence of whom to “consult with”, then “spiritual stability” and “affection” follow by the analysis result of Quantification Method Ⅱ. The most influential item for the necessity of partner is “Partner listens to me what say”, and then such items as “Character is similar”, “Can consult with anything”, “Can rely upon”, “Can trust”, “Can associate without reserve” follow. These results coincide with those of Factor Analysis.

By the Factor Analysis concerning the necessity of partner, 1st axis shows “that having common sense of values” and the 2nd axis shows “the sense of reliability”. 3rd axis shows “the similarity with partner”.

From the Key Graph Analysis, we can find following issues. As for the attribute and the effect of partner, co-occurrence rate between “Think it very good” and such items as “Single”, “Low income class”, “Senior male” is high. As for the important items and the necessity of partner, co-occurrence rate among such items as “Share common sense of values”, “Can trust”, “Have a different feature”, “Can associate without reserve”, “Can consult with anything”, “Have a similar hobby”.

These results are similar to those of Single Variable Analysis and Factor Analysis. Thus, utilizing various analysis methods stated above, effective and useful analysis is executed.

Key Graph is a method of text mining and is proved to be useful to visualize the total structure among items.

Based upon the Single Variable Analysis and Multivariate Analysis, questionnaire items can be selected flexibly and they are utilized for the analysis of total structure by using Key Graph.

Various case studies should be examined in order to refine these methodological schemes.

5. CONCLUSION

In this paper, a questionnaire investigation concerning partner was executed. Multivariate Analysis including Multi Correspondence Analysis, Factor Analysis and Quantification Method Ⅱ was applied.

Key Graph analysis was also utilized. These methods were compared and useful and instructive results were obtained. These result had a consistent results on the whole. Further development can be expected by adding much more data.

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APPENDIX: Questionnaire Concerning the Partner

Ⅰ We ask questions about yourself.

Q1. Sex. ①Male ②Female
Q2. Age. ①10～19 ②20～29 ③30～39 ④40～49 ⑤50～59 ⑥More than 60
Q3. Occupation. ①Student ②Officer ③Company Employee ④Clerk of Organization ⑤Independents ⑥Miscellaneous
Q4. Official Position. ①President ②Executive ③General manager ④Section Chief ⑤Chief ⑥Office employee ⑦Miscellaneous
Q5. Annual Income. ①0～3million yen ②～5million yen ③～7.5million yen ④～10million yen ⑤～15million yen ⑥More than 15 million yen
Q6. Address. ①Prefecture ( ) ②City ( )
Q7. Blood Type. ①A Type ②B Type ③O Type ④AB Type ⑤Unknown
Q8. Are you married? ①Single ②Married

Q9. How many children do you have?
①One child ②Two Children ③Three Children ④Four children ⑤None

Q10. Are you positive to do anything?
① Positive ②Can not choose either ③Not positive

Q11. Do you like to be alone?
⑤Think it so much. ④Slightly think it so ③Can not choose either ②Slightly do not think it so ①Not think it so

Q12. How do you spend holidays?
①Outdoor ②Indoor ③Can not choose either

Q13. What is most important to you? Choose only one.
①Affection ②Money ③Honor ④Clothes/Eating/House ⑤Self realization ⑥Miscellaneous

Q14. What is your position among your brother?
①First ②Middle ③Last ④Do not have brother

Q15. Do you have "partner”now? Who is he/she?
①Sweetheart ②Brother ③Intimate friend ④Husband/Wife ⑤Miscellaneous ⑥None

Q16. How long have you been with your partner?
①Within 1 year ②～3 years ③～5 years ④6～10years ⑤More than 10 years

(1) We ask questions about your current condition.

Q17. How about your physical condition?	⑥ Very ood physical condition	④ Rather good physical condition	③Ordinary good physical condition	②Not so good physical condition	①Bad physical condition
Q18. Is your work or study progressing smoothly?	⑤Very smooth	④Rather smooth	③Neither smooth nor not smooth	② Not so smooth	① Not smooth
Q19. Do you living a full life?	⑥ Much full	④Rather full	③Neither full nor not full	②Not so full	①Not full
Q20. Are you confident in your self?	⑤Very confident	⑤ Slightly confident	② Neither confident nor not confident	② Not so confident	① Not confident

Ⅱ We ask questions about your partner.
If you have multiple partners, please answer for the most important partner.
[Except for the person who selected ⑥ in Ⅰ Question 15]

Q21. When did you meet with your partner first?
①Within 1 year ②～3 years ③～5 years ④6～10years ⑤More than 10 years

Q22. How often do you meet with your partner?
①Everyday ②Week ③Month ④Some months ⑤Miscellaneous

Q23. How do you make a contact?
①Mail ②Mobile phone ③Fixed telephone ④A post card ⑤Letter ⑥Face to face ⑦Miscellaneous

Q24. Age ①10～19 ②20～29 ③30～39 ④40～49 ⑤50～59 ⑥More than 60
Q25. Sex of partner ①Same with you ②The other sex
Q26. Occupation ①Student ②Officer ③Company Employee ④Clerk of organization ⑤Independents ⑥Part Time Job ⑦Miscellaneous
Q27. Official Position ①President ②Executive ③General manager ④Section Chief ⑤Chief ⑥Office employee ⑦Miscellaneous
Q28. Address ①Prefecture（ ） ②City（ ）
Q29. Blood Type ①A Type ②B Type ③O Type ④AB Type ⑤Unknown

Q30. What is your partner's position among his/her brother?

①First ②Middle ③Last ④Do not have brother

(1) We ask questions about the relation with your partner.

Q31. How about the difference with your partner in the way of thinking?	⑤ Very similar	③ Slightly similar	③ Neither similar nor not similar	② Not so similar	① Not similar
Q32. How about the difference with your partner for about the character?	④ Very similar	④ Slightly similar	③ Neither similar nor not similar	② Not so similar	① Not similar
Q33. Is the opinion of your partner instructive to you?	⑤ Very instructive	④ Slightly instructive	⑤ Neither instructive nor not instructive	② Not so instructive	① Not instructive

Ⅲ Please answer your views concerning partner.

Q34. Is it a good thing for you to have a partner?

⑤Think it very good ④Slightly think it good ③Can not choose either ②Slightly not think it good ①Not think it good

(1)What is good for?

	⑤Think it very good	④Slightly think it good	③ Can not choose either	②Slightly not think it good	①Not think it good
Q35. A. Spiritual stability	⑤	④	③	②	①
Q36. B. Motivation to act	⑤	④	③	②	①
Q37. C. Relief	⑤	④	③	②	①
Q38. D. Absorb wisdom/knowledge	⑤	④	③	②	①
Q39. E. Compete with each other	⑤	④	③	②	①
Q40. F. Aspiration	⑤	④	③	②	①
Q41. G. Affection	⑤	④	③	②	①
Q42. H. Friendship	⑤	④	③	②	①
Q43. I. Consult with	⑤	④	③	②	①
Q44. J. Play together	⑤	④	③	②	①
Q45. K. Drink together	⑤	④	③	②	①
Q46. L. Miscellaneous (　　　　)	⑤	④	③	②	①

(2) Q47. Which item is most important?

①A ②B ③C ④D ⑤E ⑥F ⑦G ⑧H ⑨I ⑩J ⑪K ⑫L

(3) What is the necessary factor as a partner?

	⑤Think it necessary	④Slightly think it necessary	③Can not choose either	②Slightly not think it so necessary	①Not think it necessary
Q48. A. Character is similar	⑤	④	③	②	①
Q49. B. Share common sense of values	⑤	④	③	②	①
Q50. C. Share similar Life style	⑤	④	③	②	①
Q51. D. Have a similar hobby	⑤	④	③	②	①
Q52. E. Have a different feature	⑤	④	③	②	①
Q53. F. Can respect	⑤	④	③	②	①
Q54. G. Can trust	⑤	④	③	②	①
Q55. H. Can rely upon	⑤	④	③	②	①
Q56. I. Can associate without reserve	⑤	④	③	②	①
Q57. J. Can consult with anything	⑤	④	③	②	①
Q58. K. Partner listens to me what I say.	⑤	④	③	②	①
Q59. L. Partner agrees with my proposition.	⑤	④	③	②	①
Q60. M. Partner makes me an advice.	⑤	④	③	②	①
Q61. N. Partner scolds me if necessary.	⑤	④	③	②	①
Q62.O. Miscellaneous (　　　)	⑤	④	③	②	①

Q63. (4) Which item is most important?

①A ②B ③C ④D ⑤E ⑥F ⑦G ⑧H ⑨I ⑩J ⑪K ⑫L ⑬M ⑭N ⑮O

Q64. (5) Is partner necessary to you?

⑤Think it necessary ④Slightly think it necessary ③Can not choose either ②Slightly not think it so necessary ①Not think it necessary

Paper ID: 79

ESTIMATION OF SMOOTHING CONSTANT OF MINIMUM VARIANCE AND ITS APPLICATION TO INDUSTRIAL DATA

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Abstract

Focusing that the equation of exponential smoothing method(ESM) is equivalent to (1,1) order ARMA model equation, new method of estimation of smoothing constant in exponential smoothing method is proposed before by us which satisfies minimum variance of forecasting error. Generally, smoothing constant is selected arbitrary. But in this paper, we utilize above stated theoretical solution. Firstly, we make estimation of ARMA model parameter and then estimate smoothing constants. Thus theoretical solution is derived in a simple way and it may be utilized in various fields.

Furthermore, combining the trend removing method with this method, we aim to improve forecasting accuracy. An approach to this method is executed in the following method. Trend removing by a linear function is executed to the stock market price data of three advertising companies. The combination of linear and non-linear function is also introduced in trend removing. For the comparison, monthly trend is removed after that. Theoretical solution of smoothing constant of ESM is calculated for both of the monthly trend removing data and the non monthly trend removing data. Then forecasting is executed on these data. In two cases, the variance of forecasting error of linear trend removing and monthly trend removing data was minimum. For another case was the one that linear and non-linear trend removing and monthly trend removing data was minimum. The new method shows that it is useful especially for the time series that has stable characteristics and has rather strong seasonal trend. The effectiveness of this method should be examined in various cases.

Key Words: minimum variance, exponential smoothing method, forecasting, trend

1. Introduction

Many methods for time series analysis have been presented such as Autoregressive model (AR Model), Autoregressive Moving Average Model (ARMA Model) and Exponential Smoothing Method (ESM)[1]−[4]. Among these, ESM is said to be a practical simple method.

For this method, various improving method such as adding compensating item for time lag, coping with the time series with trend [5], utilizing Kalman Filter [6], Bayes Forecasting [7], adaptive ESM [8], exponentially weighted Moving Averages with irregular updating periods [9], making averages of forecasts using plural method [10] are presented. For example, Maeda [6] calculated smoothing constant in relationship with S/N ratio under the assumption that the observation noise was added to the system. But he had to calculate under supposed noise because he couldn't grasp observation noise. It can be said that it doesn't pursue optimum solution from the very data themselves which should be derived by those estimation. Ishii [11] pointed out that the optimal smoothing constant was the solution of infinite order equation, but he didn't show analytical solution. Based on these facts, we proposed a new method of estimation of smoothing constant in ESM before [13]. Focusing that the equation of ESM is equivalent to (1,1) order ARMA model equation, a new method of estimation of smoothing constant in ESM was derived.

In this paper, utilizing above stated method, revised forecasting method is proposed. In making forecast such as shipping data, seasonal trend is removed by dividing the original time series by Monthly Ratio which is calculated using moving average data. Utilizing above stated method, forecasting is executed with this data in which seasonal trend is removed. Monthly Ratio is multiplied after that, and forecasting data is obtained. This is a revised forecasting method. Variance of forecasting error of this newly proposed method is assumed to be less than those of previously proposed method.

The combination of linear and non-linear function is also introduced in trend removal.

The rest of the paper is organized as follows. In section 2, ESM is stated by ARMA model and estimation method of smoothing constant is derived using ARMA model identification. The combination of linear and non-linear function is introduced for trend removing in section 3. The Monthly Ratio is referred in section 4. Forecasting is executed in section 5, and estimation accuracy is examined.

2. Description of ESM Using ARMA Model

In ESM, forecasting at time $t+1$ is stated in the following equation.

$$\hat{x}_{t+1} = \hat{x}_t + \alpha\left(x_t - \hat{x}_t\right) \tag{1}$$

$$= \alpha x_t + \left(1-\alpha\right)\hat{x}_t \tag{2}$$

Here,

$\hat{x}_{t+1}$: forecasting at $t+1$

x_t : realized value at t

α : smoothing constant $\left(0 < \alpha < 1\right)$

Equation (2) is re-stated as

$$\hat{x}_{t+1} = \sum_{l=0}^{\infty} \alpha\left(1-\alpha\right)^l x_{t-l} \tag{3}$$

By the way, we consider the following (1,1) order ARMA model.

$$x_t - x_{t-1} = e_t - \beta e_{t-1} \tag{4}$$

Generally, $\left(p,q\right)$ order ARMA model is stated as

$$x_t + \sum_{i=1}^{p} a_i x_{t-i} = e_t + \sum_{j=1}^{q} b_j e_{t-j} \tag{5}$$

Here,

$\left\{x_t\right\}$: Sample process of Stationary Ergodic Gaussian Process $x(t)$ $t = 1,2,\cdots,N,\cdots$

$\{e_t\}$: Gaussian White Noise with 0 mean σ_e^2 variance

MA process in Equation (5) is supposed to satisfy convertibility condition.

Utilizing the relation that

$$E\left[e_t \middle| e_{t-1}, e_{t-2}, \cdots\right] = 0$$

we get the following equation from Equation (4).

$$\hat{x} = x_{t-1} - \beta e_{t-1} \tag{6}$$

Operating this scheme on $t+1$, we finally get

$$\begin{aligned} \hat{x}_{t+1} &= \hat{x}_t + (1-\beta)e_t \\ &= \hat{x}_t + (1-\beta)(x_t - \hat{x}_t) \end{aligned} \tag{7}$$

If we set $1-\beta=\alpha$, the above equation is the same with Equation (1), i.e., equation of ESM is equivalent to (1,1) order ARMA model, or is said to be (0,1,1) order ARIMA model because 1st order AR parameter is -1[1][3].

Comparing with Equation (4) and Equation (5), we obtain

$$\begin{cases} a_1 = -1 \\ b_1 = -\beta = \alpha - 1 \end{cases}$$

From Equation (1), (7),

$$\alpha = 1 - \beta .$$

Therefore, we get

$$\begin{cases} a_1 = -1 \\ b_1 = -\beta = \alpha - 1 \end{cases} \tag{8}$$

From above, we can get estimation of smoothing constant after we identify the parameter of MA part of ARMA model. But, generally MA part of ARMA model become non-linear equations which are described below.

Let Equation (5) be

$$\tilde{x}_t = x_t + \sum_{i=1}^{p} a_i x_{t-i} \tag{9}$$

$$\tilde{x}_t = e_t + \sum_{j=1}^{q} b_j e_{t-j} \tag{10}$$

We express the autocorrelation function of $\tilde{x}_t$ as $\tilde{r}_k$ and from Equation (9), (10), we get the following non-linear equations which are well known[3].

$$\left.\begin{aligned}\tilde{r}_k &= \begin{cases} \sigma_e^2 \sum_{j=0}^{q-k} b_j b_{k+j} & (k \le q) \\ 0 & (k \ge q+1) \end{cases} \\ \tilde{r}_0 &= \sigma_e^2 \sum_{j=0}^{q} b_j^2 \end{aligned}\right\} \tag{11}$$

For these equations, recursive algorithm has been developed. In this paper, parameter to be estimated is only b_1, so it can be solved in the following way.

From Equation (4), (5), (8), (11), we get

$$\left.\begin{aligned} q &= 1 \\ a_1 &= -1 \\ b_1 &= -\beta = \alpha - 1 \\ \tilde{r}_0 &= \left(1 + b_1^2\right)\sigma_e^2 \\ \tilde{r}_1 &= b_1 \sigma_e^2 \end{aligned}\right\} \tag{12}$$

If we set

$$\rho_k = \frac{\tilde{r}_k}{\tilde{r}_0} \tag{13}$$

the following equation is derived.

$$\rho_1 = \frac{b_1}{1 + b_1^2} \tag{14}$$

We can get b_1 as follows.

$$b_1 = \frac{1 \pm \sqrt{1 - 4\rho_1^2}}{2\rho_1} \tag{15}$$

In order to have real roots, ρ_1 must satisfy

$$|\rho_1| \le \frac{1}{2} \tag{16}$$

From invertibility condition, b_1 must satisfy

$$|b_1| < 1$$

From Equation (14), using the next relation,

$$(1 - b_1)^2 \ge 0$$

$$\left(1+b_1\right)^2 \geq 0$$

Equation (16) always holds.

As

$$\alpha = b_1 + 1$$

b_1 is within the range of

$$-1 < b_1 < 0$$

Finally we get

$$\left.\begin{aligned} b_1 &= \frac{1-\sqrt{1-4\rho_1^2}}{2\rho_1} \\ \alpha &= \frac{1+2\rho_1-\sqrt{1-4\rho_1^2}}{2\rho_1} \end{aligned}\right\} \tag{17}$$

which satisfy above condition. Thus we can obtain a theoretical solution by a simple way.

Focusing on the idea that the equation of ESM is equivalent to (1,1) order ARMA model equation, we can estimate smoothing constant after estimating ARMA model parameter.

It can be estimated only by calculating 0th and 1st order autocorrelation function.

3. Trend Removal Method

As trend removal method, we describe linear and non-linear function, and the combination of these.

[1] Linear function

We set

$$y = a_1 x + b_1 \tag{18}$$

as linear function.

[2] Non-linear function

We set

$$y = a_2 x^2 + b_2 x + c_2 \tag{19}$$

$$y = a_3 x^3 + b_3 x^2 + c_3 x + d_3 \tag{20}$$

as 2nd and 3rd order non-linear function.

[3] The combination of linear and non-linear function

We set

$$y = \alpha_1\left(a_1 x + b_1\right) + \alpha_2\left(a_2 x^2 + b_2 x + c_3\right) \tag{21}$$

as the combination of linear and 2nd order non-linear function, and

$$y = \beta_1\left(a_1 x + b_1\right) + \beta_2\left(a_3 x^3 + b_3 x^2 + c_3 x + d_3\right) \tag{22}$$

as the combination linear and 3rd order non-linear function. Here, $\alpha_2 = 1 - \alpha_1$ and $\beta_2 = 1 - \beta_1$. Comparative discussion concerning Equation (18), (21) and (22) is described in section 5.

4. Monthly Ratio

For example, if there is the monthly data of L years as stated bellow

$\{x_{ij}\} \quad (i = 1, \cdots, L) \quad (j = 1, \cdots, 12)$

Monthly Ratio $\tilde{x}_j$ is calculated as follows.

$$\tilde{x}_j = \frac{\frac{1}{L}\sum_{i=1}^{L} x_{ij}}{\frac{1}{L}\cdot\frac{1}{12}\sum_{i=1}^{L}\sum_{j=1}^{12} x_{ij}} \qquad (j = 1, \cdots, 12) \tag{23}$$

5. Forecasting the Stock Prices Data of Advertising Agency

５．１ Analysis Procedure

The stock prices data of advertising agency for 3 cases from January 2005 to December 2007 are analysed. First of all, graphical charts of these time series data are exhibited in Figure 5-1,5-2,5-3.

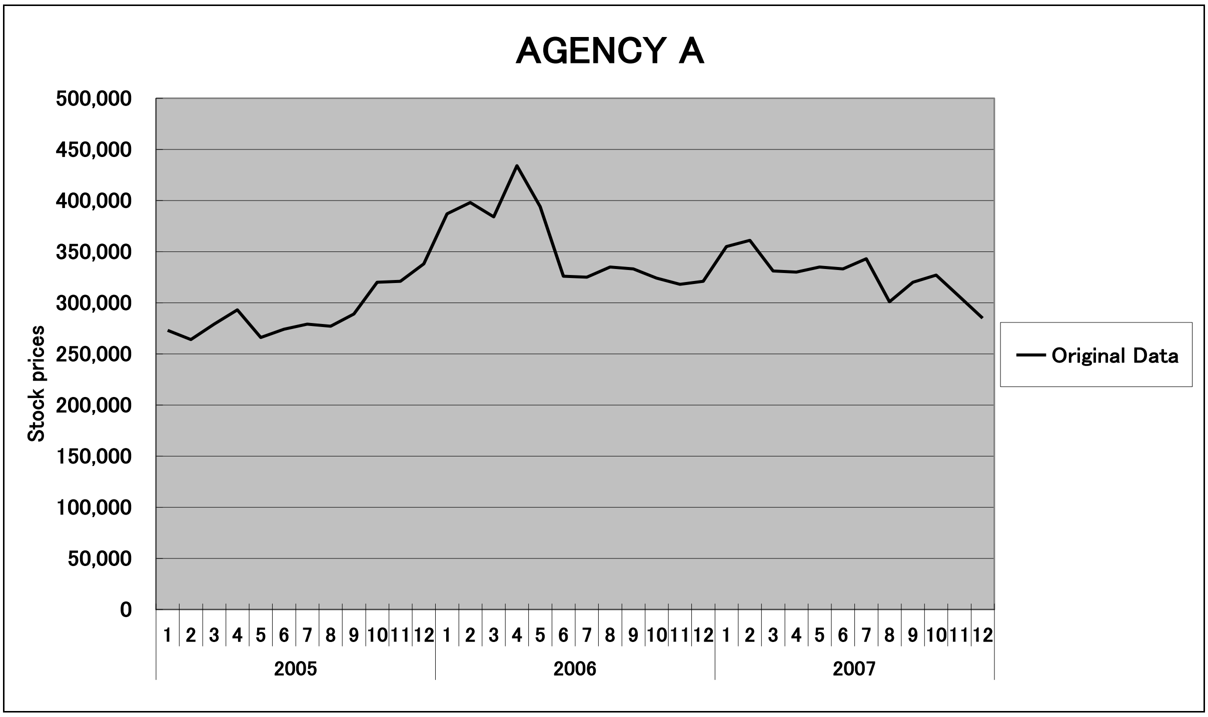

Figure 5-1. Stock prices data of Agency A

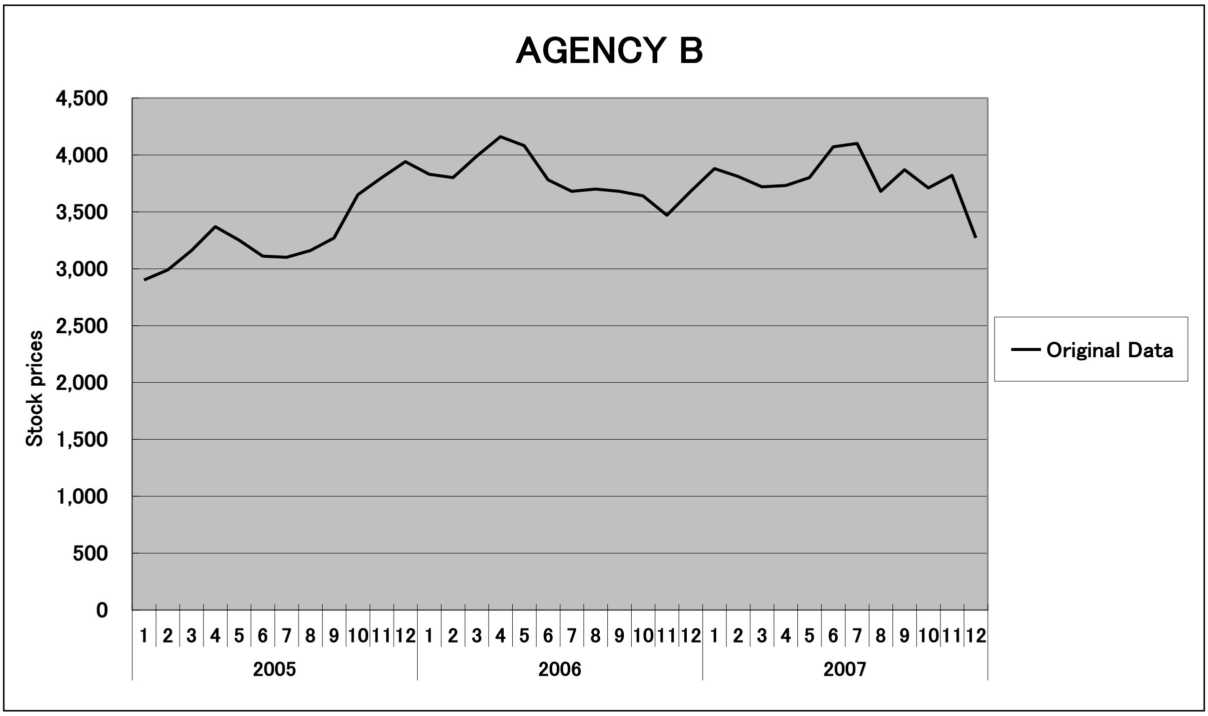

Figure 5-2. Stock prices data of Agency B

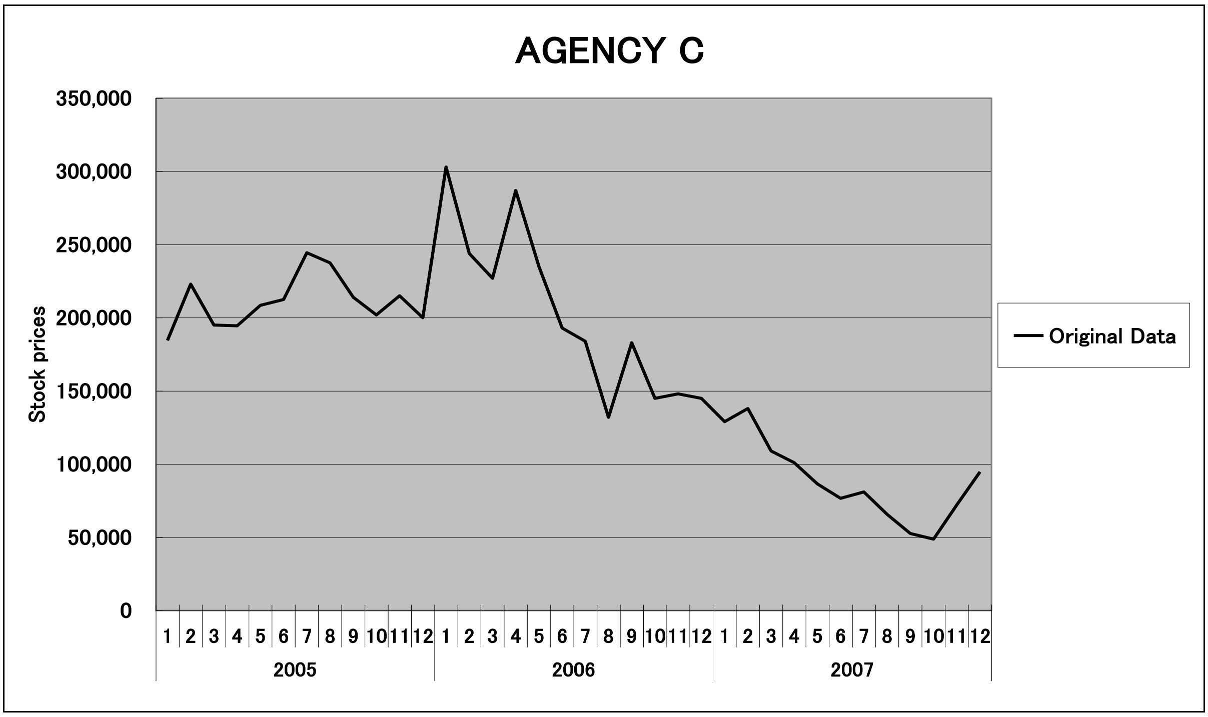

Figure 5-3. Stock prices data of Agency C

Analysis procedure is as follows. There are 36 monthly data for each case. We use 24 data(1 to 24) and remove trend by the method stated in 3. Then we calculate monthly ratio by the method stated in 4. After removing monthly trend, the method stated in 2 is applied and Exponential Smoothing Constant with minimum variance of forecasting error is estimated. Then 1 step forecast is executed. Thus, data is shifted to 2nd to 25th and the forecast for 26th data is executed consecutively, which finally reaches forecast of 36th data. To examine the accuracy of forecasting, variance of forecasting error is calculated for the data of 25th to 36th data. Final forecasting data is obtained by multiplying monthly ratio and trend.

Forecasting error is expressed as:

$$\varepsilon_i = \hat{x}_i - x_i \tag{24}$$

$$\bar{\varepsilon} = \frac{1}{N}\sum \varepsilon_i \tag{25}$$

Variance of forecasting error is calculated by:

$$\sigma_\varepsilon^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(\varepsilon_i - \bar{\varepsilon}\right)^2 \tag{26}$$

５．２ **Trend Removing**

Trend is removed by dividing original data by Equation (18), (21), (22). Parameter estimation result is exhibited in Table 5-1 for the case of calculation result of 1st to 24th data. Where weight of $\alpha_1, \alpha_2, \beta_1, \beta_2$ are set 0.5 in Equation (21), (22).

Table 5-1. Parameter Estimation Result

	1st		2nd					3rd					
	parameter		weight		parameter			weight		parameter			
	a_1	b_1	α_1	α_2	a_2	b_2	c_2	β_1	β_2	a_3	b_3	c_3	d_3
Agency A	3763.5	275957	0.5	0.5	-524.93	16887	219089	0.5	0.5	-65.491	1931	-8176.6	276557
Agency B	34.848	3114	0.5	0.5	-4.2456	140.99	2654	0.5	0.5	-0.3239	7.9017	17.02	2938.3
Agency C	2134.8	233226	0.5	0.5	-602	12915	168010	0.5	0.5	-19.294	121.51	5531.5	184940

Graphical chart of trend is exhibited in Figure 5-4,5-5,5-6.

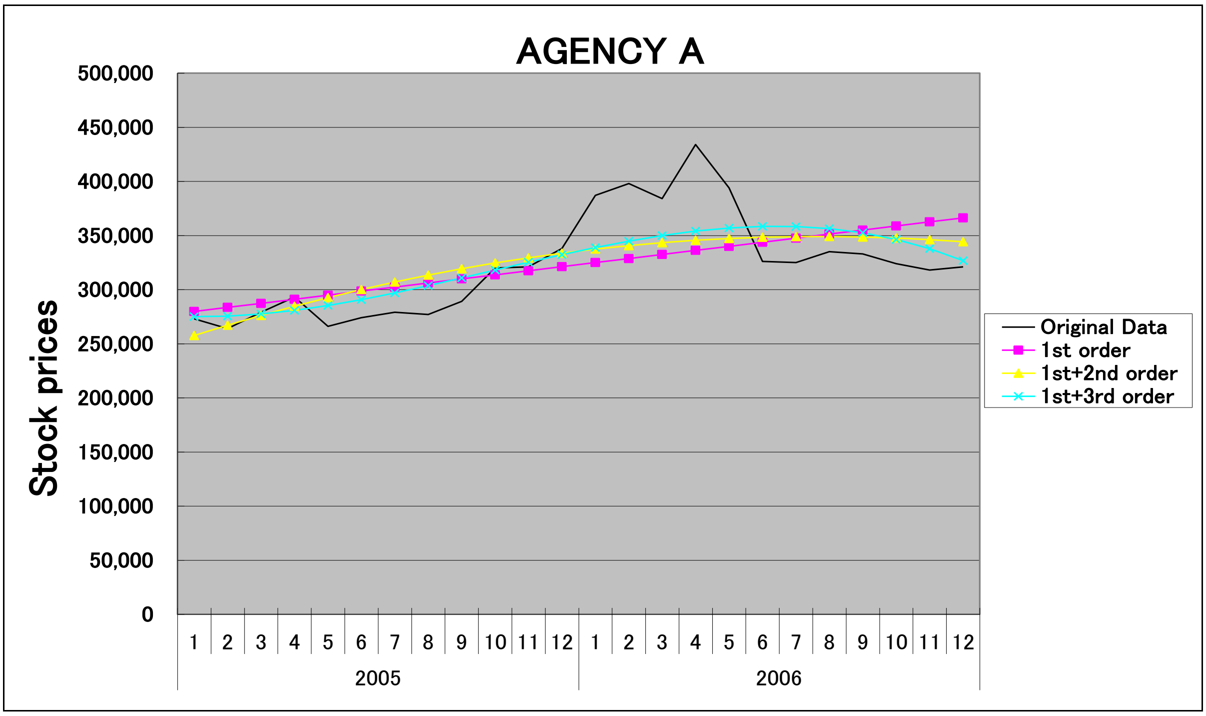

Figure 5-4. Trend of Agency A

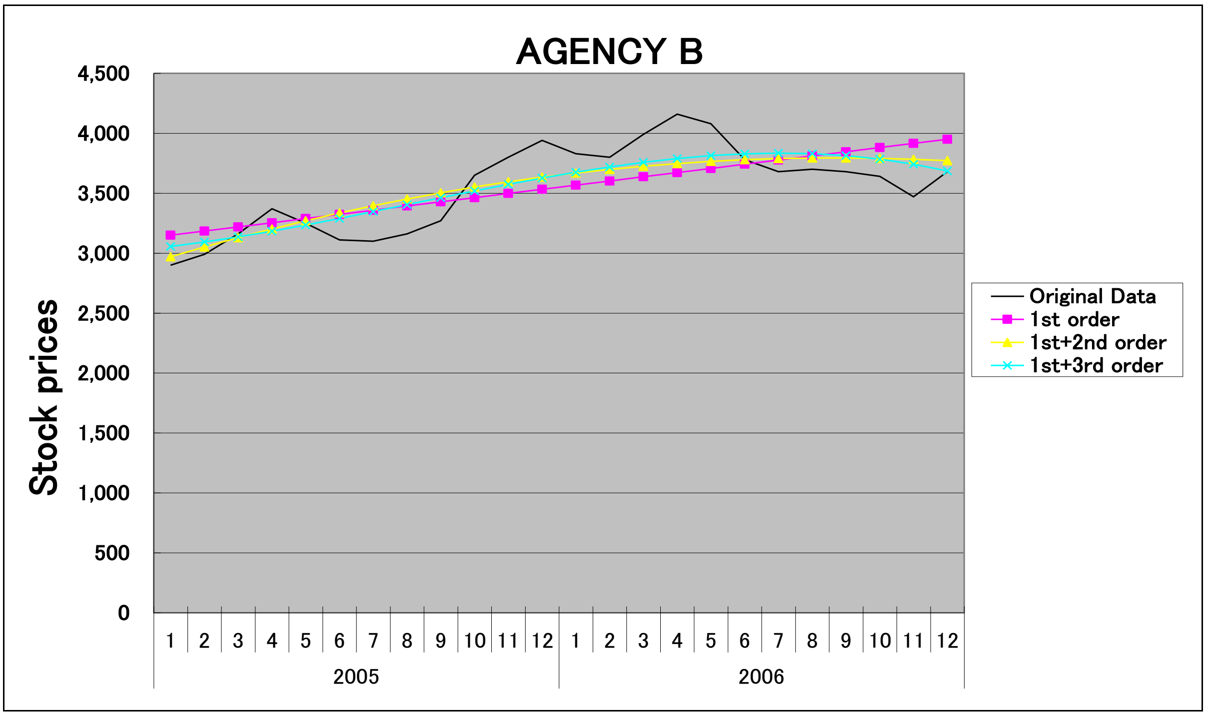

Figure 5-5. Trend of Agency B

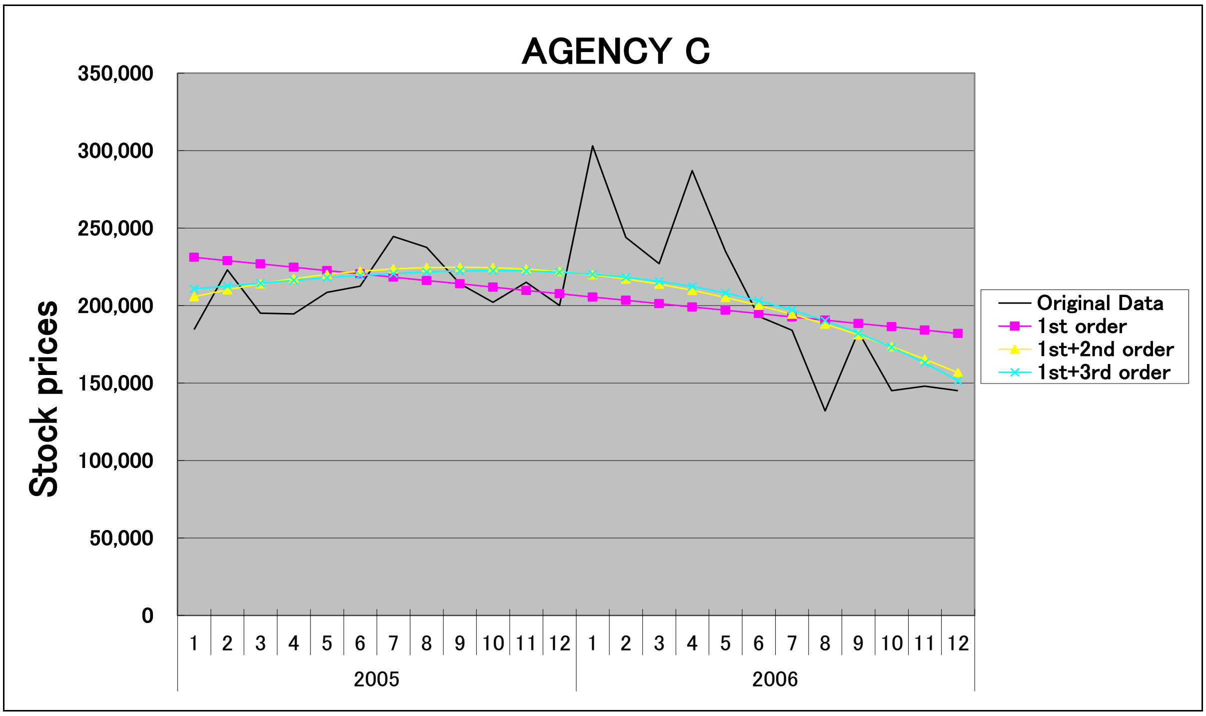

Figure 5-6. Trend of Agency C

5．3　Removing trend of monthly ratio

After removing trend, monthly ratio is calculated by the method stated in 4. Calculation result for 1st to 24th data is exhibited in Table 5-2,5-3,5-4.

Table 5-2. Monthly ratio(1st order)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Agency A	1.08	1.07	1.06	1.15	1.03	0.93	0.93	0.93	0.94	0.96	0.94	0.96
Agency B	1.00	1.00	1.04	1.08	1.04	0.97	0.95	0.95	0.96	1.00	0.99	1.02
Agency C	1.14	1.09	0.99	1.15	1.07	0.98	1.04	0.90	0.99	0.87	0.91	0.88

Table 5-3. Monthly ratio(1st + 2nd order)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Agency A	1.1	1.08	1.07	1.14	1.02	0.93	0.92	0.92	0.93	0.96	0.95	0.97
Agency B	1.01	1.00	1.04	1.08	1.04	0.97	0.94	0.95	0.95	0.99	0.99	1.03
Agency C	1.14	1.1	0.99	1.14	1.05	0.96	1.02	0.88	0.99	0.87	0.93	0.92

Table 5-4. Monthly ratio(1st + 3rd order)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Agency A	1.07	1.06	1.05	1.14	1.02	0.93	0.93	0.93	0.94	0.98	0.97	1.00
Agency B	1.00	1.00	1.04	1.08	1.04	0.97	0.94	0.95	0.96	1.00	1.00	1.04
Agency C	1.13	0.89	0.99	1.13	1.05	0.96	1.03	0.89	0.99	0.88	0.94	0.93

５．４ Estimation of Smoothing Constant with Minimum Variance of Forecasting Error

After removing monthly trend, Smoothing Constant with minimum variance of forecasting error is estimated utilizing Equation (17). There are cases that we cannot obtain a theoretical solution because they do not satisfy the condition of Equation (16). In those cases, Smoothing Constant with minimum variance of forecasting error is derived by shifting variable from 0.01 to 0.99 with 0.01 interval. Calculation result for 1st to 24th data is exhibited in Table 5-5,5-6,5-7.

Table 5-5. Estimated Smoothing Constant with Minimum Variance (1st order)

	ρ_1	α
Agency A	-0.006167	0.993833
Agency B	-0.024049	0.975937
Agency C	-0.275180	0.700065

Table 5-6. Estimated Smoothing Constant with Minimum Variance (1st + 2nd order)

	ρ_1	α
Agency A	-0.1638307	0.8315188
Agency B	-0.0073929	0.9926067
Agency C	-0.342432	0.6038205

Table 5-7. Estimated Smoothing Constant with Minimum Variance (1st + 3rd order)

	ρ_1	α
Agency A	-0.1671009	0.8279529
Agency B	-0.2154788	0.7734631
Agency C	-0.3451637	0.5994612

５．５ Forecasting and Variance of Forecasting Error

Utilizing smoothing constant estimated in the previous section, forecasting is executed for the data of 25th to 36th data. Final forecasting data is obtained by multiplying monthly ratio and trend. Variance of forecasting error is calculated by Equation (26).

Forecasting results are exhibited in Figure 5-7,5-8,5-9.

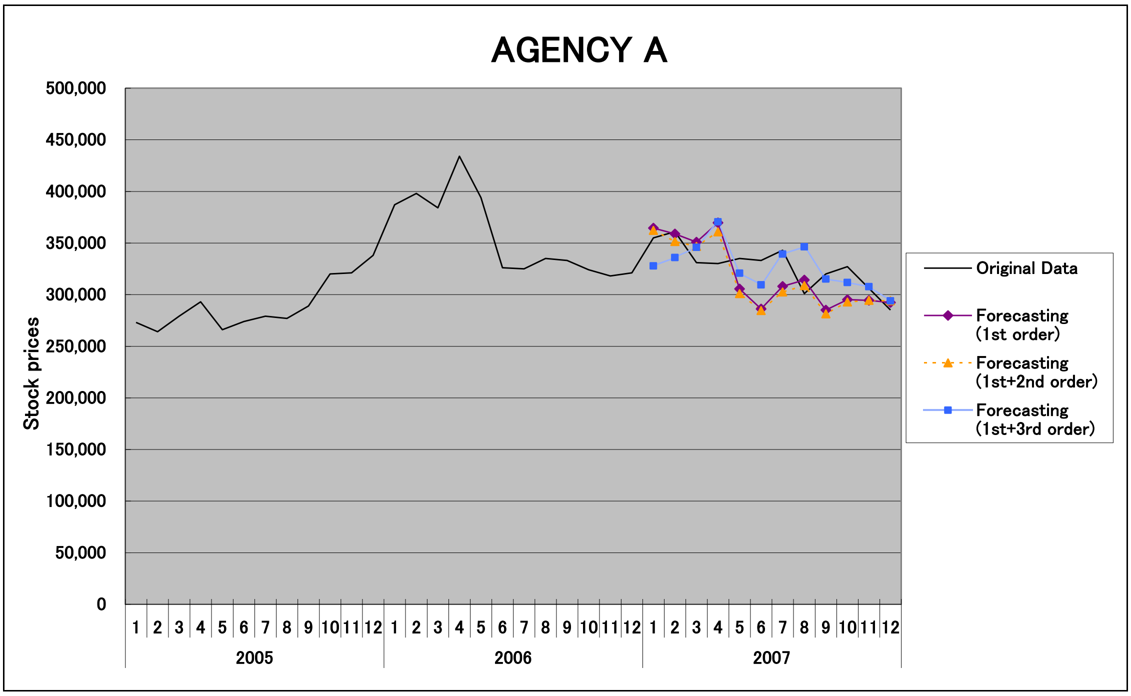

Figure 5-7. Forecasting Results of Agency A

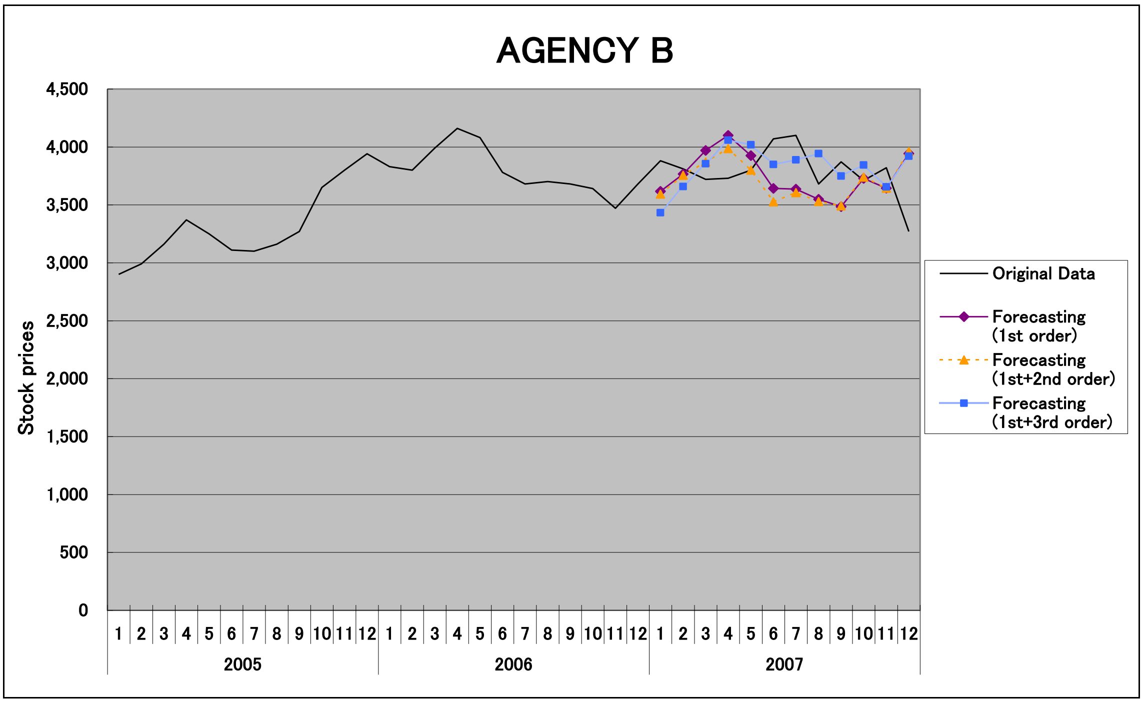

Figure 5-8. Forecasting Results of Agency B

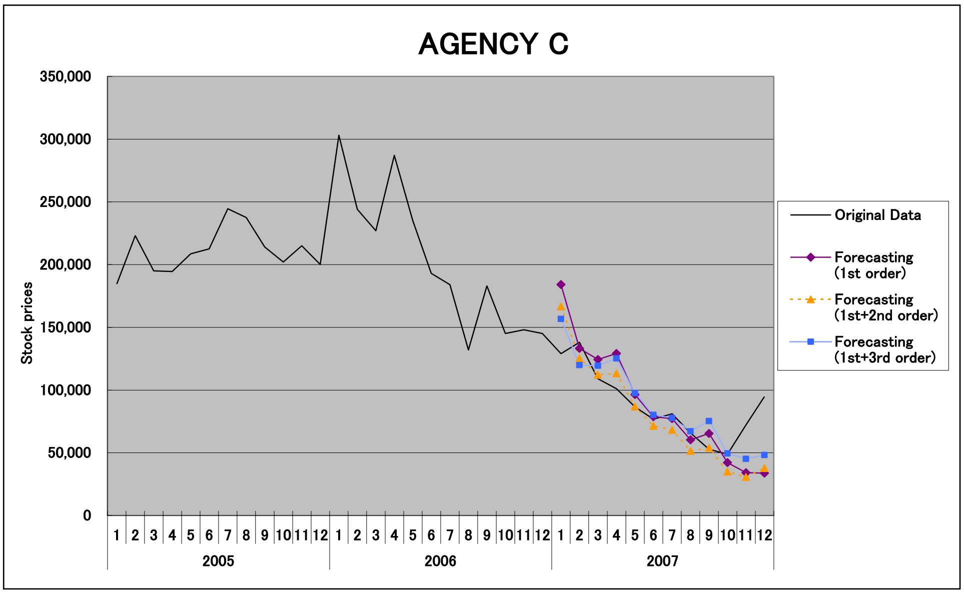

Figure 5-9. Forecasting Results of Agency C

Variance of forecasting error is exhibited in Table 5-8. Variance of forecasting error in the case that monthly ratio is not used is exhibited in Table 5-9.

Table 5-8. Variance of Forecasting Error

	1st order	1st+2nd order	1st+3nd order
Agency A	367,422,771	411,638,424	636,751,844
Agency B	53,523	61,322	65,643
Agency C	420,967,723	258,273,798	277,685,959

Table 5-9. Variance of Forecasting Error (Monthly Ratio is not used)

	1st order	1st+2nd order	1st+3nd order
Agency A	734,213,562	693,653,095	581,271,805
Agency B	119,762	119,000	93,654
Agency C	873,313,166	582,852,289	486,634,076

５．６ Remarks

Forecasting accuracy is apparently improved by introducing monthly ratio. The combination of linear and non-linear function in trend removing is also examined. In Agency A and B, 1st order trend removing has better forecasting accuracy than other methods. On the other hand, 1st + 2nd order trend removing has better forecasting accuracy in Agency C.

Thus, 1st order trend removal method would be effective for the time series data which have stable characteristics.

６．Conclusion

Focusing on the idea that the equation of exponential smoothing method(ESM) was equivalent to (1,1) order ARMA model equation, new method of estimation of smoothing constant in exponential smoothing method was proposed before by us which satisfied minimum variance of forecasting error. Generally, smoothing constant was selected arbitrary. But in this paper, we utilized above stated theoretical solution.

Firstly, we made estimation of ARMA model parameter and then estimated smoothing constants. Thus theoretical solution was derived in a simple way and it might be utilized in various fields.

Furthermore, combining the trend removal method with this method, we aimed to increase forecasting accuracy. An approach to this method was executed in the following method. Trend removal by a linear function was applied to the original stock prices of agencies. The combination of linear and non-linear function was also introduced in trend removing. For the comparison, monthly trend was removed after that. Theoretical solution of smoothing constant of ESM was calculated for both of the monthly trend removing data and the non monthly trend removing data. Then forecasting was executed on these data. In two cases, the variance of forecasting error of linear trend removing and monthly trend removing data was minimum. For another case was the one that linear and non-linear trend removing and monthly trend removing data was minimum. The new method showed that it was useful especially for the time series that had stable characteristics and has rather strong seasonal trend. The effectiveness of this method should be examined in various cases.

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Paper ID: 85

Finding Essential Points of Innovation in TRIZ by Comparing It with the Equivalent Transformational Thinking

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Abstract

The author has applied TRIZ to development of innovative business solutions since 2000. In the process, the business idea database based on 40 inventive principles and contradiction matrix was developed and applied to three business problems. The author also applied the equivalent transformational thinking developed by Kikuya Ichikawa to the same problems and compared two methods. Analyzing similarity and difference of two thinking processes made essential points of innovation clear. Abstraction of concerned problems, unexpectedness, flexible thinking, experience of objects and comprehensibleness of ideas which have been found in previous study were reconfirmed. Additionally, controlling abstraction and using knowledge base were found by analyzing the Equivalent transformational thinking.

Keywords: Business Innovation, the Business Idea Database, the Equivalent Transformational Thinking Method, Abstraction.

1. Introduction

The author proposed the TRIZ based business idea database (BID) using 40 inventive principles and the contradiction matrix for creating innovative business models and products (Ishida, 2003), then, an innovative products' lifecycle model including it was proposed (Ishida, 2007). The BID was revised by including two functions. One is a table of business contradiction statements based on improving / degrading parameters to define potential business problems before taking out contradictions. The other is a way of finding hidden technical needs (Ishida, 2008). The revised BID was applied to three business solutions and results were evaluated from perspectives of abstraction and innovation

(Ishida, 2009). The author tried to compare TRIZ with other innovation method to make essential points of innovation clear, and selected the Equivalent Transformational (ET) thinking developed by Kikuya Ichikawa as an object of comparison with TRIZ. In the section 2, the original TRIZ based BID and the revised one are introduced. In the section 3, the ET thinking is introduced. In the section 4, processes of applying the TRIZ based BID and the ET thinking to three problems on business are presented. In the section 5, results of comparisons are summarized. In the section 6, essential points of innovation are discussed.

2. TRIZ-Based business idea database

2.1 Objectives of the business idea database

The main object of the TRIZ based business idea database (BID) is to suggest innovative solutions of problems on business. It is based on a hypothesis that new business models are born from contradictions which are generally believed to be irresolvable then. The other object is modelling of business solutions. In the original BID, strategies of business or products were classified and essential subjects and contradictions on business were defined with them to model contradictions on business and solutions of them.

2.2 The revised business idea database

There were two hurdles to clear for increasing efficiency and flexibility of the original BID. One was that it’s difficult to find essential problems, unknown needs or lurking risks on business. To solve it, business contradiction statements were introduced. The other was that ensuring feasibility of ideas inhibited flexible thinking. To solve it, patterns of technologies were released from generated ideas and a way of finding hidden technical needs from new ideas of business models was introduced. Figure 1 shows a concept of the revised BID. Essential problems on business are made from business contradiction statements. Each statement corresponds to a pair of an improving parameter and a degrading parameter. The revised BID also has a table of business idea statements. Each pair of an improving parameter and a degrading parameter corresponds to some business idea statements (Ishida, 2008) (Ishida, 2009). Inputs of the revised BID are nothing but concrete problems and outputs are new ideas of business models or products. From now on, the BID means the revised one in this paper, The BID was applied to three business problems. Applying processes and generated business ideas were evaluated from perspectives of abstraction and innovation (Ishida, 2009).

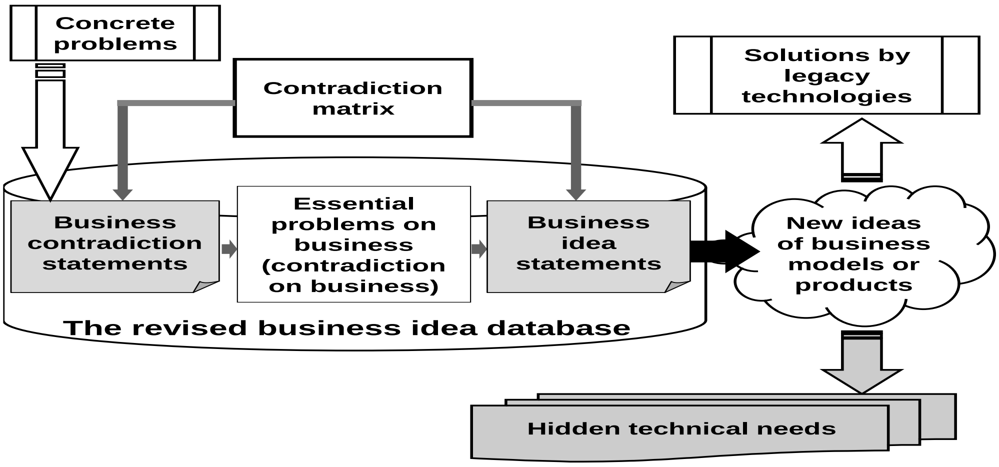

Figure 1. Concept of the revised BID.

3. The Equivalent Transformational thinking

3.1 What is the Equivalent Transformational (ET) thinking?

The Equivalent Transformational (ET) thinking was developed by Kikuya Ichikawa in 1955. It's one of creative engineering methodologies, based on a kind of analogy of shapes and characteristics in various fields. Features of the ET thinking is described based on "Ichikawa,1977".

The ET thinking is based on patterns of inventive processes. It is expressed by a formula shown in Figure 2. Suppose that (1) and (2) are given and they are abstracted by (7). If (3) and (4) common to both of them were found, there could be an equivalent relation between (1) and (2). If only (1) is given and abstracted by removing (5), then (2) is introduced by adding (6), (2) could be equivalently transformed from (1).

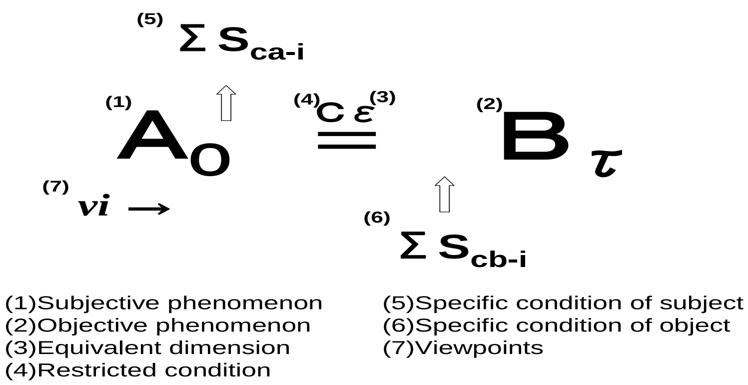

Figure 2: A formula of ET innovation pattern

The ET thinking isn't based on pure and simple analogy but it includes abstraction. Think about a concept of equivalent in the ET thinking. Objects are abstracted through a specific viewpoint beforehand then compared each other. If two abstracted objects are analogous they are treated as 'equivalent'. As an example, think about relation between an electric discharge and a tree. Trails of flying are images abstracted from an electric discharge. Branches are images abstracted from a tree. Since trails of flying and branches look analogous, an electric discharge and a tree would be equivalent.

3.2 The process of Equivalent Transformational (ET) thinking

In the ET thinking, current contents are translated and reconstructed to future contents from a new perspective, inheriting past record (Ichikawa, 1977). Figure 3 shows an innovation process based on the ET thinking. It's composed of two lines, one is an analogue route that intends to create innovative ideas instinctively, the other is a digital route that intends to analyze real condition on business or products. Both of them start from 'Concrete problem'. In the analogue route, the second step is 'Define the problem'. It's based on desire which is produced by idealizing real world. Remaining steps run as follows, 'Select essential problem', 'Select a essentially similar idea (A_0)', 'Eliminate specific elements from A_0', 'Produce essential ideas' and 'Make concrete ideas'. A digital route is composed of watching the world and finding ways of realization. It is linked with the analogue route for making concrete and feasible ideas. In this paper, it's not customized for applying to business problem solving.

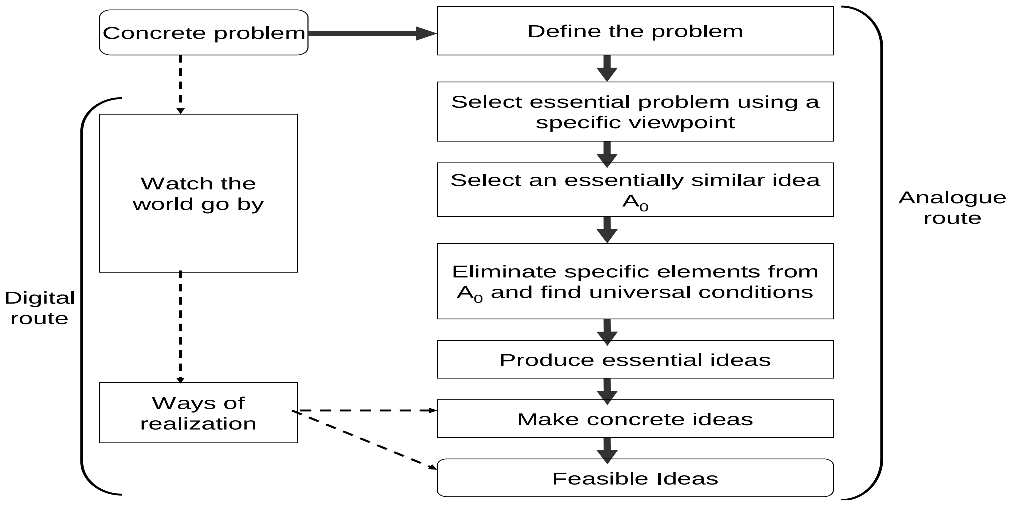

Figure 3: An innovation process based on the ET thinking

4. Applying TRIZ and the ET thinking to business solutions

4.1 Objectives and prerequisite conditions

In this paper the author evaluates effectiveness of TRIZ and the ET thinking by focusing on business innovation. For the purpose the TRIZ based BID instead of pure TRIZ and an analogue route of the ET thinking without customizing are used. The TRIZ based BID and the ET thinking are applied to solve three business problems, namely (1) A fantastic plan for making training courses in a sharply growth company, (2) A feasible idea of moving an office to an effective place without high cost, (3) Employment under depression which would be a vague problem.

4.2 Making training courses in a sharply growth company

Company-A is an IT consulting farm which has expanded sharply. Employees have been doubled in one year, from 300 to 600. Employees have different back grounds, different mind and different levels of consulting skills. On the other hand, the company-A has not enough resources for training and development. Figure 4 shows a process of applying the BID to training and development. A main solution got from the method is that human resources data drives training courses. For each course temporary coordinators are made automatically. They manage and operate the training course. Exchange trainers and trainees make frictions and stimulation. It's difficult to realize those ideas, because there are no feasible technologies.

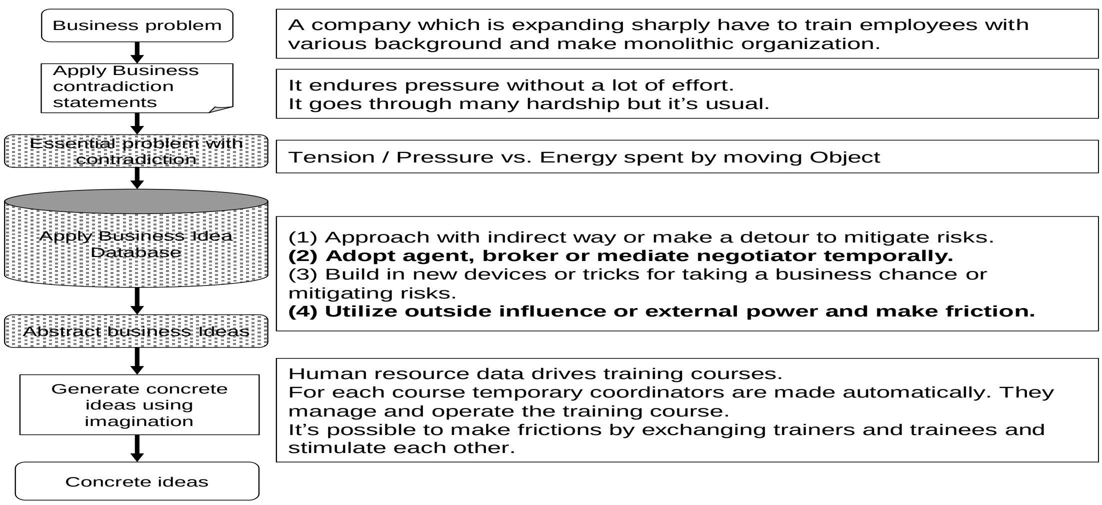

Figure 4: Applying the TRIZ based BID to making training courses

Figure 5 shows a process of the ET thinking applied to the same problem. A main solution got from the method is that many kinds of training are prepared to employees so that they can take every available time and they are announced that which training courses are offered. Every employees can be a trainer when he / she is available. It's easy to realize those ideas because no new technologies are required.

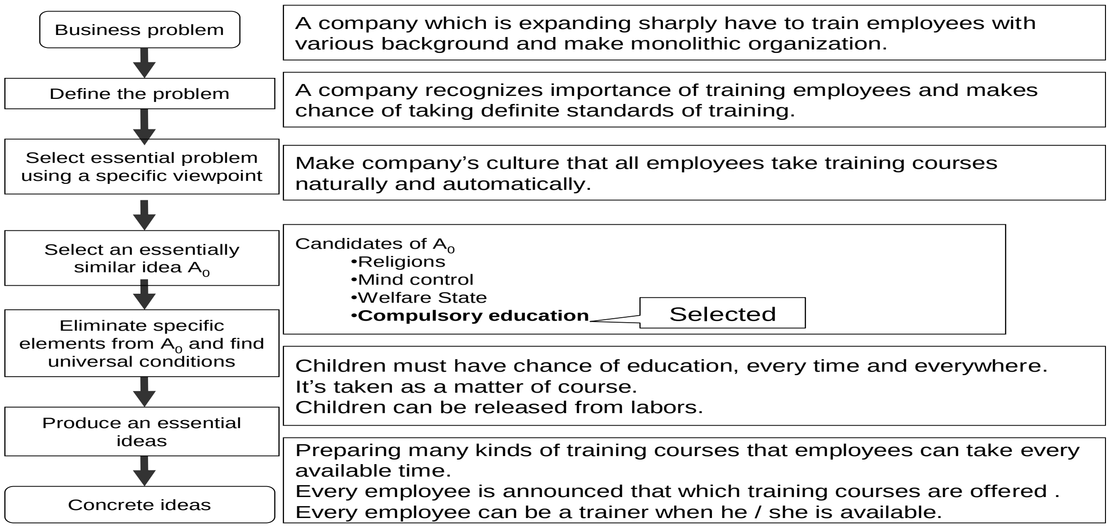

Figure 5: Applying the ET to making training courses

Figure 6 shows two processes applied to making training courses. Each idea generated from each phase is plotted on coordinates of abstraction and innovation. Final ideas got from the TRIZ based BID and ones got from the ET thinking are rather similar. But the former is more advanced and more abstract than the latter which is feasible and reasonable.

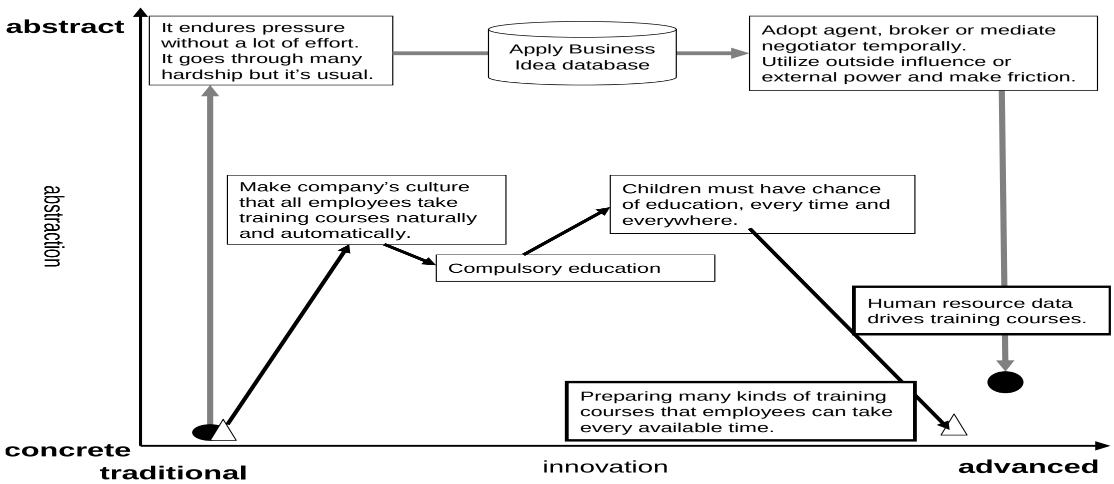

Figure 6: Comparing two processes applied to making training courses

4.3 Moving an office to an effective place

Company-A has paid a high rent for an office. For maintaining cost reduction, company-A will decide to move the office. But it's not effective for business to make the move to suburbs.

Figure 7 shows a process of applying the BID to moving an office to an effective place. A main solution got from the method is that the company decentralizes its operations and separates offices by each characteristic. High grade main office keeps brand images. It also convenient to main clients. For employees satellite offices and home offices connected with internet are served. Those ideas are feasible and concrete.

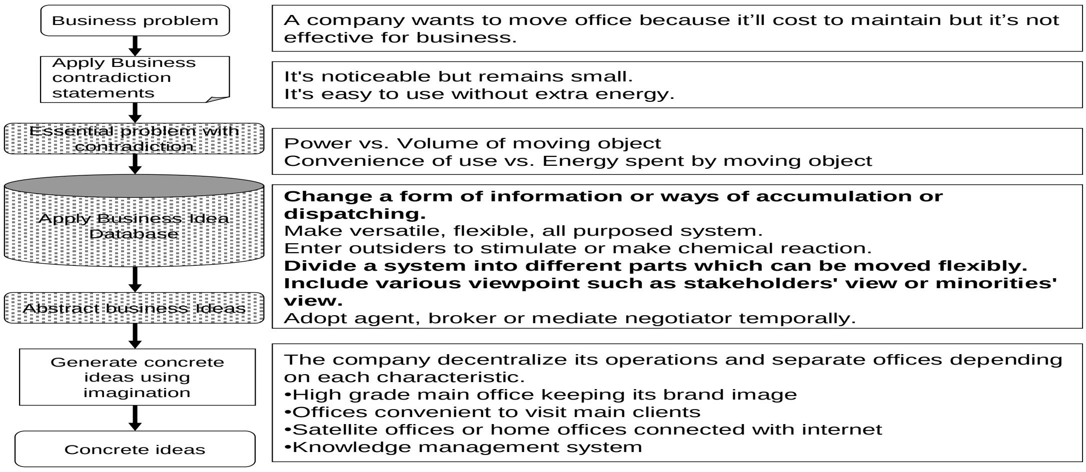

Figure 7: Applying the TRIZ based BID to moving office

Figure 8 shows a process of the ET thinking applied to the same problem. A main solution got from the method is that a main office is placed in a famous business street and employees work in several factories or offices. Those ideas are rather abstract because there are no criteria for decentralization.

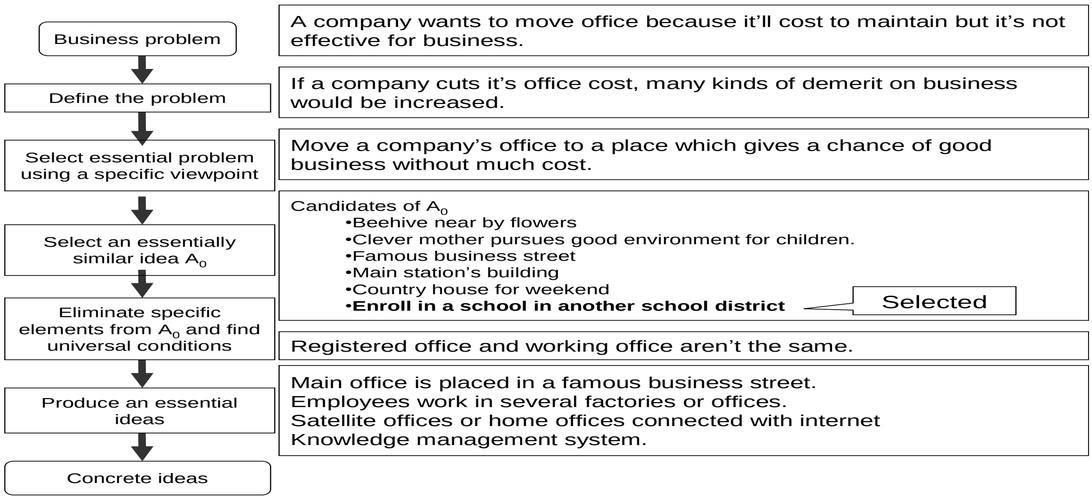

Figure 8: Applying the ET to moving office

Figure 9 shows two processes applied to moving office. Each idea generated from each phase is plotted on coordinates of abstraction and innovation. Final ideas got from the TRIZ based BID and ones got from the ET thinking are almost the same, but the former is more concrete and advanced than the latter. It would depend on variations of abstract business ideas got from the BID.

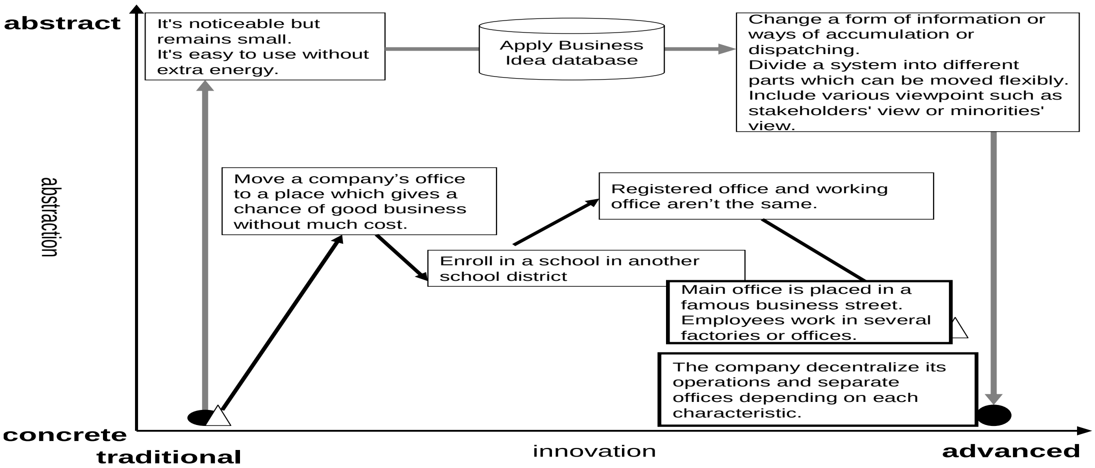

Figure 9: Comparing two processes applied to moving office

4.4 Employment under depression

For traditional Japanese companies, it's important to keep full employment continuously although a depression would hit them.

Figure 10 shows a process of applying the BID to employment under depression. A main solution got from the method is that a company expands its business to defend against immediate risks, and makes a versatile and flexible organization. It can't be translated to concrete ideas. Intimate knowledge and experience about real business situations are required for making concrete ideas.

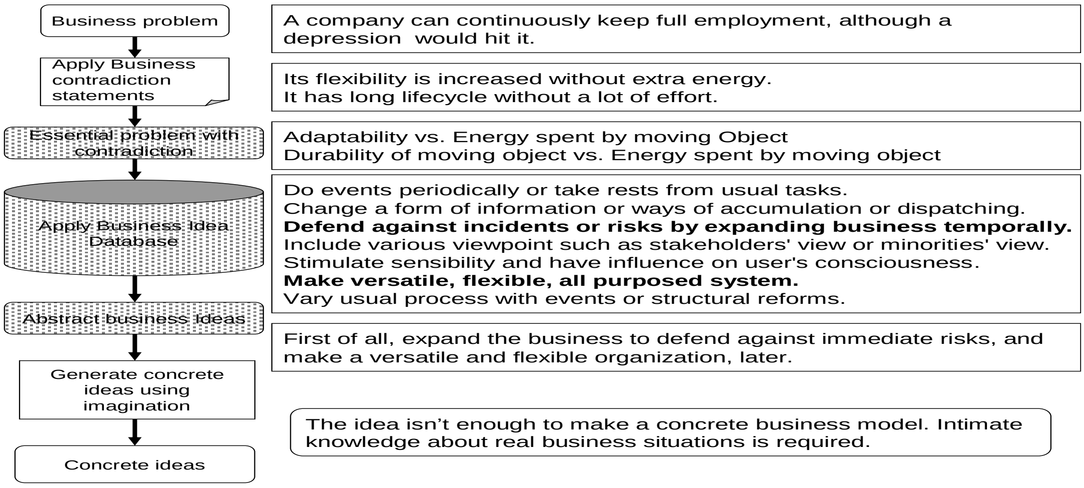

Figure 10: Applying the TRIZ based BID to employment

Figure 11 shows a process of the ET applied to the same problem. No solutions are got from the method because of next two reasons. (1) The applier can't imagine concrete situation because the problem definition is ambiguous. (2) Good similar ideas can't be found because of poor imagination.

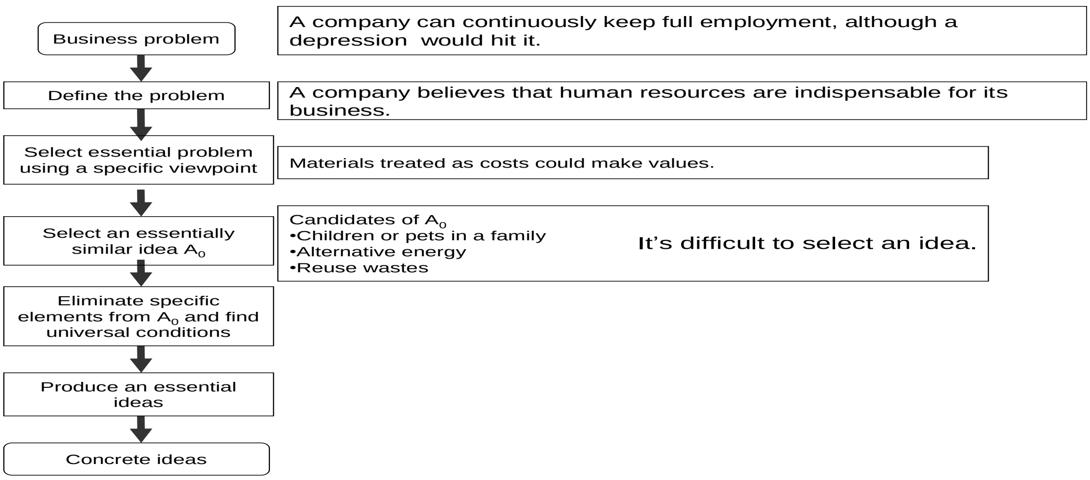

Figure 11: Applying ET to employment

Figure 12 shows two processes applied to employment under depression. Each idea generated from each phase is plotted on coordinates of abstraction and innovation. A final ideas got from the TRIZ based BID are implicative but ambiguous. But there are possibilities that generate concrete advanced ideas by deliberating abstract ideas using knowledge and experience about depression. The result of applying the ET thinking suggests that it's difficult to imagine similar ideas useful to find essential ones from ambiguous problem definition.

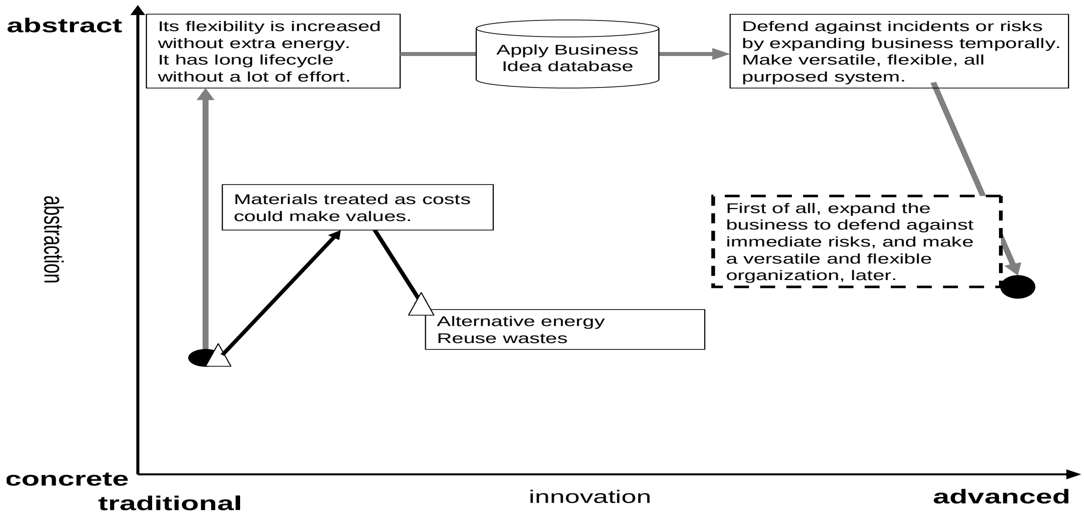

Figure 12: Comparing two processes applied to employment

5. Compare two methods through applying to business problems solving

As previously discussed, TRIZ and the ET thinking were applied to the same business problems to evaluate them by focusing on business innovation. In this section results of application are discussed with two points of view, i.e. processes of thinking and levels of abstraction. Other effective points such as cases and supporting tools are also discussed.

A thinking process using the TRIZ based BID is specific to business problem solving and it's rather automatic. Then it's easier for users to apply it to business problems than the ET thinking. If users could define concrete problems on business they could translate them to essential problems expressed as contradictions using contradiction statements. Then users could get abstract business ideas automatically using contradictions and business idea statements. On the other hand, users of the ET thinking need much effort to recognize the formula shown in figure 2 because it's simple but hard to apply to real world. When users follow the process shown in figure 3, experience and knowledge about concerned business domain affect imagination and creative thinking. But, once they could imagine similar facts or situations they could get concrete innovative ideas.

A large part of a process of the TRIZ based BID is in the abstract. Users can easily get images abstracted from concrete problems using business contradiction statements. Then they can stay in the abstract to get unexpected business ideas. When concrete business ideas are got from abstract ones, users' flexibility would affect their innovation. User's inflexibility makes final ideas normal because real conditions and current technologies would affect final ideas. On the other hand, weather a process of the ET thinking is abstract or not depends on users' thinking. As the innovation model of the ET thinking (the formula shown by figure 2) is too abstract to use for creating new ideas, users tend to translate them to their own concrete conditions.

Other important points for supporting innovative thinking are cases and tools. On one hand, many kinds of case studies according to TRIZ in the world are useful for borrowing new ideas from other domains. Many supporting tools and knowledge base for TRIZ could also assist problem definition and making new ideas. On the other hand, numbers of cases or supporting tools of the ET thinking are less than TRIZ. It's one of reasons that the ET thinking has not infiltrated.

6. What is essential for innovation?

The goal of the study is finding essential points of innovation through applying the TRIZ based BID and the ET thinking to problems on business. Next four essential points for innovation were got from applying TRIZ to three business problems (Ishida, 2009). They are also applicable to the ET thinking.

(1) Abstraction of thinking process would bring ideas to an unexpected direction and make them innovative. It's because ideas aren't affected by real conditions or current technologies.

(2) Flexible mind would bring abstract ideas to concrete innovative ones. But inflexibility could translate innovative abstract ideas to usual ones because final ideas are affected by common sense.

(3) Experience about concerned domain are useful for making problem clear, which would bring smooth processing. But, it could inhibit creative thinking.

(4) Comprehensibleness is useful to make ideas be accepted by the people concerned. .

By analyzing both of TRIZ and the ET thinking in detail, two important points came out. One is controlling abstraction. Concrete models like ERP packages are easy to install but inflexible. On the other hand, abstract models like 'spirit' or 'way' could be applicable to broad area, but need enormous exertions to recognize and install. Users of the ET thinking tend to translate the formula in Figure 2 to a concrete level thinking process and final produced ideas could be affected by real condition and current technologies. To introduce a thinking model or a process effectively, abstraction of them should be controlled. The other is usable knowledge base. Cases and knowledge management tools could complement experience. Useful cases could support to broad innovator's horizons.

7. Summary

Essential points of innovation are found through evaluating TRIZ and the Equivalent Transformational (ET) thinking by applying them to three business problems. Thinking process and final results are analyzed with several points of view such as innovation, abstraction and other points. It's found that abstraction, flexibility, and experience are important for creating innovative ideas. Comprehensibleness is also important to make acceptable innovative ideas. Another important point got from this study is controlling abstraction of thinking model and process. Innovator needs to watch real world and keep abstraction. The other important point is useful knowledge base supporting to broad innovator's horizon.

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Paper ID: 92

Agile, Adaptive Systematic Innovation

(Building Bespoke Processes From Innovation DNA, Atoms, Molecules & Polymers)

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Abstract
The paper introduces a 'periodic table' of creativity and innovation tools, methods and philosophies. The main intention of the chemical analogy is to describe the broad range of combination possibilities of the constituent elements that make up the table. The main purpose of the table is then to allow users to assemble appropriate combinations of elements for any given innovation challenge.

Introduction

The world of Classical TRIZ still sees individuals spending an inordinate amount of time arguing the case for their own particular version of ARIZ or equivalent process. All are consistent in their desire to describe a linear, sequential set of process steps. This is understandable in some ways, since the large majority of newcomers to TRIZ appear from a background in which step-wise sequential processes are the norm. It is less understandable, however, when looked at from the perspective any kind of discussion about whether one thing is better or worse than another. Less understandable because one of the key tenets of TRIZ is that any kind of either/or debate fundamentally fails to address an underlying contradiction. Innovation is very largely about resolving such contradictions. Thus, this paper proposes, it makes considerable sense to take a higher level perspective on such trade-off based debates and, as a consequence, find a higher level both/and process solution.

We have previously shown (Reference 1) that a host of TRIZ/SI case studies, all of which reached a successful conclusion, got to such solutions using very different sequences of tools and strategies. The differences were so large in fact that it was tempting to say that the problem solvers didn't use any kind of process at all, or that, if they did, the sequence of process steps used in each case was random.

Upon more detailed analysis, however, a clear pattern emerged. That basic pattern is shown in Figure 1. Essentially it describes a minimum set of activities necessary to work from an inventive problem/opportunity situation to an acceptable 'breakthrough' solution. That set comprises a pair of divergent-convergent (DC) cycles, one operating in the definition domain $(DC)_d$, and the other operating in the solution generation $(DC)_s$ domain.

There is nothing new in the observation of this pattern of pairs of divergent-convergent activities (References 2 and 3, for example, offer early illustrations). The pairs might be thought of as creativity 'molecules'. Using this analogy, a single divergent or convergent tool can be thought of as representing an 'atom'. Taking this a step further, the minimum structure required to complete an inventive problem solving cycle comprises a pair of DC molecules – as shown, again, in Figure 1.

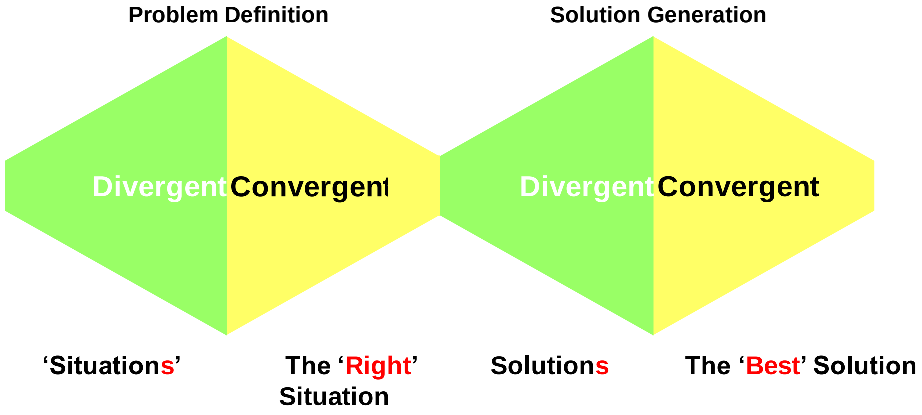

Figure 1: Basic Atoms Of A Problem Definition/Solution Process

One of the nice things about this 'atomization' of the problem solving process is that it provides the ability to construct atom and molecule combinations that, in the extreme, can be thought of as long-chain polymers – a problem solver working on tough problem could, for example, assemble a chain something like $(DC)_d(DC)_s(DC)_d(DC)_s$. Someone else, could assemble something more like $D_dC_dD_s$ $C_sC_sD_dC_dD_sC_s$. A more ambitious, probably team, structure might look something like the branched polymer shown in Figure 2.

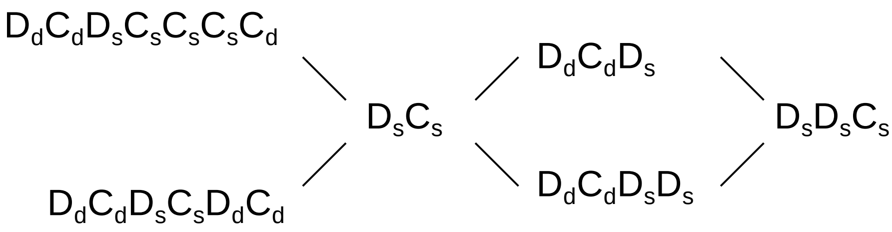

Figure 2: Exemplar Problem-Solving Process 'Polymer'

The point here is, as in chemistry, there is a virtually unlimited set of atom and molecule combinations that can be made.

Using this kind of atomic-level problem definition/solution architecture offers many benefits in terms of flexibility of use. Provided an individual has a minimum of four atoms - D_d C_d D_s C_s – in their toolkit, they should have a good chance of being able to work through a very wide variety of problems. Clearly too, like any good chemistry lab, the more elements we have available to us, the more sophisticated the structures we are able to build.

Previously we have published how the various tools of Classical and new TRIZ can be mapped onto these four basic creativity atoms (Reference 1 again). In this paper, we take that story a step further by expanding the atomization concept to a host of other non-TRIZ tools and techniques. The hope in arranging all the world's problem solving capabilities in this way is that we achieve a higher level understanding of the overlap, conflict, and complementarity synergy between the myriad individual efforts of the last 80 years of thinking about the creative process. One of the aims of this, then, has been to begin resolving some of the – in some cases – extraordinarily high levels of confusion inside organisations about what tools are best suited to a given task. The aim, in turn, of doing this is to help those organisations avoid some of the damaging near-random selection decisions that result in the large majority of implementation initiatives ending in miserable failure.

A Periodic Table Of Creativity And Innovation Tools

Figure 3 illustrates the basic periodic table analogy that has been constructed following the systematic analysis of the myriad different tools, methods and philosophies present in and around the domains of creativity, innovation and change management:

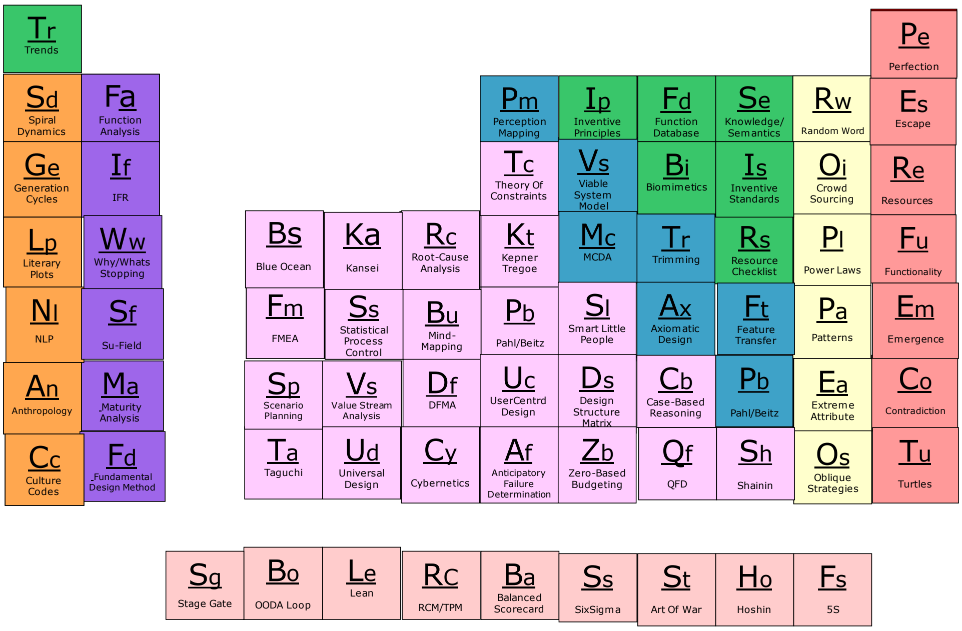

Figure 3: Periodic Table Of Creativity And Innovation Tools

Like any analogy, the model is not intended to provide a direct one-on-one mapping between chemical elements on the one hand and innovation tools on the other. There are, however, some analogical connections that are consistent across the two very different worlds that hopefully help to re-enforce the basic model:

Nobles – the far right hand column of the periodic table comprises the Noble gases. The principle analogical connection between the actual noble gases and their innovation equivalent relates to their stability. In the world of innovation the most stable elements are the seven pillars first discussed in Reference 4. These seven pillars are presented in the table using the 'PERFECT' acronym as introduced in Reference 5. These are the basic 'DNA' elements of the innovation story that should ideally be present to some degree in all projects. They are:

Perfect – the concept of 'perfection' as the ultimate evolutionary goal of all industries, and therefore giving a compass heading

Escape – the need to escape from the box defining 'the current way' of doing things

Resources – the maximal use of existing resources in and around systems

Function – the ultimate purpose of any system is defined by the functions ('jobs', 'outcomes', 'benefits') that it delivers

Emergence – the exploitation of the emergent properties characteristic of any complex system

Contradiction – the fundamental mechanism by which systems step-change towards their 'perfect' goal

Turtles – (or '**T**est' for the squeamish) the concept of recursive laws and behaviours that need to be present in any viable system

Metals/Non-Metals – the periodic table also sees the world of chemistry divided into metals and non-metals (Figure 4). The equivalent division in the world of innovation tools in our analogy involves the split between problem definition and solution generation tools. Merely by dint of the fact that the world has more metal than non-metal elements and that likewise there are many more problem definition tools and schemas than solution generators, in the innovation periodic table, the ‘non-metals’ are analogous to the solution generation tools, and the ‘metals’ are the problem definition tools.

Metalloids – these are the elements positioned on the borders between metals and non-metals (boron, silicon, germanium, etc). They are often semi-conductors. As such, in the innovation world, they are essentially the tools and strategies that can act as problem definition or solution generation tools. The Perception Mapping tool (Reference 4, Chapter 9) for example, although primarily about complexity management – turning large quantities of fuzzy input into a much clearer output picture – more often than not defines a situation so well that the solution becomes ‘obvious’ enough that no additional tools are needed. As it turns out, this also means, like the Perception Mapping again, tools that serve the purpose of doing the ‘convergent’ tasks of either finding the ‘right’ problem or identifying the ‘best’ solution.

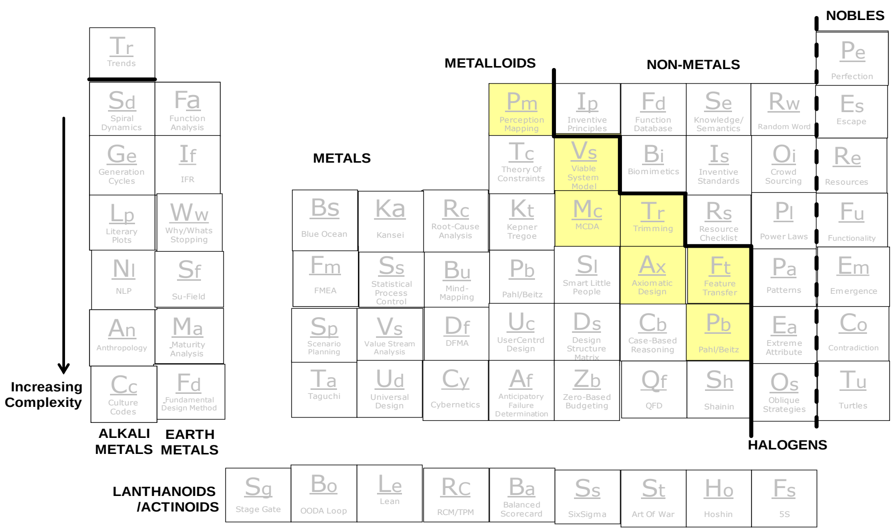

Figure 4: Main Zones Of The Periodic Table

Alkali Metals - are all highly reactive and are therefore never found in elemental form in nature, and tend to form very stable compounds in combination with other elements. In the analogy of the innovation world, the equivalent of the alkali metals are the most ‘highly reactive’ (and potentially unstable) problem definition tools, methods and approaches. Things like culture codes and societal patterns and cycles fall into this category. They offer approaches that are inherently complex and very easy to mis-interpret, but at the same time, if combined correctly with the appropriate other elements, capable of making some extremely powerful breakthrough solutions (as described in Reference 6).

Halogens – are the equivalent highly reactive non-metals (solution generation tools); highly unstable when used alone (and therefore often likely to alienate when they are deemed to have ‘not worked’), but capable of generating significant jumps when used in combination with other tools and strategies.
Lanthanoids/Actinoids – for little other reason than that we need another group, the so-called ‘f-block’ of the chemical periodic table – often thought of as a ‘footnote’ – comprises elements that in the innovation world denote the tools, methods and thought processes that, like the lanthanoids, are ‘abundant but elusive’. They are the things that come after the basic creative idea generation part of the innovation story, and comprise all the change-related activities that will help turn the inventive idea into the value-generating innovation.

One Or Two Illustrations

Kepner-Tregoe (KT), to choose an example at random, is a well established set of tools designed to assist problem solvers to perform a number of different tasks. In simple terms, the KT toolkit consists of four main tools:

1) Situation Appraisal ('what's going on?')
2) Problem Analysis ('why did this happen?')
3) Decision Analysis ('what course of action should we take?')
4) Opportunity Analysis ('what lies ahead?')

Three of these tools (1, 2 and 4) are clear examples of D_dC_d molecules. The Decision Analysis tool is C_s. KT has no real capability in the divergent part of the solution generation task – rather it relies on traditional brainstorming at points where new ideas are required. The absence of a real D_s capability should not detract from the use of KT, but it should remind users that KT is not a 'sufficient' toolkit in terms of an overall inventive problem solving framework.

The use of KT is widespread, but not so much so as, say 6Sigma. Does this mean that 6Sigma is in some way 'better'? Or merely better 'advertised'? Examine all of the tools within a classical 6Sigma tool-chest and the absence of any sensible form of D_s capability also becomes evident. From the perspective of overall sufficiency for the problem solving role, 6Sigma is thus no better than KT.

6Sigma has most likely become the phenomena that it has because of a host of big ticket endorsements from organisations like Motorola and GE. Choosing to 'do 6Sigma' because 'GE saved $9B' is to more often than not make one of the most costly mistakes in the corporate world. Not only is there very little evidence that GE did save this amount of money – where is the evidence, for example, showing that they wouldn't have made equivalent or even bigger savings by implementing DFMA, Lean, TRIZ or any other toolset? – but there is even less evidence that the GE context is even remotely similar to the context within any other organisation. 'You can never step in the same river twice' states a popular aphorism. It is time for organisations to stop looking for off-the-shelf 'cookie-cutter' solutions to their needs, tempting as such strategies might be.

In our increasingly interconnected, speed-of-light world, and the overwhelming amount of choice when it comes to knowing what to do, organisations seem to more and more act like rabbits caught in the headlights of an oncoming truck. Doing something is better than doing nothing. Doing the wrong thing, though, can end up being fatal.

This, then, may end up being the new contradiction that organisations need to resolve. This paper is effectively about a model of the world intended to assist in the resolution of that contradiction.

In times of high-speed innovation such as happen in any recessionary period (such as most parts of the world at the time of writing), the institutions that will survive are typically the ones that are able to change and adapt faster than their competitors. Hence one of the main ideas of the making a 'helicopter view' assessment of all of the innovation tools and techniques has been to 'atomize' the fine work of creativity and problem solving pioneers and to then show how these atoms fit into the higher level 'Agile, Adaptive Systematic Innovation' (AASI) jigsaw defined by a 'periodic table of innovation elements'.

The dual divergent-convergent, definition and solution cycles - $(DC)_d(DC)_s$ – represent a minimum 'complete set' for the innovation team inside any organisation. In the periodic table analogy, this means ensuring the (institutional?) presence of metals, metalloids and non-metals during the creativity phases of an innovation project. In general terms, it tends to be the 'non-metals' where most organisations tend to be the most deficient.

Fortunately, given the cyclical nature of any innovation project, it is not necessary to have each of the $(DC)_d(DC)_s$ parts to be in full effect at any single moment in time. Indeed, some organisations appear to have made the decision to import the rarer and more time intensive $(DC)_s$ parts as and when needed.

Another consideration at this point is a recognition that the choice of appropriate tools and strategies also depends on the capability of the organisation. As with the actual periodic table of chemical elements, the further down the table the more complex (in terms of atomic structure) the elements become. Thus, to take the 'halogens' as an example, the use of Edward DeBono's concept of random word connections is perhaps the very simplest idea generation 'tool'; whereas Brian Eno's 'Oblique Strategies' (Reference 7) collection of solution triggers are somewhat more abstract and needing of some practice before they are likely to help deliver genuine breakthrough idea clues.

All this is to suggest that there is not any kind of universal recipe that organisations can follow. Ultimately, the success of organisations in doing the innovation job will depend – fundamentally – on their ability to manage the inherent complexities of not just what tools they choose to introduce, but how people are encouraged to use them, and, most important of all, how the organisation develops the capability to sense and respond to changes in its environment. Changes that may create the need for swift and non-linear modification to what they do and how they do it. At least now we have a high enough level view of the innovation world for companies to begin making informed choices about the what, where, when and why aspects of their innovation obligations.

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Paper ID: 93

Forecasting Analysis of the Maturity of Automobile Steering Wheel System Based on TRIZ

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Abstract： The technology of steering wheel system, which controls the safety of automobile driving, is developed rapidly with the increasing advancements of automobiles. Like the biological evolution process, the automobile steering wheel system will also pass through processes of infancy, growth, maturity and decline. It's crucial to determine the current stages of steering system for enterprises to draw up further development plans Based on the TRIZ theory, the technical maturity and development directions of the automobile steering wheel system are forecasting analyzed in this paper.

Keywords: forecasting analysis, technical evolution, steering wheel system, technical maturity.

Now the automobile has become one of the indispensable products in people's working and living. As an important part of the automobile, steering system has been evolved on its structure, material, function and outward appearance modeling with the development history of automobiles. According to the TRIZ theory, any product is the technology system supported by its core technology, and will go though its technical lifecycle—infancy, growth, maturity and decline. Therefore, it is significant to ensure the present period of products for their future development directions and enterprise's overall strategies.

1 Technical Forecasting Theory and Process of TRIZ

TRIZ is the Russian abbreviation which means "The Theory of Inventive Problem Solving", established by a former Soviet Union inventor named G.S.Altshuller in 1946. One of the cores of TRIZ theory is evolution principle of technique system, which can forecast the development trends of future products and techniques and help enterprises to develop new competitive products.

The technical maturity forecasting theory of products has three processes. Firstly, the time-patents amount curve, time-patents level curve, time-performance curve and time-profits curve are set up by collecting and analyzing relevant data and patents analysis. Secondly, the four curves are compared with the standard curve of technical maturity forecasting theory, and its maturity is determined according its location on S-shape curve. Finally, the forecasting results are evaluated by the product technology, current performance and profit capability, etc..

2 Technical Maturity Forecasting of Steering Wheel System

Due to the limitations in patents searching, patents can only be collected since

1985 in this research. Therefore, the absolutely accuracy of forecasting results in this paper are not guarantee.

The four curves were based on interrelated patents. According to the patents searching data, the technical patents related to steering wheel system techniques are produced during the following several conditions:

(1) amenity improving;
(2) security improving;
(3) manipulation mode improving;
(4) functionality increasing;
(5) innovation material;
(6) human vision quality innovating;
(7) high technology applying.

2.1 Time-Patents Amount Curve

The technical patents were picked out from the ones related to steering wheel by reading patent specifications. Then, the time-patents amount curve (figure 1) was obtained according to the statistic results.

Comparing this smoothed curve with the standard one of technical maturity forecasting theory (figure 2), the curve shape in figure 1 is similar to the previous three stages in TRIZ lifecycle theory including infancy, growth and maturity.

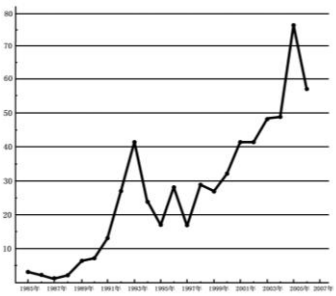

Fig.1 Time-patents amount curve

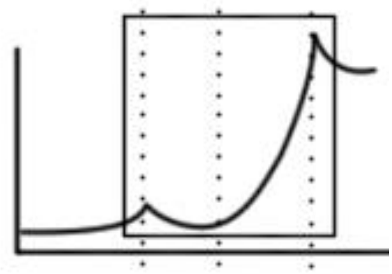

Fig.2 Time-patents amount curve of technical maturity forecasting theory

2.2 Time - Performance Curve

The transformations of steering wheels' performance was analyzed from several aspects, including amenity, security, power-assisted system, function, material, visual quality and high technology application.

2.2.1 Amenity of Steering Wheel System

Improvements in amenity of steering wheel system brought many patents. For example, the problem of iciness was solved by electro-thermal steering wheels which appeared in the mid of the 1980s, and healthcare steering wheels could alleviate human fatigue caused by a long time driving.

Steering wheel covers have been developed from adding frictions to strengthening amenity, and been drove to maturity stage gradually, such as massage steering wheel, wireless communications steering wheel, etc.. Some special materials, such as nanometer dilute magnetic anti-fatigue, were also used in steering wheel cover.

From analyzing the patents' era, the amenity of steering wheel was improved slowly from 1985 to 1992, and it was improved greatly by the applications of variety designs from 1992 to 2001. From 2001 to 2006, angle and height adjust steering wheel was created besides new materials. Figure 3 gives amenity-time curve.

2.2.2 Security of Steering Wheel System

Security is the most important element of steering wheels' performance. Many innovations were used to prevent accidents occurred effectively, such as the airbag, flexible universal joint, foldable, multifunction and extension type, kinetic energy absorption type, and an safety device of automatic tracking the drivers steering wheel and instant alarm while the car was out of control. An Emergency application was designed to get a rapid reaction when encountering danger so as to pursue a higher security.

By concluding the development process of the patents related to the security of steering wheel system, there are some turning points in security improving. The time-security curve is shown in figure 4.

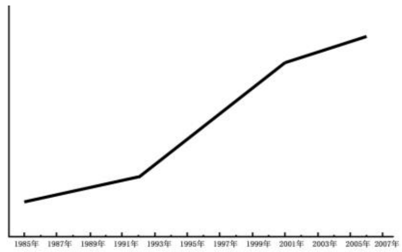

Fig.3 Amenity-time curve

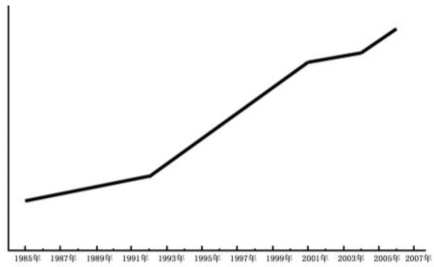

Fig.4 Time-security curve

2.2.3 Power-Assisted of Steering Wheel System

Power-assisted steering wheel saves more labor for drivers. Examples are displayed as following. Singlehanded twirl steering wheels, loaded a raised rocking handle on it, make one-hand control possible. Radio frequency steering wheels afforded a new method to guide any appliances in the car. A synchronous rotation steering wheel (shown in figure 5) relaxed drivers by a couple of wheels which were connected via gear and chain. It made drivers avoid arm folding and transposing when the deflection angle of the two wheels exceeds 180°.

According to the survey of guiding performance patents of steering wheel, the manipulation technique developed slowly from 1985 to 1992, symbolized a rising trend from 1992 to 1998, and had a rapid increase in power-assisted system from 1998 to 2002 based on high technology. Then, the time-manipulation curve is received as shown in figure 6.

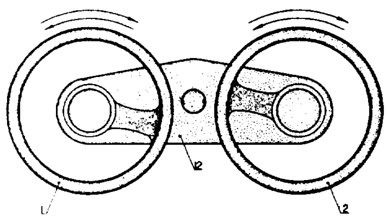

Fig.5 Synchronous rotation steering wheel

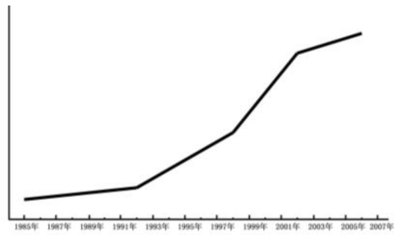

Fig.6 Time-manipulation curve

2.2.4 Function of Steering Wheel System

From the initial steering function to a multifunction unit combined with many buttons, steering wheels make drivers enjoy themselves during the process of manipulation. Brake steering wheels could raise drivers' security when driving. An angular display unit attached to steering wheel was able to point out driving accuracy. Whirling headlights steering wheels helped drivers see the crooked road clearly in the night. Particularly, a recoverable steering wheel patent with a display screen and a linkage protective shield was invented in 2006. It could effectively prevent passengers from dangers of outer objects and being thrown out.

The numbers of lock patents increased rapidly year by year and their technique also became perfect from 1985 to 2006. More advanced lock patents were invented, such as code mode, fingerprint mode, folding type, protective cover type, cantilever type, hinge type, auto-stretched type, airbag pickproof lock, split hard abnormity barcode identification mode, handlebar alarm type, and so on.

There are three stages which were divided by the year 1992 and the year 1998 to classify the interrelated patents from 1985 to 2006. The time-function curve is shown in figure 7.

2.2.5 Material of Steering Wheel

There are many attempts on materials of steering wheel. Wooden steering wheels made drivers feel more comfortable. Carbon fibrous steering wheels reduced coldness and strengthen friction. Specifically, the nanometer antibacterial steering wheel could create a fresh and clean surrounding to optimize human psychosis, strengthen their immunity, and increase their blood circulation by purifying germ, virus and some harmful gas including formaldehyde, ammonia and benzene in the surface of steering wheel and the inner atmosphere. The time-material curve is shown in figure 8.

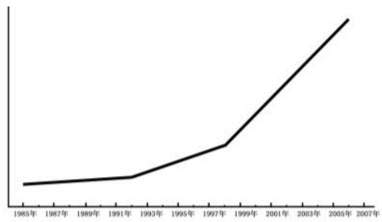

Fig.7 Time-function curve

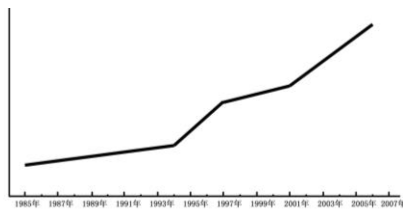

Fig.8 Time-material curve

2.2.6 Visual Quality of Steering Wheel

Drivers who are fatigued after longtime driving can be excited by the high visual quality of steering wheel. For example, steering wheels with noctilucent cover could fluoresce in the night and bring convenience to drivers. Luminous and pleochromatic steering wheels made from soft optical fibers could supply various kinds of personal patterns easily. And for drivers, perfect glow, brought about by optical frequency controllers through three LED lights could express their individuality and relax them simultaneously. The time-visual quality curve is concluded, as shown in fig.9.

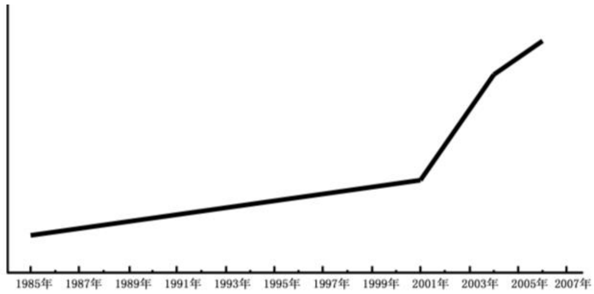

Fig.9 Time-visual quality curve

2.2.7 High Technology applying

With the development of high technology, more and more technologies are used in steering wheel. For example, the display screen, placed in the middle of steering wheel and controlled by the module computer, gave convenience for drivers observing meter panel, increase security, and expand monitor range. The bluetooth dial system could strengthen the convenience for drivers to handle phones (shown in Figure 10). Figure 11 shows the time- high tech curve.

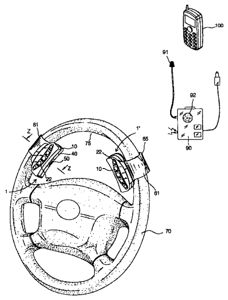

Fig.10 Bluetooth dial system

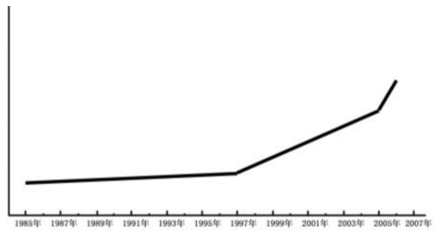

Fig.11 Time- high tech curve

2.2.8 Integrative Analysis and Curve Establishing

On the foundation of data analysis, information arranging and balancing the above curves, the integrative time-performance curve is summarized in figure 12.

From figure 12, the crucial moment in improving performance of steering wheel appeared in 1992 and 2001. Comparing this smoothed curve with the standard one of technical maturity forecasting theory (as shown in fig.13), the curve shape in figure12 is similar to the previous three stages of TRIZ lifecycle theory including infancy, growth and maturity.

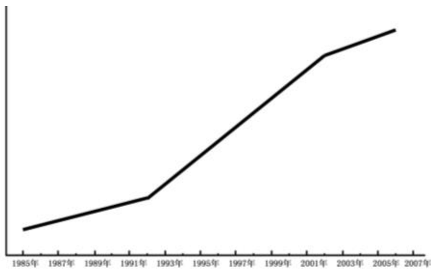

Fig.12 Time-performance curve

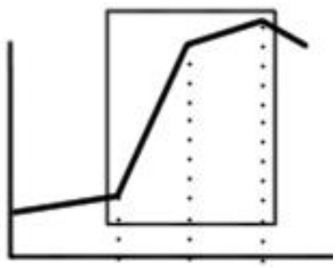

Fig.13 Time-performance curve of technical maturity forecasting theory

2.3 Time-Profits Curve

Since the product profitability is confidential and manufactories are numerous and widespread, it is hard to collect profits data veritably. On the other hand, the steering wheel profits goes with auto profits which depends on sales volume that rests with auto output, so the time-profits curve of steering wheel should be a similar trend to the time-output curve of auto. Therefore, the time-auto output curve was drawn first (figure 14), and the time-auto sales volume curve (figure 15) was able to get from the previous one, then the time-profits curve of steering wheel was described in figure16.

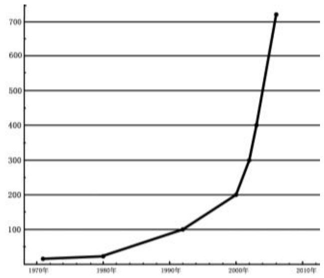

Fig.14 Time- auto output curve (Ten thousand per year)

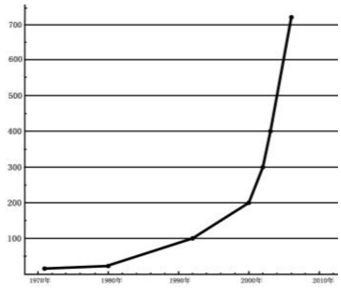

Fig.15 Time-auto sales volume curve (Ten thousand per year)

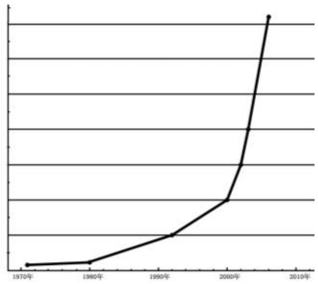

Fig.16 Time-profits curve of steering wheel

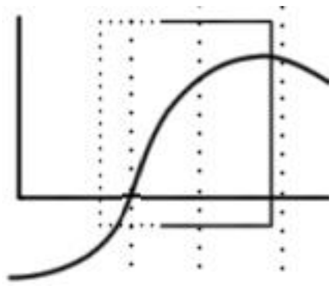

Fig.17 Time-profits curve of technical maturity forecasting theory

Comparing the smoothed curve in figure16 with the standard one of technical maturity forecasting theory (figure 17), the curve shape in figure16 is similar to the previous three stages of TRIZ lifecycle theory including infancy, growth and maturity. But it is unable to determine the profits in about 1985, so the exact position of infancy is not sure, which is described as approximate dashed wireframes in figure 17.

2.4 Time-patents level curve

The levels of technical patents of steering wheels were classified considered the categories summarized by Altshuller. From 1985 to 2006, many patents were existed to improve or compensate the elder ones, Some of them changed fewer on system for the purpose of solving local problems in steering wheel system. And some others were merely functional grouping but less novelty. When analyzing the levels of technical patents, it should be clearly on what tech-problem the patent wants to solve by reading each patent specification in detail.

The number and level of such patents were recorded on basis of their periods for figuring out the average level of each year. And the time-patents level curve was described in figure 18.

In figure 18, there is a peak in 1995 which probably owing to several high-level patents of airbag system. For airbag steering wheels, how to protect drivers effectively is the most important standard to evaluate technical maturity of steering wheel system.

Comparing this smoothed curve with the standard one of technical maturity forecasting theory (shown in figure 19), the curve in figure 18 is similar to the previous three stages of TRIZ lifecycle theory including infancy, growth and maturity.

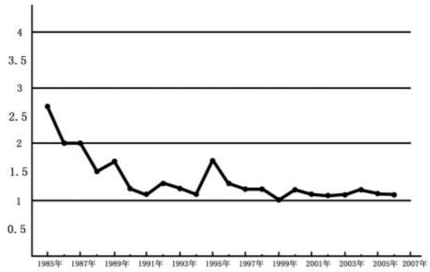

Fig.18 Time-patents level curve

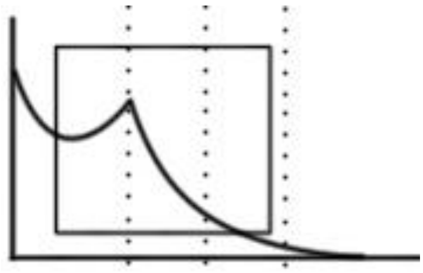

Fig.19 Time-patents level curve of technical maturity forecasting theory

3 Comprehensive evaluation and Forecasting of the Maturity of Automobile Steering Wheel System

This analysis is based on the patents produced from 1985 to 2006, while the steering wheel system is associated with automobile nearly a hundred years, so the previous developments before 1985 should be considered and research on the whole evolution process should be done.

According to the above analyses, the steering wheel system was known in infancy and developed slowly before the 1980s. The invention and application of airbag system made the steering wheels have obvious changes in appearance, shape, material and structures that have made preparations for later technical development. Therefore, it was confirmed that the 1980s is the milestone for the technical progress in steering wheel system.

After comparing these curves with the standard technical maturity forecasting curve based on TRIZ theory, the conclusion can be drawn that the technology development in steering wheel system has been in maturity around 2000 in the fields of mechanical structure, material, performance and shape, etc.. Many facts are enumerated as follows. The transmission agent was changed from mechanical steering to Power-assisted Steering; the materials were transformed from metal or plastics in the 19th century to nanometer or carbon fiber, until composite material and leather which were proved to be the best materials for steering wheel; the transmission ratio was started from one to one to a high level that has used in racing cars; the performance originated from a handle only in early time to airbag-added ones which appeared in the 1980s; the style was evolved from attractive and various shapes in modern cars to gearlever handles which have been used in concept vehicles, etc.. All above aspects are the arguments to illustrate how mature the technology developments in steering wheels are.

4 Conclusions

Based on the analysis and research in this paper, the steering wheel technique is in mature period at present, but still has further prospects for its potential progresses in structure, material and performance. It should be promoted and perfected to full maturity. In a word, the current technique of steering wheel system is in the middle stage of mature period.

According to TRIZ theory, there must be some vicarious inventions to make preparations for prospective market competition if products' technique is in mature period. In view of above forecasts, the research staff working in automobile companies should do something urgently as follows.

(1) To perfect steering wheel technology to a high level in security, power-assisted, material and appearance modeling.

(2) Simultaneously, enterprises ought to grasp the trend of future control system of automobile and high technology, and try to product new system to replace the current steering wheel system. Only in this way, they can remain invincible in future market and be vanguards in technical innovation.

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Paper ID: 95

TRIZ-based Innovation Approach with *2 X 2* Function Class Block on Complex System

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Abstract:

The chief of idea in paper is to create one matrix table, *2 X 2* Function Class Block (FCB), which cover all sub-systems and deliver them to FCB by production, management and core, assistant etc attributes. One complex top model is separate to 4 lower and operational sub-model which including several sub-system set. The problems which inside FCB or outside, whether standard problem or special problem, to system analysis and resolve contradiction with TRIZ theory is became simpler and smart. The contribution to evolution and improvement of complex system and to innovation of FCB influenced by algorithm or controlling process of AI is obviously. The innovation approach with *2 X 2* FCB is proved in some practice cases of Business Processing Rebuilding (BPR).

Keywords: TRIZ, Innovation, Function Class Block, Complex System

In the 20 century, the great scientist, Ludwig.Von.Bertalanffy, came out with the general concept of systematic and approach of system engineering firstly [1]. The system science became one integrated subject field, which are academic research and engineering practice, gradually from then. By utilizing the theory and approach of system, solve the many problems in against human society by scientist and engineer [2]. In the same century, another great scientist, Generich.Alshuller, created the theory system about TRIZ and innovation approach [3]. To solve the technical problems or physical problems existing in the technical system and to carry out the evolution of system and consummate. The studying of evolution pattern and approach about technical system is the core content and front line of TRIZ theory on academic research and practice application in these decades [4,5].

The technical system, be divided two study branch by the researchers of TRIZ theory, which with framework character and non-framework character [6, 7]. The conflict with framework attributes is defined standard problems and that with non-framework attributes is defined specific problems [8]. The eight patterns of evolution and approach of technical systems are core theory and foundation to TRIZ technology. It is significant contribution to TRIZ theory, patterns of evolution about technical system specially, by Alshuller as well as her followers [9]. But another TRIZ experts thought is that same technical systems as management, commerce and logistics etc., technical system with non-framework character, ought to apply some special approach of TRIZ to solve the special problems [10, 11].

System resource (system elements) and system functions are two important attributes to a whole technical system [12]. One complex system is made of more system resource (system elements) and multi-function, to accomplish systematic goal on running procedure. In the recent world, each huge-scale complex technical system is also including with operating, management, communication, intelligent information subsystem and so on. It is difficult to outline the boundary of these subsystems and describe these relations of their subsystems functions clearly [13,14].

The main idea of this article is to set up a system analysis model, 2 X 2 Function Class Block (FCB) matrix, and cross divide that by the function character with production, management and core production, assistant production. All subsystems are allocated to the one of FCB blocks fit with their attributes, then utilize 39 conflict matrix and 40 invent principle to solve technology problems as well as evaluate the lever of innovation approach to whole system.

1. 2 X 2 Function Class Block modeling.

The technical system is not only the production of man-made, but also the producing process controlled by man. There are several task phase, such as preparation, task planning and information management phase, in one larger complex production system. That technical system is deal with the producing equipment running real-time and the producing process management by the instruction from managers. For example, the real-time navigate of space shuttle and astronaut is great technical system, and the brake apparatus of car and driver is small technical system. So the large scale of technical system is including with thousands small and simple technical subsystem to work together.

To abstract the functions framework and functions model from the large complex technical system and to ignore the actual physical character such as substance, machine or software program. Then the structure of function model were separate the several sub-functional layer like the top system was took parts of several subsystem in our traditional impression. The top subsystem was made of which lower layer. To separate these subsystems with their function attributes by the cross divide in Set Theory [15], so 2 X 2 FCB model is define follow as:

1. Define,

$$S = \left(S_k \mid S_k \subseteq A, S_k \neq \phi, k = 1,2,,,,,n\right)$$
$$\sum \bigcap S_k = \phi, k = 1,2,,,,,n;$$
$$\sum \bigcup S_k = A, k = 1,2,,,,,n;$$

A is a complex technical system, which is not null, and set S is whole set coving system A. So $S_k\left(k = 1,2,,,,,,,n\right)$ are completed to cover and separate upon system A. That shows in fig 1(a).

2. Define,

$$S = \left(C_{i,j} \mid C_{i,j} \subseteq S; i, j = 1,2\right);$$
$$\sum \bigcap C_{i,j} = \phi, i, j = 1,2;$$
$$\sum \bigcup C_{i,j} = S, i, j = 1,2;$$

$C_{i,j}\left(i, j = 1,2\right)$, that cross separating to system set S, which including with $S_k\left(k = 1,2,,,,,,,n\right)$ subset. C1,1 means the function sets class of core production, and C1,2 means the function sets class of assist production. C2,1 means the function sets class of core management, and C2,2 means the function sets class of assist management. That shows in fig 1(b).

3. Define,

R = { Ra, Rb, Rc, Rd, Re };

R is the relation set of function classes $C_{i,j}\left(i \neq j, i, j = 1,2\right)$

Ra shows the closet relation of function mate with $S_k\left(k=1,2,,,,,,,n\right)$ inside of FCB *C1,1*. *Rb and Rd* shows the relation of control mate with $S_k\left(k=1,2,,,,,,,n\right)$ between of FCB *Ci,2* and FCB *Ci,1* (*i = 1,2*), which including with subsets in them. *Rc and R*e shows the relation of data mate with $S_k\left(k=1,2,,,,,,,n\right)$ between of FCB *C1, j* and FCB *C2, j* (*j = 1, 2*), which including with subsets in them.

All function subsets, which to compose the complex technical system, were divide to two rows, the production core class and production aid class firstly. And then all subsystems were cross divide to two part of up and down, production class and management class. Thus the production core subsystems are belonging to C11 set block and the production aid subsystems are belongs to C12 set block. Others, the core management subsystems are belongs to C21 set block and aid management subsystems are belong to C22 set block too. The traditional system analysis model is shown in fig-1(a), and the 2 X 2 FCB model illustrate as shown in fig-1(b，c) . The relation of R set and route map in the technical system shows fig-1(d).

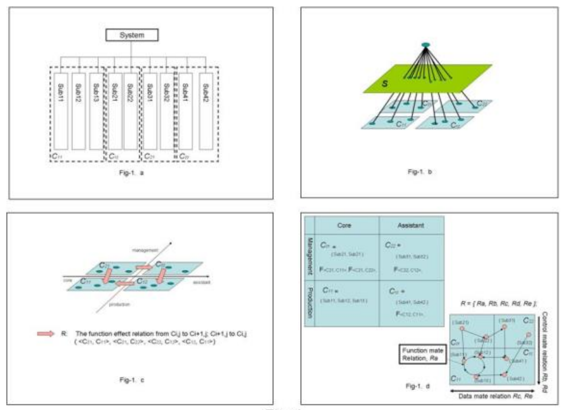

Fig 1

The TRIZ researchers are able to applying the 39 X 39 conflict matrix and 40 invent principle to seek the technical problems or physical problem convenient. And they are to achieve the ideal solution based on 2 X 2 FCB model. The evaluation of innovation and invent to contribution for whole technical system is became more easily. Alshuller delivered the 5 innovation lever about these invent value and every solution [16]. Which evolving step of subsystem within 2 X 2 FCB model will be fit one of 5 levers. The lower of subset in the technical system, the litter of contribution value in innovation and invent. The higher of subset in the technical system, the more of contribution value in innovation and invent. It will be the revolution, subversion and impact to innovation at higher lever of FBC.

The innovation or invent upon the block of FCB is more contribution than which inside block of FCB. From the study on 2 X 2 FCB model, we found that the motivation of innovation inside FCB came from the same professional field and the motivation of innovation outside FCB came from another professional field.

2. The FCB C11.

2.1 The FCB of C11 is the chief production unit of complex technical system. In the some special case, even which subsets of FCB C12, C21, and C22 are running out, but the FCB C11 is continue to work only. Of cause there are several others problems, such as business cost, energy expend and production safety in the FCB C12, C21, C22, but not in C11. When the whole system is crash or breakdown and the main whys is the some subsystem inside of C11 running out, we are think that the contribution of subsets of FBC C11 to entire system running normally is vital.

By the FCB model of define 1-3, the entire system is made of many subsystems associated each others. There are some functional nodes, which occupied in the work line, with the series, parallel, cooperate and conflict etc. connecting attributes. We suppose that the model of system function framework is link as graph G with color [17]. The node of G, maybe shows the physical materials flow or information flow. The black color is shows the node integrated physical and informational flow. The white color of node presents the single informational node only. It is colored linking sub-graph where the pre-node and next node are same color with its. The linking count, number of colored linking sub-graph, called joined node connecting with color linking sub-graph. The illustration of colored linking graph shows in fig-2.

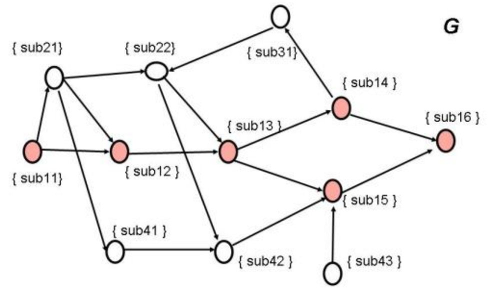

Fig - 2

The approach of Depth first Search (DFS) is to accomplish collecting the core subsystems with functional mate character and the colored nodes linked in graph G, such as the core production sets in FBC C11. The goal of application colored sub-graph theory and DFS arithmetic is to set up the model of core production unit, FCB C11, and seek the functional joint node linked with blocks of FCB. The arithmetic program visits the colored nodes of C11 in graph G is following as.

```
DFS (Graph &G,    ListType &m) {
        visited [m] = true;
        printf ( " %s    %s , ",    m.data,    m.color );
        for ( v = FirstAdjVex( G, m );    v >= 0;    v = NextAdjVex(G, m, v ) )
        if ( ! visited[v] && v.color == 1 )    DFS( G, v );
        }
```

m: the current colored node in the graph G,

v: the next colored node of m in the graph. G.

FirstAdjVex( ): As graph G is true, and m node is the first joint node.

NextAdjVex( ): As graph G is true, and v node is next joint of m node.

2.2 If there are some technical problems or physical problems in FCB C11 and we are able to complete the evolution pattern or approach of system subset because which are active and alive. In this case, the solution method of 39 X 39 conflict matrix and 40 invent principle will are the best tools to overcome the practical problems either technical or physical.

3. Others FCB model, C12, C21 and C22.

The FCB C12 block is made of systems subset with supporting production attribute by the define 2. In the general case, these subsystems are the working unit to accomplish technical supporting or aiding process. For instance, they are Communication Subsystem, Logistics subsystem etc. functional subsystem. The FCB C21 block is composing of subsystems, which maybe is MIS or firm managers. Because of workflow process or data analysis in MIS is using to control system running and operate by the manager. To maintain the running of system normally, the mission of other blocks of FCB is to support the core subsystems of FCB C11 running precision, availability and in time.

The subset aiding management is called FCB C22. They are maybe such software as CAD, CAP, or CAM etc. in general case. Certainly, FCB C22 is also including of the enterprise follow like as planner, designer and quality controller. Aiding by computer, they are playing the important role as like human in the high-tech age. The accurate processing and respond quickly are indeed exceeding the people to do. Some computer aiding machine is instead of people and some software is instead of hardware in system function specially. In the more case, there are some technical problems in the management class blocks of FCB C21 or C22. The important innovation is the development of intelligent software, such as production planning, controlling and decide supporting, specially.

From the define 3, we are know that every subsystem in FCB model existing with certain connection after cross marking off by function attributes. There is the controlling link relation from C21 to C11 and C22 to C12. For example, Rb and Rd are the controlling connect mate. From C11 to C12 and C21 to C22, there is the data communication connect mate. Rc and Rd are the data connected mate in graph G. the illustration of the relation is showed in fig-1(d).

The valuation of innovation and invent about complex technical system is the balance of former system and current in production output and cost. The production function of Cobb-Douglas is one way of valuation to these functions of subset upon the framework of FCB model [18]. The math model is follow as

$$Y_t = A_t \bullet L_t^{\alpha} \bullet K_t^{\beta} \qquad (3\text{-}1)$$

Y_t is the total production output of FBC C11 in time of t phase, L_t is the count of workers and K_t is the consume cost of FBC C11 in the time t. A_t shows the general parameter of production environment. α and β are represent of spring rate about total output Y_t to laborer number L_t and cost estimate K_t. Through analysis, we get that from formula (3-1).

$$Y_t = l_t^{\frac{\alpha}{\alpha+\beta}} k_t^{\frac{\beta}{\alpha+\beta}} L_t^{\frac{\alpha}{\alpha+\beta}} K_t^{\frac{\beta}{\alpha+\beta}} \qquad (3\text{-}2)$$

$l_t = \frac{Y_t}{L_t}$ Shows the production rate and $k_t = \frac{Y_t}{K_t}$ shows the assets rate.

$$Y = \prod_{i=1}^{n} x_i^{\frac{\alpha_i}{\sum \alpha_i}} \prod_{i=1}^{n} X_i^{\frac{\alpha_i}{\sum \alpha_i}} \qquad (3\text{-}3)$$

X_i (i=1, 2, 3, n) shows the change rate to carry into execution one innovation, $x_i = \frac{Y_i}{X_i}$ show the production rate of that. Formula (3-3) is deal with logarithm and differential coefficient, $d_t = 1$, formula (3-4) shows follow as.

$$\lambda = \sum_{i=1}^{n} \frac{\alpha_i}{\sum \alpha_i} \frac{\Delta x_i}{x_i} = \frac{\Delta Y}{Y} - \sum_{i=1}^{n} \frac{\alpha_i}{\sum \alpha_i} \frac{\Delta X_i}{X_i} \qquad (3\text{-}4)$$

λ shows the progress speed rate from the technical innovation of subset in C12,(C21,C22). Formula 4 divide by $\frac{\Delta Y}{Y}$, move the item and we get that formula (3-5)

$$\sum_{i=1}^{n}\frac{\frac{\alpha_i}{\sum \alpha_i}\frac{\Delta X_i}{X_i}}{\frac{\Delta Y}{Y}}+\frac{\lambda}{\frac{\Delta Y}{Y}}=1 \qquad (3\text{-}5)$$

$$C_\lambda=\left\lfloor\frac{\lambda}{\frac{\Delta Y}{Y}}\right\rfloor\times 100\% \qquad (3\text{-}6)$$

So we define that C_λ means the contribute rate to FBC C11 from the technical progress of FBC C12,(C21,C22).

4. Case study on container terminal system.

Tianjin Port Container Terminal # 4 Yard production processing rebuild program, The technology innovation, CCCT (Computing, Communicating, Controlling Technology), solved the bottleneck of container terminal production logistics [19]. That realize the whole terminal yard production process control real time on the logistics chain based container terminal MIS COSMOS existing[20]. The CCCT include wireless data communication (WLAN) in the terminal resource management and the container located data were confirmed as well as working RTG dynamic trailed by GPS [21]. The container production process in terminal will be easy, smart, orderly and harmony to operate for controller and RTG driver. The working plan sheet and interphone were giving up by workers. The illustration is shown in fig-3.

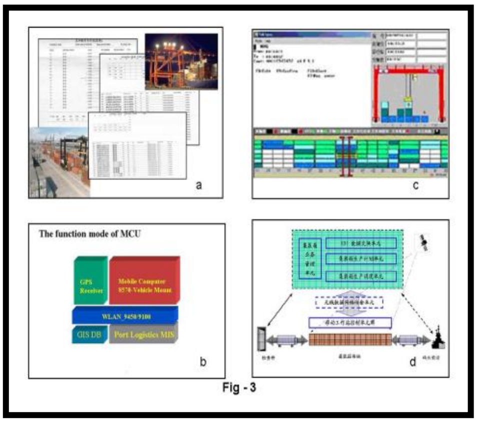

Fig - 3

The application of innovation theory, 39 X 39 conflict matrix and 40 invent principle, shows in fig-4(a). The main contradiction parameters are including with the loss information (24), measurement accuracy (28), manufactory precision (29), difficulty of detecting and measuring (37), extent automation (38). The 2X2 FCB model and evolve approach of terminal production system shows in Fig-4(b) and Fig-4(d). The chief contribution of innovation and invention to container production system [22] are

1. To rebuild the process of terminal yard and to using the RTG with mobile computer adding GPS function instead of yardmen.
2. The renewal of production communication subsystem, the WLAN system instead of interphone system.

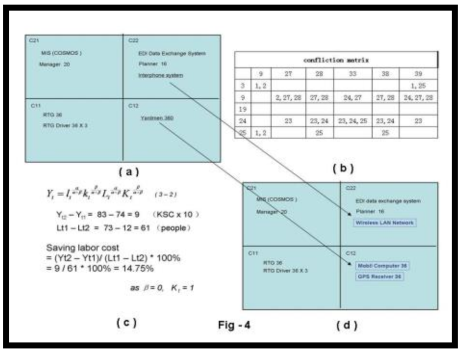

Fig - 4

Based existing container terminal production capacity, the logistics cost comes down 14.68% on the supply chain for whole terminal enterprise. And the production effect/cost is up 4% to same work season of last year [24]. It is improved obviously to the container port throughput and custom server lever. The valuation of this technical rebuilding program shows in Fig-4(c).

5. Discussion.

There are a lot of complex technical systems with different kind of character and with different working environment. The most technical systems are used in industrial manufactory field and they called man-make system yet. They are made of production procedure and information processing etc. subsystem. Even in the CAD, CAM, CAC, CAE etc. IT technology application fields, they are playing the important role that the innovation of arithmetic in the evolution pattern and evolution approach of technical system. The FCB model, 2 X 2 Function Class Block, is simple, smart and effective tools as complex system analysis and TRIZ theory application. By the FCB model to seek the major problem in the technical system and estimate the contribution lever of technical system evolution are significances. To solve the technical problems or physical problems of the innovation practice in Business Processing Rebuilding is more visible and outstanding.

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Paper ID: 99

An innovative matrix-based approach for designing product variety

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Abstract

New product development (NPD) and innovation are key factors that affect a company's long-term survival and growth. The design process is an important stage in new product development (NPD). Based on graph theory and the weighting concept, this paper presents a Quantified Design Structure Matrix (QDSM) which is a systematic planning method of optimizing design priorities and product architecture for managing product variety from an informational structure perspective. Focusing on product variety and the design process in concurrent engineering (CE), the planning model is divided into two phases: global planning and local planning. The proposed method helps designers optimize the design planning and plan better design strategies for product variety. A case study is used to illustrate this method. The results verify that designers may concurrently create variant design solutions in a product family that can meet different market needs without extra effort being spent on redundant design loops.

Key words: new product development (NPD); graph theory; concurrent engineering (CE); quantified design structure matrix (QDSM)

1. Introduction

New product development is a key factor to corporate success in the market. To face today's dynamic and competitive market environment, company strategies must thus be adjusted to these variable environments. New product development (NPD) must not only satisfy the quality, cost and speed of production, but it must also ensure that products have innovative value. In order to survive and stay in a highly competitive market, companies need to develop robust product platform architecture. The major benefits are reduced design effort and time-to-market. Dominating markets with a single product is increasingly difficult; many industries are evolving towards mass customization, which is the production of individually customized and highly varied products or services (Pine 1993). Therefore, an optimal design process and designing for variety are very important design strategies for designing product families. Design for variety (DFV) is a design strategy and methodology that helps designers reduce the impact of variety on the life-cycle costs and time of a product (Martin and Ishii 1997). Various investigations have explored issues dealing with the strategic benefits of developing product platforms and the management of product families.

Suh (1990) viewed product variety as the proper selection of design parameters that satisfy variant functional requirements. Fujita and Ishii (1997) formulated the task structure of product variety design. Erens (1996) developed product variety under functional, technological, and physical domains. Martin and Ishii (1997) proposed Design for Variety (DFV), which is a series of methodologies with quantifying indices for reducing the influence of product variety on product life-cycle costs, and thus helping design teams develop decoupled product architectures. These studies have established a basis for product variety management.

In research on product families, Fujita *et al.* (1999) utilized optimization techniques to identify the optimum architecture of a module combination across products in a family of aircraft. Robertson and Ulrich (1998) proposed a method of balancing distinctiveness with commonality by identifying the importance of various factors going into this tradeoff. Moreover, Maier and Fadel (2001) looked at the early stages of product family design to help designers choose appropriate manufacturing and design strategies. Claesson *et al.* (2001) modeled product platforms using configurable components. Dahmus and Otto (2001) considered the effect of service costs on developing product architecture. Blackenfelt (2000) used the quality loss function to help optimize the degree of variety within a product platform.

Most of the above investigations focused on optimizing family structure, rather than explicitly identifying the physical arrangement and interaction among components in the product architecture. The design priorities of components are seldom discussed in these studies. Design priority is a critical issue for reducing the redesign time and design iterations in a concurrent engineering (CE) (Yassine and Braha 2003, Yassine and Sreenivas 2008) environment. In recent years, concurrent engineering (CE) has become increasingly important for product development. CE is a philosophy that suggests the need to consider design issues simultaneously where they were considered sequentially in the past. The important transformation approach practically relevant to this paper is the product design process re-engineering (Huang and Mak 1998). When applied to re-engineer the product design process, it is mainly concerned with the rationalization of design priorities of the product components, with the belief that a rationalized product design process is more likely to result in better product design decisions.

Although the aforementioned research has established a basis for product variety management and gives considerable insight into product architecture and configuration, it has some shortcomings. First, they emphasize the local areas, not overall fields for design configurations. Second, although all these studies provided some insight into the dependent relationships of a complex product for product variety design, they failed to expose and explore the logic behind these dependencies. Therefore, this paper focuses on optimizing product architecture by identifying the attributes of product components for design variety and on design priorities of product components for concurrent engineering (CE).

To deal with this problem, this paper proposes a structural matrix-based method called Quantified Design Structure Matrix (QDSM) based on the design structure matrix (DSM) (Steward 1981). Although a classical DSM can provide a clear and useful analysis method for a complex design process by decomposing and rearranging the product components, it has some disadvantages. For instance: (1) the traditional path searching method (Weinblatt 1972) adopted in the partitioning procedure is computationally inefficient; it is difficult to solve large design matrix. (2) Although many researchers (Kusiak and Wang 1993, Rogers 1989) have tried to improve the tearing algorithm, no optimal method exists for tearing. (3) The dependency strength between two product components cannot be really reflected using a binary matrix with "1 "and "0 ". The information is insufficient to dispose the coupled components for further analysis. Thus, this study attempts to solve these problems using the QDSM model.

The proposed methodology is divided into two phases: global planning and local planning. Based on graph theory (Roberts 1976) and the weighting concept, we enhance the traditional DSM to a quantified design structure matrix (QDSM) to represent the complete dependency structure profile and dependency uncertainty of the design process and product architecture. The proposed QDSM can be best captured by using fuzzy linguistics variables. In the global planning phase, we apply Interpretive Structural Modeling (ISM) (Warfield 1973, 1990) to develop an improved partitioning algorithm for QDSM. ISM is an algebraic technique used for system representation and analysis that was first introduced by Warfield (Warfield 1973). Using Boolean matrix operations, it helps compute and analysis a complex system. ISM has been used in various research fields (Kitamura 1999, Sharma *et al.* 1995).

The objective of this paper is to facilitate designers in creating product variety based on currently existing product, thus forming a product family to reduce redundant design effort and satisfying requirements of segmented markets. Our proposal is an enhanced structural model which can be used to visualize the hierarchical structure of product components and to optimize the design process for CE.

2. Outline of research framework

The information modeling is carried out using the dependency strength between design components with EDG based on graph theory and the weighting concept. EDG is then mapped to a QDSM. Finally, the re-engineering of a product architecture and design process is achieved using the global planning and local planning methods. Figure 1 shows the research framework.

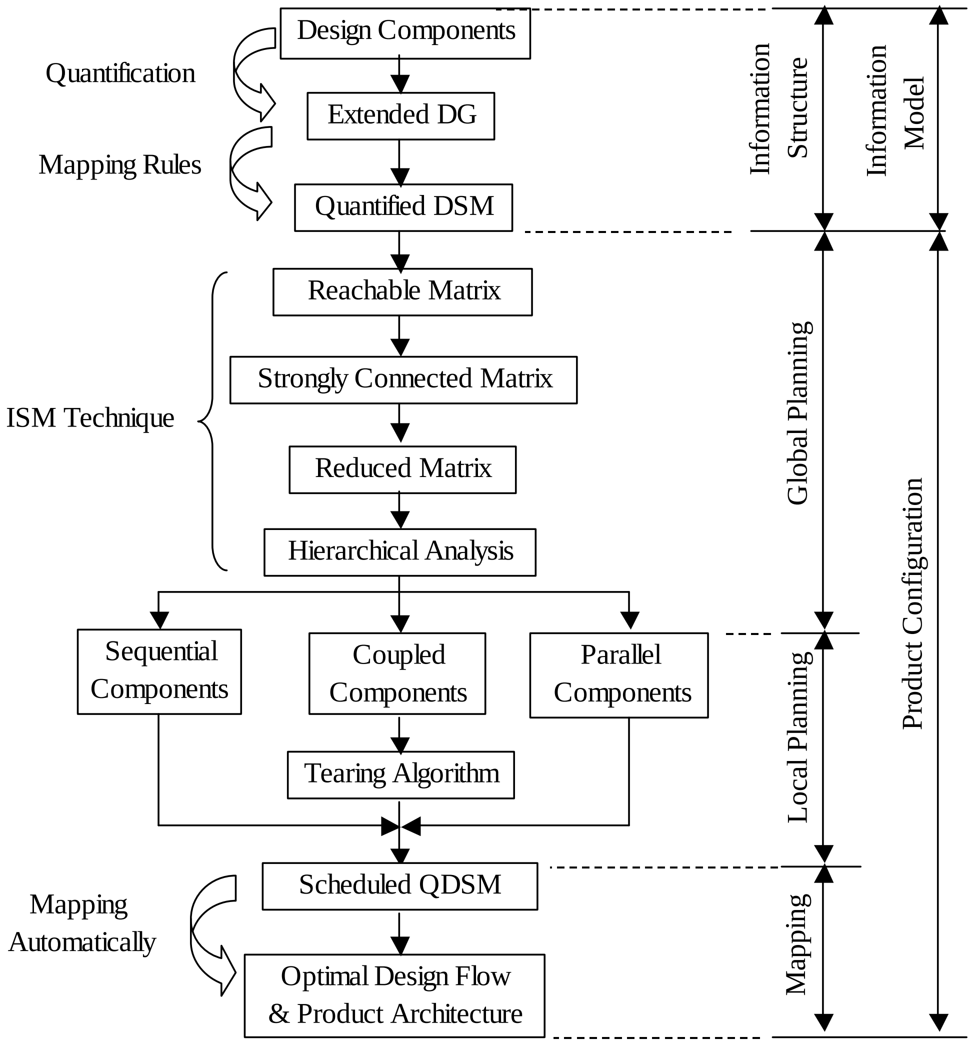


Figure 1. Research framework.

3. Methodology: information structure analysis

3.1 Extended directed graph (EDG)

Once decomposed, the design process and product architecture can be described as a directed graph based on graph theory (Roberts 1976). The directed graph consists of a set of nodes, representing the design components, and a set of directed lines connecting these nodes. The directed lines or linkages reflect a dependency or a relationship between the connected components. Assume that $G = \langle V, E \rangle$ is a directed graph, where $V = \{v_1, v_2, ..., v_n\}$ is a set of nodes denoting n components, and $E = \{e_1, e_2, ..., e_n\}$ is a set of directed lines denoting the path and direction of information linkages. Each element of E corresponds to two nodes in V. However, there are some disadvantages to directed graphs. For instance: (1) Simple relationships. Most directed graphs can only describe sequential relationships. (2) The dependency strength between the product components cannot be described. (3) The hierarchical relationships of the design components cannot be clearly represented. (4) Furthermore, if information flows are complex or information content is great, the directed graph model will be messy.

Thus, we propose an extended directed graph (EDG) to present the original information model of a complex design process by quantifying the dependency strength between the product components. According to the weighting scale, we use the linguistics variables to describe the dependency strength based on the sensitivity and variability attributes between product components. Using the weighting concept, EDG can represent the degree of information relationships between product components. This is very useful when disposing the coupled components in the local planning procedure.

3.2 Design structure matrix (DSM)

According to graph theory, the relationships between design components can be mapped to a matrix. The matrix is called a Design Structure Matrix (DSM) (Steward 1981), in which the rows and columns correspond to the design components. The DSM can be defined as follows:

Definition 1. Let A be a DSM with a $n \times n$ square matrix, where n denotes the number of components. The DSM is a binary Boolean matrix $A = [a_{ij}]_{n \times n}$. Its elements, a_{ij}, can only be “0” or “1”. Thus, it can be defined as:

$$a_{ij} = \begin{cases} 0 & (i = j \quad or \quad a_j \not\to a_i) \\ 1 & (a_j \to a_i) \end{cases} \tag{1}$$

In the matrix, the element $a_{ii} = 0$ is on the diagonal. "$a_j \to a_i$" denotes that component a_j input information to component a_i. Then, $a_{ij} = 1$, otherwise $a_{ij} = 0$. Figure 2 shows a classical DSM.

Figure 3 (Smith 1992) shows three configurations that characterize a system mapped from a directed graph to a DSM representation.

Feedback

Feed forward

$$\begin{array}{c|cccc} & a_1 & a_2 & \cdots & a_n \\ \hline a_1 & a_{11} & a_{12} & \cdots & a_{1n} \\ a_2 & a_{21} & a_{22} & \cdots & a_{2n} \\ & \vdots & \vdots & \ddots & \vdots \\ a_n & a_{n1} & a_{n2} & \cdots & a_{nn} \end{array}$$

Figure 2. Design Structure Matrix.

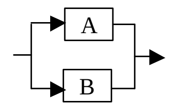
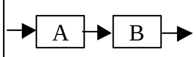
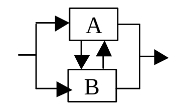
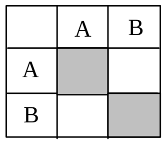
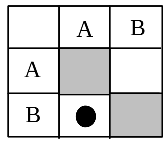
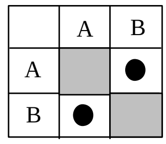
Three Configurations that Characterize a System			
Attribution	Independent	Dependent	Interdependent
Relationship	Parallel	Sequential	Coupled
Graph Representation			
DSM Representation			

Figure 3. Characterizing a system by DSM and directed graph.

3.3 Mapping from EDG to QDSM

In order to assign weights to the relationships between design components, we apply a weighting scale with linguistics variables to define the degree of the dependency strength. After mapping EDG to DSM, the evaluation value a_{ij} of the dependency strength will be used instead of a "1" in DSM. The matrix will become a numerical DSM. It is called a quantified design structure matrix (QDSM).

Based on the weighting concept, we can employ linguistics variables to describe the degrees of the dependency strength within the product components. A variable is represented using a linguistic variable V, which is based on the linguistic scale: S_v = EL, VL, L, M, H, VH, EH where EL: Extremely Low (0); VL: Very Low (0.1); L: Low (0.3); M: Medium (0.5); H: High (0.7); VH: Very High (0.9); and EH: Extremely High (1). The element a_{ij} presents quantitatively the dependency strength between component a_i and component a_j and is defined as follows:

$$a_{ij} = \begin{cases} 0 & (i = j \quad or \quad a_j \nrightarrow a_i) \\ M & (a_j \rightarrow a_i) \end{cases}, \tag{2}$$

where $M \in \{0,\ 0.1,\ 0.3,\ 0.5,\ 0.7,\ 0.9,\ 1\}$. The element a_{ij} is associated with a real number in the interval [0; 1]. To establish the universal weighting scale of linguistics variables, the linguistic variable set L_v is defined as:

$$L_v = \left\{ \frac{0}{extremely\ \ low}, \frac{0.1}{very\ low}, \frac{0.3}{low}, \frac{0.5}{medium}, \frac{0.7}{high}, \frac{0.9}{very\ high}, \frac{1}{extremely\ \ high} \right\} \tag{3}$$

Figure 4 shows the mapping procedure from EDG to QDSM.

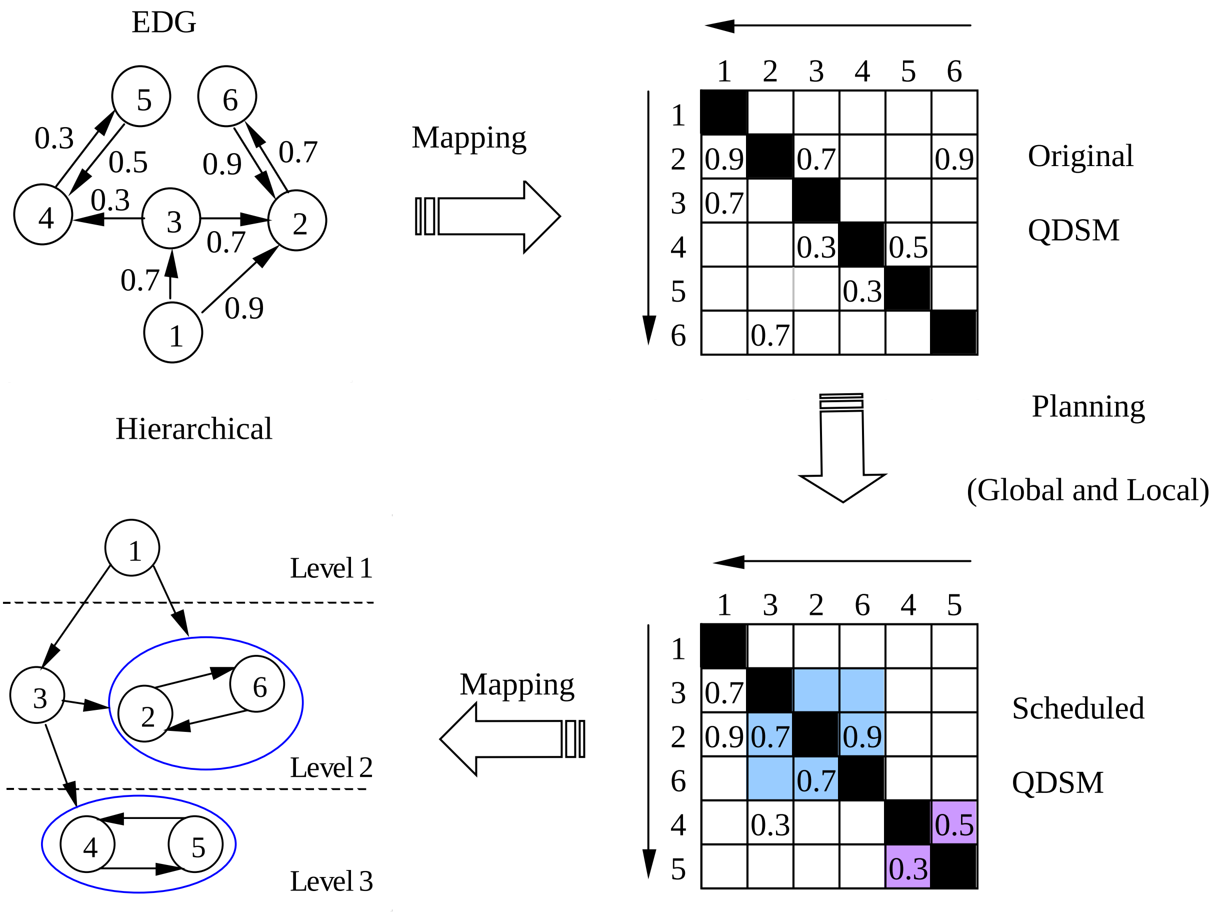


Figure 4. Mapping from EDG to QDSM.

4. Re-engineering process based on QDSM

In the next subsection, we introduce the proposed planning method based on QDSM.

The method includes two phases: global planning and local planning.

4.1 Global planning of the design process

QDSM can be considered as the transpose of the incidence matrix corresponding to EDG. The partitioning algorithm is adopted to identify the coupled components. The upper-diagonal marks of QDSM signify feedback and iterations of components. The purpose of partitioning is to transform QDSM into a lower triangular matrix in the global planning phase of the design process and product architecture. The Interpretative Structural Modeling (ISM) method (Warfield 1973, 1990) is adopted to realize and improve the partitioning algorithm of QDSM in the global planning phase. There are three main steps in the global planning phase: (1) sorting independent components, (2) identifying coupled components, and (3) arranging the ranks of the uncoupled components. We first introduce some definitions which will be used in the partitioning algorithm. The procedures of the partitioning algorithm are as follows:

Procedure 1. Sorting independent components.

The purpose of partitioning is to push forward the process of each component and recognize the coupled components in the design process. It is a gradually decreasing process. The gradually decreasing analysis of partitioning includes the sorting of independent components and also the recognition of coupled components. An independent component is defined in Definition 2.

Definition 2: In the fuzzy design structure matrix *A*, the components with a zero row-sum or a zero column-sum are called independent components. We take the condition $a_{ij} \in R$, if $\sum_{j=1}^{n} a_{ij} = 0$ or $\sum_{i=1}^{n} a_{ij} = 0$, and then we define the corresponding component of a_i, a_j as the independent component.

Procedure 2. Identify the coupled components.

The problem of identifying the coupled components set is translated into the problem of seeking strongly connected components in QDSM. Based on the algebraic technique of ISM, we can deduce a reachable matrix and a strongly connected matrix for identifying the coupled components from the incidence matrix of QDSM.

Definition 3 (Warfield 1990, Xiao 1997). Let *A* be the incidence matrix of QDSM and let I_n be the n-dimensional Boolean unity matrix; then, the transitive closure of $(A \cup I_n)^n$ is defined as the reachable matrix *P* of this QDSM.

The reachable matrix $P = (A \oplus I_n)^n = (p_{ij})_{n\times n}$ is deduced from incidence matrix *A* if a Boolean n-multiple product of $A \oplus I_n$ uniquely converges to *P* for all integers $n >\ n_0$, where n_0 is an appropriate positive integer, I_n is a n-dimensional Boolean unity matrix, and $\oplus$ is the logic Sum operator in Boolean sense (Warfield, 1990). Matrix *P* represents all direct and indirect linkages between components. Relationship transitivity is a basic assumption in ISM.

Definition 4 (Xiao 2001). Let *Q* be a strongly connected matrix. Matrix *Q* is the strongly connected judgment matrix of the reachable matrix *P*. *Q* is defined as follows:

$$Q = P \bigcap P^T = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & {}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix} \bigcap \begin{bmatrix} p_{11} & p_{21} & \cdots & p_{n1} \\ p_{12} & p_{22} & \cdots & p_{n2} \\ \vdots & \vdots & \ddots & \vdots \\ p_{1n} & p_{2n} & \cdots & p_{nn} \end{bmatrix} = \begin{bmatrix} p^2{}_{11} & p_{12}\cdot p_{21} & \cdots & p_{1n}\cdot p_{n1} \\ p_{21}\cdot p_{12} & p^2{}_{22} & \cdots & p_{2n}\cdot p_{n2} \\ \cdots & \cdots & \ddots & \cdots \\ p_{n1}\cdot p_{1n} & p_{n2}\cdot p_{2n} & \cdots & p^2{}_{nn} \end{bmatrix}$$

(4)

where the matrix $P = (p_{ij})_{n\times n}$ is reachable, and P^T is the transpose of *P*. Matrix *Q* is denoted as $P \bigcap P^T = (p_{ij})_{n\times n} = (p_1, p_2, \cdots, p_n)^T$ (5)

where p_i is a n-dimensional row vector. Let the set composed by any of the unequal p_i be $\{p'_1, p'_2, \cdots, p'_m\}$ $(1 \le m \le n)$, Then:

(1) The number of coupled components in QDSM is $m'\,(m' \le m)$, where m' is the total number of row vectors that have at least one component whose value is equal to 1 in $\{p'_1, p'_2, \cdots, p'_m\}$.

(2) If p'_i is the row vector that has at least one component whose value is equal to 1 and all the components whose value is equal to 1 are $p_{ik1}, p_{ik2}, \cdots, p_{ikp}, (2 \le p \le n)$, then C = $\{C_{ik1}, C_{ik2}, \cdots, C_{ikp}\}$ is a coupled components set.

Procedure 3. Arrange the ranks of the uncoupled components.

Definition 5 (Cui *et al.* 1997). The reachable matrix *P* becomes a reduced matrix *P'*, if every coupled component set is merged into one component, and the rows and columns corresponding to the coupled component set have been merged into one row and column.

Definition 6 (Xiao 1997). Let $P' = (p'_{ij})_{m\times m}$ be the reductive matrix of a QDSM.

$P'E_{l-1} = (p_1, p_2, \cdots, p_m)^T$, where $l \geq 1$, $1 \leq m \leq n$, the m-dimension vector

$E_0 = (1,1,\cdots,1)^T$, $E_l = (e_1, e_2, \cdots, e_m)^T$, where

$$e_i = \begin{cases} 0, & p_i \in \{0,\ 1\}\ ; \\ 1, & p_i \notin \{0,\ 1\}\ ; \end{cases} \qquad (i = 1,\ 2,\ ,\cdots, m)$$

(6)

Then, for component C_i , $p_i = 1$ is the necessary and sufficient condition of $L_l = \{C_i\}$,where L_l means that the level of component C_i is l in QDSM.

Definition 6 can be easily realized on a computer to arrange the level of coupled components sets. According to the above method, the partitioned QDSM of the design flow can be easily obtained. The execution of design components becomes sequential. The rank of the design components indicates the priority level of all the components. The design process is in a lower triangular form, and there are no large-scale or whole iterations.

4.2 Local planning of the design process

Creating a lower triangular form by partitioning avoids large-scale iterations, but loops in coupled blocks still exist. The basic principle of the tearing algorithm is to cut off the loops at the weakest point and to design the components with the least information-dependent intensity.

In this paper, we propose a simple and efficient method to decouple the coupled components sets. We now look at tearing each block separately. For each block in the partitioned QDSM, the block information input-degrees (*IIi*) and the block information output-degrees (*IOi*) are calculated for all the components within that block. Note that *IIi* and *IOi* are the row and column sums of component *i*, respectively; however, only the subset of components and marks contained within the block is considered. Next, we calculate the ratio *Ri* = *IIi*/*IOi*, which is a relative importance index. Another issue to consider is the relative importance of input and output information. In a QDSM, the elements above the diagonal denote the iteration of design information. The feedback information of more downstream components will cause more large-scale iterations. We want to have the least amount of feedback information during the design process in concurrent design. In order to identify the weights for the element $E_{ij}\,(i < j \leq n)$ above the diagonal, we can adopt the related distance from E_{ij} to the corresponding element E_{ii} on the diagonal to denote the relative importance. The weight of the element $E_{ij}\,(i < j \le n)$ above the diagonal can be defined as $W_a = |j - i|$. For element $E_{ij}\,(j < i \le n)$ below the diagonal, we define its weight as $W_b = 1$. Both *IIi* and *IOi* can be defined as follows:

$$II_i = \sum_{j=1}^{i-1} C_{ij} \cdot W_b + \sum_{j=i+1}^{n} C_{ij} \cdot W_j \qquad (i, j \le n) \tag{7}$$

$$IO_i = \sum_{i=1}^{i-1} C_{ij} \cdot W_i + \sum_{i=j+1}^{n} C_{ij} \cdot W_b \qquad (i, j \le n) \tag{8}$$

where, n denotes the number of coupled components, and W_i and W_j are the weights corresponding to the elements. The steps of the tearing procedure are listed as below:

(1) Calculate the *IIi* and *IOi* of component *i* , where *i* = 1 to *n*.

(2) Calculate the ratio *Ri* = *IIi*/*IOi*.

(3) Compare each *Ri* corresponding to component *i*. Component *i* with the minimum *Ri* value is scheduled first within the block, since it requires minimum input and delivers maximum output.

(4) After choosing the top-priority component, the scheduled component and all its corresponding marks are removed from the block. Next, we check if the loop was broken by the removal of the scheduled component using the above procedure. If an information loop is encountered again within the block, the process of finding new *Ri* values is repeated. After ranking all the components within a block, we tear all the feedback marks in the block.

5. A case study

5.1. Object product

This study employs the variant design of a PLC (Power Line Communication) product to illustrate the proposed methodology. This case study involves a Taiwanese electronic appliances manufacturer (Company A). Based on their experiences and manufacturing technologies, Company A aims to develop a series of products to simultaneously meet the requirements of each segmented market, and to provide variety in mass customization.

5.2 Identify market-driven variety

5.2.1 Market planning

At present, the position of the PLC products of Company A belongs to cost driven market segmentation with unrefined style and low-tech. Company A hopes that their PLC product can be developed toward high-value market segmentation with high-style and high-tech in the future (Figure 5). In this case study, the market planning is aimed at two different markets (technology variety) with two different appearances (style variety), so four products need to be concurrently developed, as illustrated in Figure 6. Finally, the design team identifies the initial product specifications (Table 1) for concurrently developing four variant PLC products for the different segmented markets.

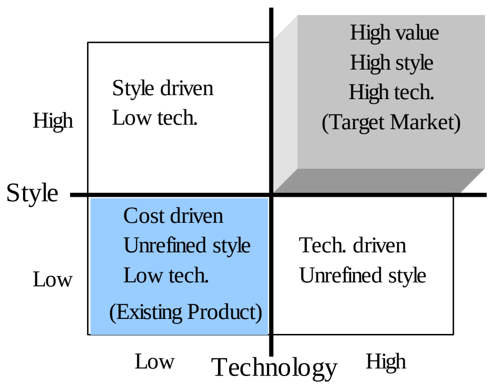


Figure 5. Market segmentation and position map of PLC Product.

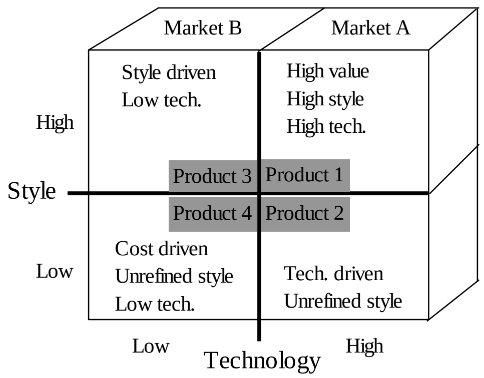


Figure 6. Developing four variant PLC products concurrently.

Table 1. Initial PLC product specifications.

Initial Product Spec.	Product 1	Product 2	Product 3	Product 4
Main Function	200 Mega PLC	85 Mega PLC	55 Mega PLC	55 Mega PLC
Extensional Functions	Audio, Video, VoIP	Audio, Video	X	X
Security device	Electronic Key	X	Electronic Key	X

Based on the existing PLC product of Company A and the initial product specifications, the design team identifies all required physical components, as shown in Table 2.

Table 2. Components list for PLC product.

1. Key PCBA	9. Functional Base Cover
2. Functional PCBA	10. Power Plug
3. Main System PCBA	11. Power Button
4. Key Front Cover	12. Key Button
5. Key Back Cover	13. Led Lens
6. Main Top Cover	14. Main IO Plate
7. Main Base Cover	15. Functional UI Plate
8. Functional Top Cover	

5.3 Build QDSM for PLC product

Next, we represent the interdependent relationships of 15 product components from an EDG mapping to a 15 x 15 square QDSM using the proposed weighting method (Equation 3) which assigns weights to the dependency strength between each pair of product components. This numerical DSM becomes a QDSM (Figure 7).

Part Name	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Key PCBA	1					0.3							0.2			
Functional PCBA	2									0.3						
Main System PCBA	3							0.5				0.2		0.2		
Key Front Cover	4	0.5		0.5		0.5					0.6		0.3			
Key Back Cover	5	0.5			0.3											
Main Top Cover	6			0.8				0.4				0.3		0.2		
Main Base Cover	7			0.9			0.6									
Functional Top Cover	8		0.6	0.8						0.2						
Functional Base Cover	9		0.5						0.6							0.4
Power Plug	10			0.9			0.5									
Power Button	11			0.8			0.7									
Key Button	12	0.8			0.9											
Led Lens	13			0.9			0.8									
Main IO Plate	14			0.4				0.3								
Functional UI Plate	15		0.8												0.7	

Figure 7. Original QDSM for PLC product components.

5.4 Global planning

5.4.1 Sorting procedure

Using the sorting procedure in section 4.1, we found no independent components. Thus, we can proceed with the next step of identifying coupled components.

5.4.2 Identifying coupled components sets

The original QDSM can be clustered and reordered using the improved partitioning algorithm illustrated in section 4.1. The incidence matrix, reachable matrix, and strongly connected matrix can be deduced. First, we can transform the original QDSM into a binary Boolean matrix. Second, according to Definition 3 and Definition 4, the reachable matrix *P* and the strongly connected matrix *Q* can be obtained as below.

$$P=\begin{bmatrix}
1&0&1&1&1&1&1&0&0&1&1&1&1&0&0\\
0&1&1&0&0&1&1&1&1&0&1&0&1&1&1\\
0&0&1&0&0&1&1&0&0&0&1&0&1&0&0\\
1&0&1&1&1&1&1&0&0&1&1&1&1&0&0\\
1&0&1&1&1&1&1&0&0&1&1&1&1&0&0\\
0&0&1&0&0&1&1&0&0&0&1&0&1&0&0\\
0&0&1&0&0&1&1&0&0&0&1&0&1&0&0\\
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1&0&1&1&1&1&1&0&0&1&1&1&1&0&0\\
0&0&1&0&0&1&1&0&0&0&1&0&1&0&0\\
0&0&1&0&0&1&1&0&0&0&1&0&1&1&0\\
0&1&1&0&0&1&1&1&1&0&1&0&1&1&1
\end{bmatrix},\quad
Q=P\cap P^{T}=\begin{bmatrix}
1&&&1&1&&&&&&&1&&&\\
&1&&&&&&1&1&&&&&&1\\
&&1&&&1&1&&&&1&&1&&\\
1&&&1&1&&&&&&&1&&&\\
1&&&1&1&&&&&&&1&&&\\
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&&&&&&&&&1&&&&&\\
&&1&&&1&1&&&&1&&1&&\\
1&&&1&1&&&&&&&1&&&\\
&&1&&&1&1&&&&1&&1&&\\
&&&&&&&&&&&&&1&\\
&1&&&&&&1&1&&&&&&1
\end{bmatrix}$$

From matrix *Q*, we can find that the strongly connected components include

$\{C_1, C_4, C_5, C_{12}\}$, $\{C_2, C_8, C_9, C_{15}\}$, $\{C_3, C_6, C_7, C_{11}, C_{13}\}$, $\{C_{10}\}$, and $\{C_{14}\}$. The coupled components sets are $\{C_1, C_4, C_5, C_{12}\}$, $\{C_2, C_8, C_9, C_{15}\}$, and $\{C_3, C_6, C_7, C_{11}, C_{13}\}$.

5.4.3 Arranging the ranks of the uncoupled components

According to Definition 5, the reduced matrix *P'* of the reachable matrix *P* is:

$s_1\ s_2\ s_3\ s_4\ s_5$

$$P' = \begin{bmatrix} 1 & & 1 & 1 & \\ & 1 & 1 & & 1 \\ & & 1 & & \\ & & 1 & 1 & \\ & & 1 & & 1 \end{bmatrix}$$ where s_1 denotes coupled set $\{C_{1,4,5,12}\}$, s_2 denotes coupled set $\{C_{2,8,9,15}\}$, s_3 denotes coupled set $\{C_{3,6,7,11,13}\}$, s_4 denotes $\{C_{10}\}$, and s_5 denotes $\{C_{14}\}$. Based on the Definition 6, the order levels of all product components can be deduced as:

$$E_0 = (1,\ 1,\ 1,\ 1,\ 1)^T,\ P'E_0 = (3,\ 3,\ 1,\ 2\ ,2)^T,\ L_1 = \{C_{3,6,7,11,13}\}.$$

$$E_1 = (1,\ 1,\ 0,\ 1,\ 1)^T,\ P'E_1 = (2,\ 2,\ 0,\ 1,\ ,1)^T,\ L_2 = \{C_{10},\ C_{14}\}.$$

$$E_2 = (1,\ 1,\ 0,\ 0,\ 0)^T,\ P'E_2 = (1,\ 1,\ 0,\ 0,\ 0)^T,\ L_3 = \{C_{1,4,5,12},\ C_{2,8,9,15}\}.$$

According to the above order levels of product components, the partitioned QDSM can be obtained as shown in Figure 8.

Level	Part Name	No.	3	6	7	11	13	10	14	1	4	5	12	2	8	9	15
1	Main System PCBA	3	■		0.5	0.2	0.2										
1	Main Top Cover	6	0.8	■	0.4	0.3	0.2										
1	Main Base Cover	7	0.9	0.6	■												
1	Power Button	11	0.8	0.7		■											
1	Led Lens	13	0.9	0.8			■										
2	Power Plug	10	0.9	0.5				■									
2	Main IO Plate	14	0.4		0.3				■								
3	Key PCBA	1								■		0.3	0.2				
3	Key Front Cover	4	0.5					0.6		0.5	■	0.5	0.3				
3	Key Back Cover	5								0.5	0.3	■					
3	Key Button	12								0.8	0.9		■				
3	Functional PCBA	2												■		0.3	
3	Functional Top Cover	8	0.8											0.6	■	0.2	
3	Functional Base Cover	9												0.5	0.6	■	0.4
3	Functional UI Plate	15							0.7					0.8			■

Figure 8. A partitioned QDSM for PLC product components.

5.5 Local planning

We next decouple the coupled components sets. We take coupled block 1 as an example. According to section 4.2, we can calculate the ratio index *Ri* = *IIi*/*IOi* as shown in Table 3.

Table 3. The calculation of the tearing procedure.

Activity i	*II i*	*IO i*	*R i*	*Rank*
C_3	2.4	3.4	0.71	1
C_6	2.4	2.1	1.14	3
C_7	1.5	1.4	1.07	2
C_{11}	1.5	1.2	1.25	5
C_{13}	1.7	1.4	1.21	4

From the above analysis, we can obtain the new order of the product components of the coupled set from [C_3, C_6, C_7, C_{11}, C_{13}] to [$C_3 \Rightarrow C_7 \Rightarrow C_6 \Rightarrow C_{13} \Rightarrow C_{11}$]. The other coupled sets can be decoupled in the same manner. After the tearing procedure, we can obtain the final component sequence in a re-engineered QDSM (Figure 9); it can be mapped to a hierarchical graph automatically. Figure10 shows the interaction matrix after an appropriate rearrangement of the order. Three chunks form in the PLC product, namely C1: Main module, C2: Key module, and C3: Functional Module. The precedence of the three chunks is determined by the inter-chunk interactions.

Chunk	Module	Level	Component	No.	3	7	6	13	11	10	14	1	5	4	12	2	8	9	15	*R-value*	*S+R*	*S-R*
C1	Main Module	1	Main System PCBA	3		0.5		0.2	0.2											0.9	*6.9*	*5.1*
		1	Main Base Cover	7	0.9		0.6													1.5	*2.7*	*-0.3*
		1	Main Top Cover	6	0.8	0.4		0.2	0.3											1.7	*4.3*	*0.9*
		1	Led Lens	13	0.9		0.8													1.7	*2.1*	*-1.3*
		1	Power Button	11	0.8		0.7													1.5	*2*	*-1*
		2	Power Plug	10	0.9		0.5													1.4	*2*	*-0.8*
		2	Main IO Plate	14	0.4	0.3														0.7	*1.4*	*0*
C2	Key Module	3	Key PCBA	1									0.3		0.2					0.5	*2.3*	*1.3*
		3	Key Back Cover	5								0.5		0.3						0.8	*1.6*	*0*
		3	Key Front Cover	4	0.5					0.6		0.5	0.5		0.3					2.4	*3.6*	*-1.2*
		3	Key Button	12								0.8		0.9						1.7	*2.2*	*-1.2*
C3	Functional Module	3	Functional PCBA	2														0.3		0.3	*2.2*	*1.6*
		3	Functional Top Cover	8	0.8											0.6		0.2		1.6	*2.2*	*-1*
		3	Functional Base Cover	9												0.5	0.6		0.4	1.5	*2*	*-1*
		3	Functional UI Plate	15							0.7					0.8				1.5	*1.9*	*-1.1*
			S-value		6	1.2	2.6	0.4	0.5	0.6	0.7	1.8	0.8	1.2	0.5	1.9	0.6	0.5	0.4			

Chunk 1 Chunk 2 Chunk 3

Figure 9. A re-engineered QDSM for PLC product design.

The last

two columns of Figure 9 list the values of (S + R) and (S –R), respectively. The (S + R) value indicates the sum of interactions of a component, including the 'supplying' and 'requiring' interactions. The (S – R) indicates the difference between the influencing and influenced interactions of a component; a higher value indicates that the component is dominant. Figure 10 shows the (S – R) plotted against (S + R). This graph is an overall indicator of how interactive/dominant a component is.

Figure 11 shows the hierarchical graph of the design constraint flow derived from the re-engineered QDSM. In this graph, the circles represent components, the oriented lines are design constraints provided by the source components, and the rounded rectangles indicate a set of mutually interactive components, which are integrated as a module. These modules and other components then are further grouped into chunks according to the frequency of their interactions.

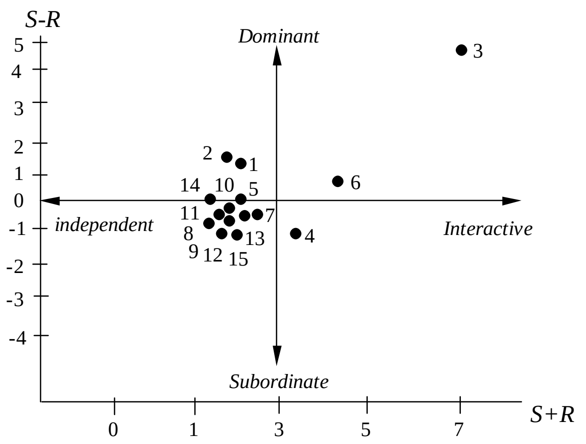

Figure 10. Plotted diagram of component interaction.

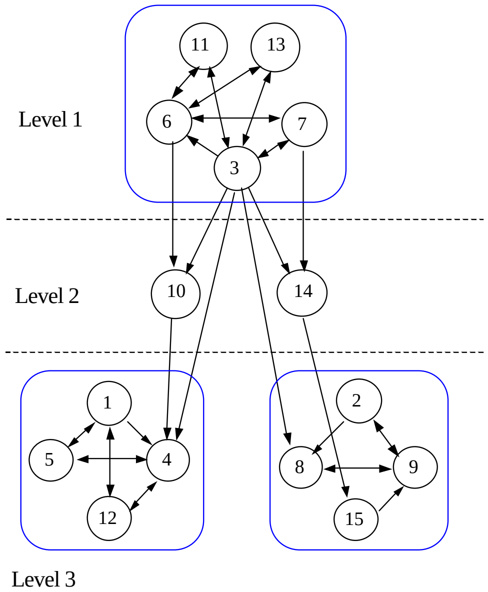

Figure 11. Hierarchical graph of component interaction.

5.6 Identifying the attributes of product components for design strategies

From the above analysis, we only establish the optimal design process for CE and determine the attributes of product components for designing a product family. According to the segmented market requirements and the analysis results of QDSM, we can illustrate the different requirements of components and define the attribute of each component for concurrently developing four variant PLC products. Figure12 shows the individually required components for four variant PLC products in hierarchy graph. Finally, based on

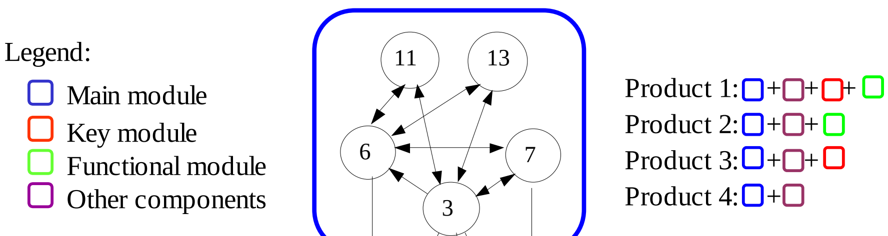

Figure 12. Individual requirements of components for four variant PLC

design variety and cost reduction criteria, we define all attributes of product components in Figure 13.

Chunk	Module	Component	No.	Attribute	Product 1	Product 2	Product 3	Product 4
C1	Main Module	Main System PCBA	3	Platformization	V	V	V	V
		Main Base Cover	7	Variety	V	V	V	V
		Main Top Cover	6	Variety	V	V	V	V
		Led Lens	13	Variety	V	V	V	V
		Power Button	11	Variety	V	V	V	V
		Power Plug	10	Standardization	V	V	V	V
		Main IO Plate	14	Standardization	V	V	V	V
C2	Key Module	Key PCBA	1	Platformization	V		V	
		Key Back Cover	5	Variety	V		V	
		Key Front Cover	4	Variety	V		V	
		Key Button	12	Variety	V		V	
C3	Functional Module	Functional PCBA	2	Platformization	V	V		
		Functional Top Cover	8	Variety	V	V		
		Functional Base Cover	9	Variety	V	V		
		Functional UI Plate	15	Standardization	V	V		

Figure 13. The attribute of each component of the PLC products.

5.7 Developing a product family

According to the above analysis and design strategies, the designers of company A create four variant products to meet two different market needs and design objective. The product proposals are shown in Figure 14.

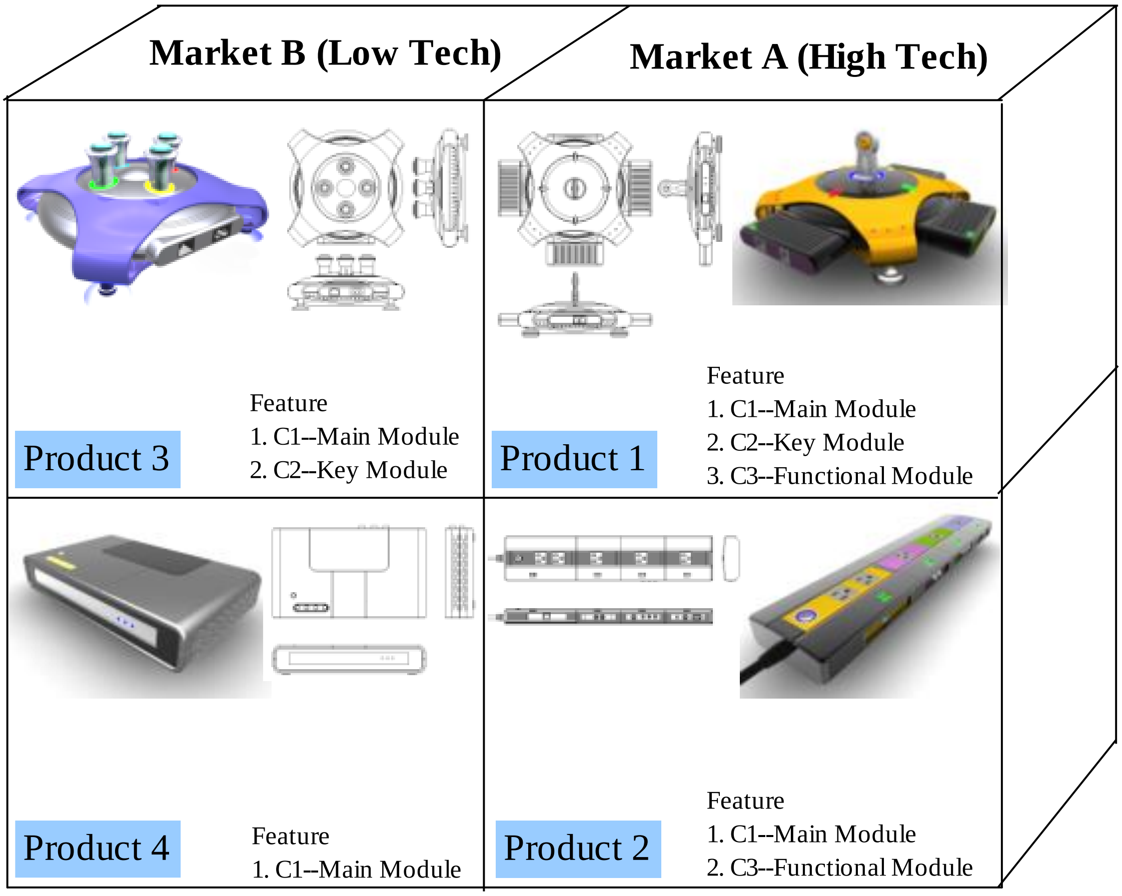

Figure 14. The product proposals for four variant PLC products.

6. Conclusions

This research proposed a new system approach for design configurations that considers the optimal design process and product architecture for product variety based on an existing product. QDSM is a compact representation of the information structure of the design process and product architecture. It is a design configuration method that shows the order in which the design components are performed, and what components need to be verified. Our proposal is an enhanced structural model which can be used to visualize the hierarchical structure of product components and optimize the design process for CE. The proposed methodology is divided into two phases: global planning and local planning. The global planning phase focuses on identifying the coupled components sets and rearranges the uncoupled sets using an improved partitioning algorithm. In the local planning phase, a new tearing algorithm is proposed to decouple the coupled components for an optimal design sequence. The procedures of global planning and local planning are presented to re-engineer a design process and product architecture. The proposed approach helps designers and managers optimize the design configurations and plan better design strategies for designing a product family. A case study in PLC product family design was conducted to demonstrate the feasibility and effectiveness of the proposed design configuration approach.

Characteristics of the proposed approach are summarized as follows:

(1) By applying the fuzzy linguistic variables to quantify the degree of dependency between product components, EDG can be carried out and mapped to the proposed QDSM model for further analysis.

(2) By modeling the global planning method, including the reachable matrix, strongly connected matrix, and hierarchical analysis based on the Boolean algebraic operation, the strongly connected components and hierarchical level of product components can be determined. It is a computable method for grouping strongly connected components and a visual hierarchical structure of product components.

(3) By modeling the local planning method, including the calculations of the information input-degrees (II_i), the information output-degrees (IO_i), and the ratio $R_i = II_i/IO_i$, the optimized design priorities and product architecture for design strategies can also be determined.

(4) By identifying the attributes of product components including modularization, platformization, standardization, and variety based on the analysis results of QDSM, better design strategies for concurrently product family design can be obtained.

Acknowledgements

We would like to thank the R&D division of the ST&T Electronic Company for their assistance in developing the examples presented in this paper. The proposed product 2 in Figure 15 won a Germany 2007 iF Product Design Award (Ko and Li 2007) for the ST&T Electronic Company.

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Paper ID: 101

Comparison of problem model change mechanisms issued from CSP and TRIZ

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Abstract

Different kinds of problem solving methods exist for different kinds of problems. One can recognize two kinds of problems: optimization ones, for which a solution can be found by adjustment of the value of problem parameters; and inventive problems, for which no solution is known. This problem insolvability can be due to the lack of a "good" solving algorithm or to a non adequate problem representation. If so, the problem, as it is modeled has to be reformulated, the model has to be changed, in order to build a representation enabling the resolution of the problem. The article will be focused on the question of problem model change and will compare the mechanisms to change this model for inventive problems from two problem solving theories: dialectical methods and models, on the one hand; and constraint satisfaction problem (CSP), on the other hand.

Keywords: over-constrained problems, dialectical methods, problem model

1. Introduction

TRIZ (Altshuller, 1988) is a theory for inventive problem resolution based on dialectical representation of problems. One among the main approaches of TRIZ for problem resolution is to use contradictions as a way to formulate problems and analyze this contradiction in order to solve the problem. A Generalized model of Contradiction has been proposed (Dubois, et al., 2009) to state inventive problems, whatever the domain of problem could be. A problem, in accordance with the generalized contradiction model, will be characterized by:

- a set of evaluation parameters, which represent the objective of the problem resolution;
- a set of action parameters, which are the resources to resolve the problem, i.e. to satisfy the evaluation parameters;
- a set of relations between the evaluation parameters and the action parameters.

One of the main interests of TRIZ is to propose principles to separate the contradictory properties of a situation, and thus to solve problems.

Constraint satisfaction problem is defined as (Freuder & Wallace, 1992):

- a set of variables;
- for each variable, a finite set of possible values (its domain);
- and a set of constraints restricting the values that the variables can simultaneously take.

The solution of a constraint satisfaction problem is an assignment of a value from its domain to every variable, in such a way that all constraints are satisfied. Such systems, where it is not possible to find valuation satisfying all the constraints, are called over-constrained. There exist different algorithms to look for a solution for CSP and over-constrained CSP.

The objective of this article it to define the kind of model change that is operated by CSP resolution mechanism and also that the TRIZ principles lead to the building a of model that cannot be obtained with CSP algorithms. When a contradiction occurs in a problem, it means that two properties that cannot be satisfied simultaneously in the initial model of problem are identified. To be able to solve such a problem a new model of the problem has to be built in which the two properties can be both satisfied. What kinds of model changes are operated by the TRIZ principles to build such a model? In the article (Rasovska, et al., 2009) the different space browsed by the mechanisms of model change have been defined. In the present article the mechanisms to define and to browse these spaces will be illustrated. In (Rasovska, et al., 2009) different spaces have been defined, as illustrated on figure 1:

- Specific problem space is defined by variables (parameters) of the problem which are limited by their domains Di. The dimension of this space is equal to the number of variables defined by the inventive problem.
- Problem space is also defined by variables (parameters) of the problem but these are not limited by their domains. The dimension of this space is equal to the number of variables too.

- Solution space is defined by all possible variables concerning the system the inventive problem concerns. The dimension of this solution space is so infinite.

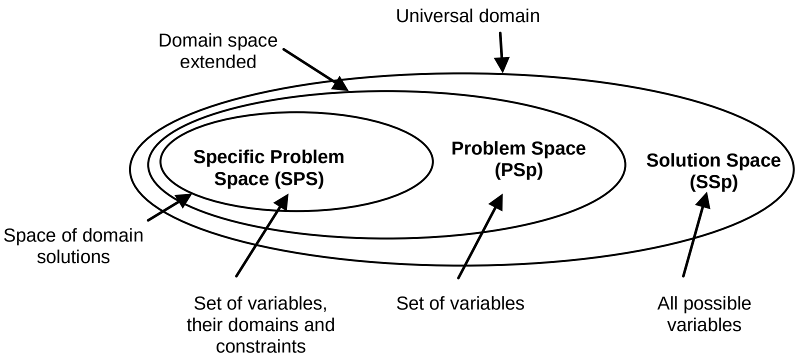

Figure 1. Definition of knowledge spaces

2. Problem statement

Let us consider an electrical circuit breaker. When an overload occurs, the overload creates a force (due to magnets and electrical field) which operates a piece called firing pin. The firing pin opens the circuit by pressing the switch, located in the circuit breaker. In case of high overload, the firing pin, this is a plastic stem, breaks without opening the switch. Components are presented on figure 2.

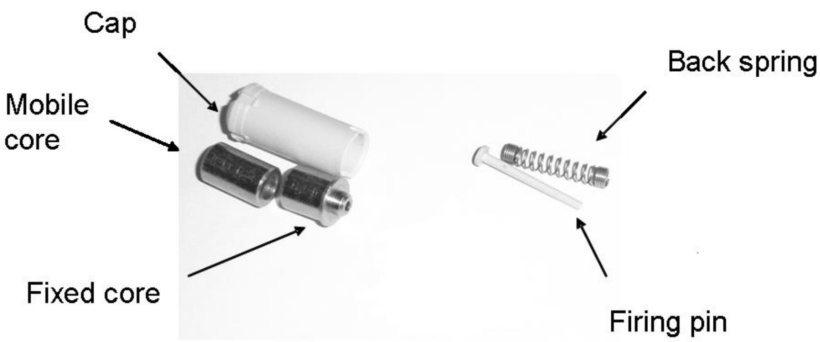

Figure 2. Components of electrical circuit breaker.

The problem has been studied and the main system parameters and their domains have been defined as: x_1: firing pin material (plastic – 1, metal – 0) ; x_2: core internal diameter (high – 1, low – 0) ; x_3: core external diameter (high – 1, low – 0) ; x_4: firing pin diameter (high – 1, low – 0) ; x_5: spring straightness (high – 2, medium – 1, low – 0) ; y_1: circuit breaker disrepair (satisfied – 1, unsatisfied – 0) ; y_2: circuit breaker reusability (satisfied – 1, unsatisfied – 0) ; y_3: spring core mounting (satisfied – 1, unsatisfied – 0) ; y_4:

firing pin bobbin mounting (satisfied – 1, unsatisfied – 0) ; y_5: normal mode release (satisfied – 1, unsatisfied – 0) ; y_6: firing pin initial position return (satisfied – 1, unsatisfied – 0). In this definition of the problem the x_i are the action parameters whereas the y_i are the evaluation ones. The system behavior was modeled by Design of Experiments and it is shown in table 1. The objectives that have been established to build the DoE are:

- the satisfaction of at least one evaluation parameter in each experiment;
- each of the action parameters has at least one time each of its possible values;
- to minimize the number of experiments.

Even if the assumption is not totally consistent, the action parameters have been considered independent in the limits of their defined domains.

Table 1. DoE for the circuit breaker

	x1	x2	x3	x4	x5	y1	y2	y3	y4	y5	y6
e1	1	1	0	0	1	1	0	1	1	1	1
e2	0	1	1	1	1	0	1	0	0	1	1
e3	1	0	1	0	0	1	0	1	0	0	0
e4	1	1	0	0	0	1	1	1	1	0	0
e5	1	0	1	0	1	1	0	1	0	1	1
e6	0	1	0	1	2	0	1	0	1	1	1
e7	1	0	1	1	0	1	0	1	0	0	0
e8	1	0	0	0	1	1	0	0	1	1	1
e9	0	1	0	0	2	0	1	0	1	1	1

First evidence is that no solution can be found in the defined DoE, as no experiment enables the satisfaction of all the evaluation parameters. This problem can be recognised as an inventive one, or an over-constrained one.

3. Resolution by means of over-constrained CSP

3.1 Application of the resolution mechanisms

One can consider each experiment of the previously defined DoE as a constraint, for example:

$$C_1: [1, 1, 0, 0, 1] \Rightarrow [1, 0, 1, 1, 1, 1] \quad (1)$$

This leads the definition of nine constraints. Then the search for a solution is defined by an optimisation function (Barták, 1999), defined in Equation (2).

$$Maximize\ \Sigma y_i \square\ Optimal\ Solution = [1, 1, 1, 1, 1, 1] \quad (2)$$

The solution to Equation (2) cannot be found in the initial Specific Problem Space, it is thus necessary to refer to methods for over-constrained problems. One of the well known methods is the hierarchy of constraints (Borning, et al., 1992). It means that the satisfaction of the evaluation parameters will be relaxed according to a defined hierarchy of importance. For example, one can define that the satisfaction of the parameters y_1, y_5 and y_6 are required, the satisfaction of the parameters $y_3$and y_4 are strong constraints and that the satisfaction of y_2 is a weak constraint. Then the solution will be searched by satisfying first the required constraints, then the strong ones and at least, if possible the weak ones.

The experiments C_1, C_5 and C_8 satisfy the required constraints, the experiment C_1 satisfy also the strong constraints, but no solution can be found to satisfy all the constraints. Then, according to this algorithm, and to this hierarchy, the solution is the experiment C_1.

3.2 Analysis of the resolution impact on the solution space

The comparison of initial domain and domain of solution lead to the following conclusions:

- The set of parameters remains the same
- The considered constraints are different, as the constraint y2=1 is not considered anymore.

The intensification of this mechanism lead to a space defined by the initial set of parameters without any constraints. This means that solving principles of constraint hierarchies and PCSP start from initial problem defined by the specific problem space 1 (SPS1) and extend this space by relaxing certain constraints and variables in order to define a new specific problem space SPS2. This space is larger than SPS1 but always covered by respective Problem Space characterized by the set of variables describing the initial problem (see figure 3).

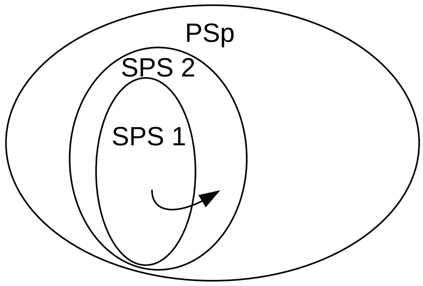

Figure 3. Model change mechanism of optimization methods

4. Resolution by means of dialectical approach

To solve an inventive problem with TRIZ-based methods, it is first necessary to formulate the problem in an adequate form, i.e. to identify the contradictions. Then, the application of resolution mechanisms could be applied

4.1 Identification of contradictions

In classical TRIZ approach (Altshuller, 1988), there exist different kinds of contradictions (administrative, technical and physical ones). Only the technical and physical contradictions are helpful as they propose of formulation of the problem enabling the application of resolution mechanisms. In (Khomenko, et al., 2007) a system of contradiction has been proposed to clarify the role of each element of the contradiction and also to clarify the link between technical and physical contradictions. In (Dubois, et al., 2009) a generalization of this concept of system of contradiction is defined as Generalized System of Contradiction and is presented on figure 4.

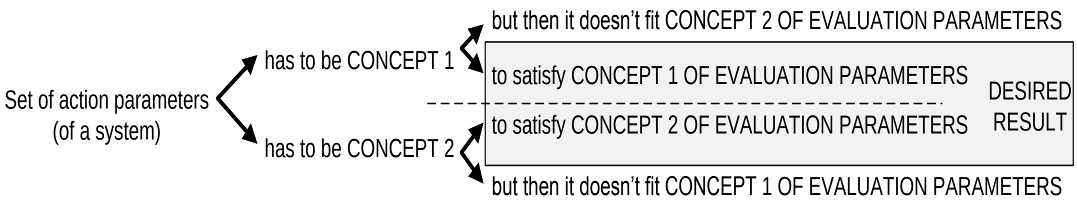

Figure 4. Generalized System of Contradictions

The analysis of table 1 enables the identification of several Generalized Systems of Contradictions; one of these GSC is presented on figure 5.

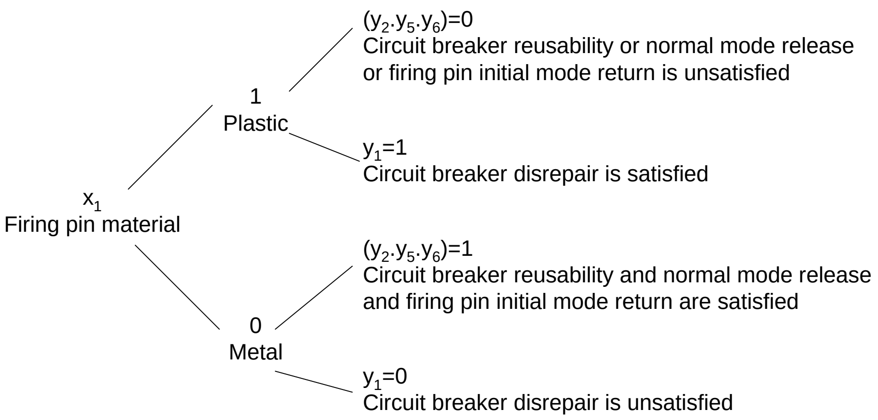

Figure 5. Generalized System of Contradictions for the example

The elicited contradiction can be reformulated this way: the firing pin material has to be plastic in order disable the disrepair of the circuit breaker; but the firing pin diameter has to be metallic in order to satisfy simultaneously the reusability of the circuit breaker, the normal mode release and the return in initial position of the firing pin.

4.2 Application of the resolution mechanisms

The GSC identified on figure 5 tackles the problem linked with the firing pin diameter which has to be high and small in the same time. One of the well known TRIZ mechanisms to solve problems is the separation of contradictory properties in space. Could the contradictory properties be separated in space? Actually the firing pin has to be metallic only from the front of the fixed core, where it begins to deform. And this fixed core is a metallic part. Then a new system of contradictions could be formulated: the fixed core has to become the firing pin as it is a metallic part, but the fixed core cannot be the firing pin as it is fixed. This contradiction can be solved easily through the application of another TRIZ resolution mechanism, the segmentation. One part of the fixed core has to become mobile. The inherent concept of solution is presented on figure 6.

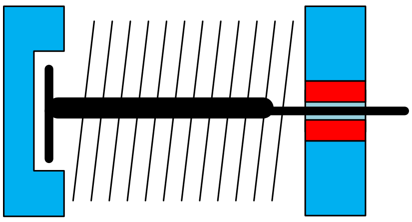

Figure 6. Concept of solution for the formulated problem

4.3 Analysis of the resolution impact on the solution space

If comparing the final concept of solution with initial model of problem, one can recognized that one parameter has been changed and a new one has been introduced. The parameter x_4, firing pin diameter has been splitted into two: the diameter of the upper part of the firing pin and the diameter of the low part of the firing pin. The parameter x_6, fixed core segmentation has been introduced. Thus the new solution corresponds to a new set of constraints which enables a new line in the initial DoE, as presented in table 2.

Table 2. Representation of the concept of solution

x1	x2	x3	x4a	x4b	x5	x6	y1	y2	y3	y4	y5	y6
1	1	0	1	0	2	1	1	1	1	1	1	1

If analyzing the kind of transformation achieved by these resolution mechanisms and the impact on the browsed solution space, one can consider that a new specific problem space is built, with new parameters and new constraints. And for this new SPS, a new Problems Space is defined, as illustrated on figure 7.

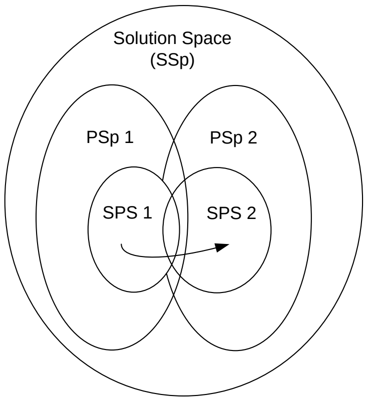

Figure 7. Model change mechanism of inventive methods

5. Conclusion

In this article the way different kind of spaces are defined by the resolution mechanisms from optimization methods (CSP ones) and inventive methods (TRIZ based ones) are illustrated. It is both showed the nature of the browsed spaces and also the way the model changes are realized.

The consideration of the complementary aspects of both families of solving principles is of great interest and it put the emphasis on the necessity to define a unified model that permits to shift easily from an optimisation approach to an inventive one.

Each inventive method involves one or more operators of model changes. At the first time, every operator of model change and its using should be described in more details. The mutual enrichment of optimization and inventive methods will support a precise description of the inventive principles involving proposition of algorithms. At the second time, the efficiency of operators should be measured in order to prove a progress in the problem resolution. Later the whole process of inventive problem solving could be described as a succession of single model changes.

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Paper ID: 107

Appling TRIZ Contradiction Matrix on Designing Safety Device for Brake Lights

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Abstract

The modern transportation system is very important to the overall economic development of a country. To ensure a fast, safe, and convenient transportation system, the governments of all countries as well as the motor companies are making great efforts to prevent traffic accidents. They also make a great of improvements on the safety facilities of vehicles to decrease the casualties of traffic accidents. This study uses a model of TRIZ contradictory matrix solving problems to obtain the following IPs (Inventive Principles): IP15 (Dynamics), IP10 (Preliminary Action), IP28 (Mechanics Substitution), IP11 (Beforehand Cushioning), IP5 (Merging), IP32 (Color Changes). These IPs was carried on the design of the security patent. By this systematization innovation method, a continual change demonstration area style of LED lighting device, which merged with a brake pedal sensor, was proposed. This new brake system enables the vehicle in the back to detect the rate of deceleration of the front vehicle and to judge

the appropriate rate of deceleration. Meanwhile, when a driver steps on the brake for 3 to 4 seconds, the sensor will make the sound connect with a horn. This device provides a protection function for the vehicle both in the back and in the front. The contribution of this device is to improve the safety of vehicle.

Keywords: continual change demonstration area style of LED brake lighting device, contradiction matrix, invention principle, vehicle safety device

1. Introduction

1.1 Research Motivation

Since the economy develops rapidly, cars have become one of main transportations in daily life and it has also become a necessity product at present. However, while the numbers of cars rapidly increase, the numbers of traffic accidents and the casualties of traffic accidents speedily increase. Traffic accident is top ten leading causes of death and it has caused serious family burden and nation productivity damage. Small cars are the highest usage in daily life and they also cause the highest casualties of traffic accidents. Therefore, this research targets on safety device of small cars and plans to provide improvement.

1.2 Research Aims

This research applies TRIZ Contradiction Matrix to a safety device for brake lights and it also provides the outset concept for developing patents.

2. Literature Review

2.1 Vehicle Safety

Since the upgrade and development in the vehicle industry, the functions of vehicles are improved gradually. However, it also leads to the tragedy of car accidents that causes a great amount of social resource waste. Therefore, it is a very important issue regarding to how to effectively reduce the loss of lives and property because of car accidents. Chai (2004) reveals that the purpose of active vehicle management is to avoid the dangerous and damage derives from traffic accidents to people lives and property, and social environment. It also makes sure the safety of driving. As to the vehicles used on the different roads and environments, they should reach the functions that be demanded. To ensure vehicles confront with the basic safety protection, it needs to be more checked on seriously.

The institution of transportation in Taiwan also recognizes the laws of safety is insufficient and the importance of the driving safety. Therefore, “the Safety Examination and Certificate System for the Style of Vehilces” for the large-size automobiles was promoted on Octomber 26th, 1996 and it was carried on to other style vehicles after incremental years. (Tseng, 2003).

2.2 Third Brake Lights

The United States passed the regulation in 1986 and ordered that all cars should be installed third brake lights after then. Farmer’s (1996) research analyzed the records of compensation amount for car accident insurances and it was approved that the numbers of rear-end accidents were reduced 5% since this regulation was effected after five years. Bar-Gera and Schechtman (2005), Mourant and Rockwell (1972) and Sivak et al.(1981) researches indicate that rear-end accidents will be remarkably reduced after a car install third brake light that helps to enhance detectable signals. Therefore, all vehicles are installed third brake lights to enhance the detectable brake signals. Third brake light also provides a great view because it is installed in a higher place. It is believed that installing third brake light can effectively make a car in the back brake earlier and to avoid rear-end accidents.

Huang（2006）reveals that the appropriate place to install third brake light is on the rear window below and the light is square and red when he evaluates the effectiveness of third brake light in a car. He also suggests that third brake light put in the centerline of the rear window. His suggestion is same as installation places that in America and in Taiwan.

2.3 Theory of Inventive Problem Solving (TRIZ)

2.3.1 TRIZ (Theory of Inventive Problem Solving)

Theory of Inventive Problem Solving (TIPS) means an inventive problem-solving method. TRIZ is one of problem-solving methods. It focuses on the problems and can be used to analyze problems and find contradictions and then offer different solutions. The contradictions include physical and technology contradictions. This theory includes a series of innovative methods. Contradiction Matrix (CM) and 40 Inventive Principles (IPs) which Altshuler developed are the tools of frequent use.

Cheng (2005) states that engineers frequently encounter system contradiction problems while solving engineering problems. In other words, when they try to improve one of engineering characters on system, it causes other engineering characters worse. Using TRIZ can efficiently help engineers to solve engineering system contradiction problems. To solve these kinds of problems, it needs to find the contradiction characters in the system first and then responds the contradiction characters to the characteristics of engineering parameters that Altshuller proposes. Finally, using contradiction matrix to find relevant innovative principles to solve the problem (see Figures 1 and 2).

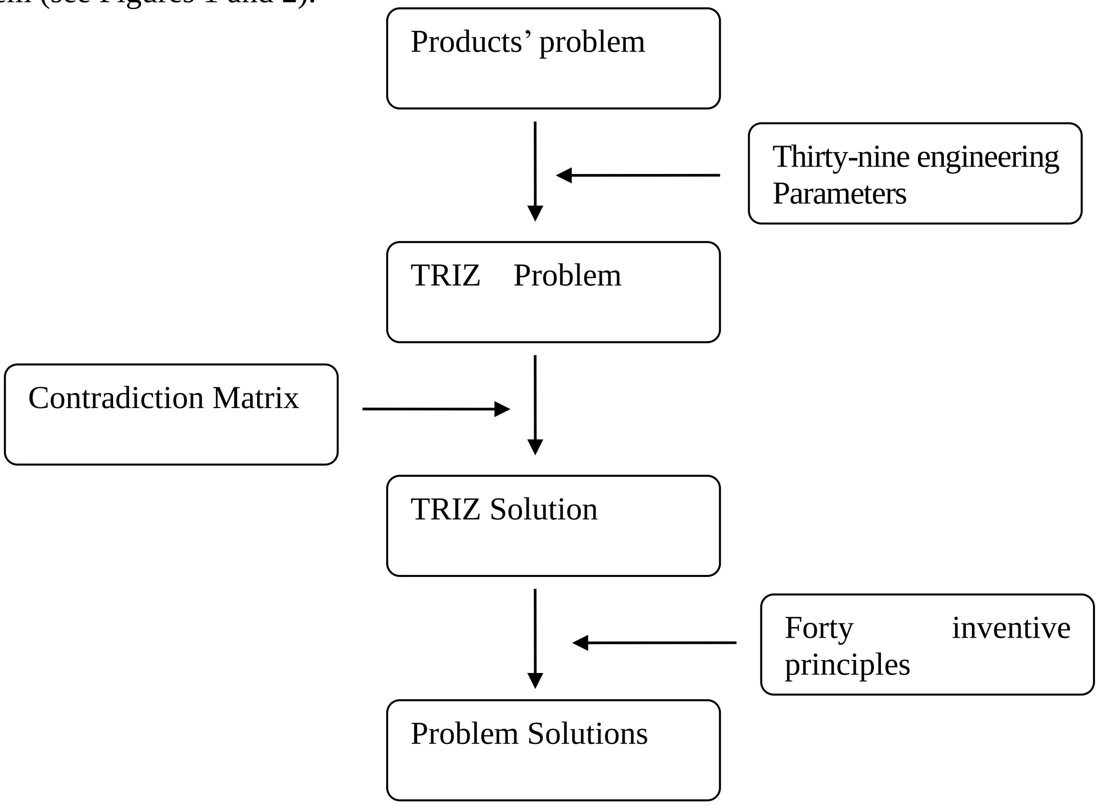

Figure 1 The model of TRIZ Problem-Solving (Cheng, 2005)

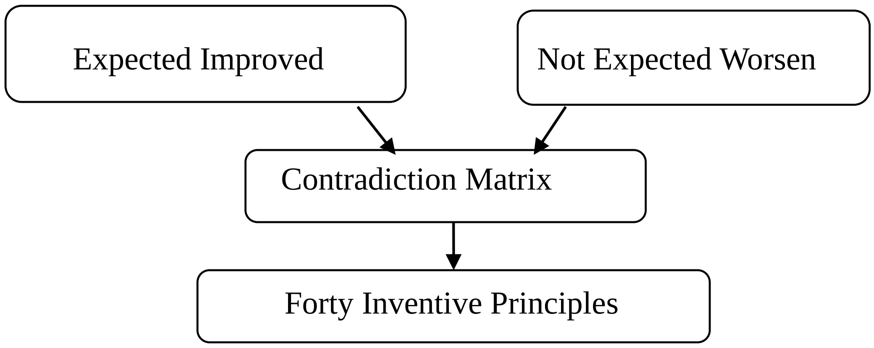

Figure 2 The model of TRIZ Contradiction Matrix problem-solving (Cheng, 2005).

2.3.2 Thirty-Nine Engineering Parameters

Altshuller concludes a list of 39 frequently occurring systematic characteristics in technology contradictions. He terms them Engineering Parameters (EPs) and uses them to describe contradictions and problems. The purpose use of EPs is transform real engineering design contradictions into general or standard technology contradictions (Wu, 2007).

2.3.3 Forty Inventive Principles

Wu (2007) states that there are 40 Inventive Principles (IPs) used to solve similar contradiction problems repeatedly in different time periods, backgrounds, and fields. Therefore, identify EPs that worsen and EPs that improved and then find the corresponding EP numbers and get matrix elements that will give the numbers of the recommend inventive principles.

2.3.4 Contradiction Matrix

Altshuller indicates that inventors frequently confront with ”Technology Contradiction” and ”Physical Contradiction” problems when they face the problems in engineering . ”Technology Contradiction” means when a parameter is improved, a parameter will be worsening in a system. For example, motor power versus oil usage of car, weight versus strength and so on. ”Physical Contradiction” means the same parameter that has two opposite characters. For example, cold and hot, long and short, soft and hard, and so on (Hua, 2006).

Contradiction Matrix (CM) is a 40-row multiple 40-column matrix. The procedure for its application is as follows: First, identify which EP worsens a product or process and which improves it among 39 engineering parameters. Then, find the corresponding EP numbers in the row and column. Finally, find the intersecting matrix elements in the corresponding row and column. These elements give the numbers of the recommend. For example, Figure 3 shows that the EP that improves is 2 (Weight of stationary object), while the one that worsens is 39 (Productivity). So, find the intersecting matrix element in corresponding row 2 and column 39. This gives 1, 28, 15, and 35, which are the numbers of the recommended IPs.

Parameter that Worsen / Parameter that Improve	1.Weight of moving object	2.Weight of stationary object	……	39.Productivity
1.Weight of moving object				35,3,24,37
2.Weight of stationary object				1,28,15,35
⋮			⋮	
39.Productivity	35,26,24,37	28,27,15,3		

Suggestive Inventive

Figure 3 Contradiction Matrix

3. The Innovative Concept for Third Brake Lights Safety Device

3.1 The Invention Principles Selection for Third Brake Lights

The definitions of third brake light safety demand problems are as follows:

Figure 4 shows a general type of brake light. When the driver steps on the brake, the third brake light will keep shine and it cannot provide the rear car the degree of brake. It causes accidents easily when the driver on the mountain roads or on the high speed driving because the driver cannot keep the appropriate distance or cannot concentrate on driving.

How the driver in front car knows the driver in the rear car drives too fast or don’t keep appropriate distance and then steps brake pedal deeply?

How the driver knows the third brake light in the back window is damage or not?

The third brake light is bright enough that can give the rear car indication

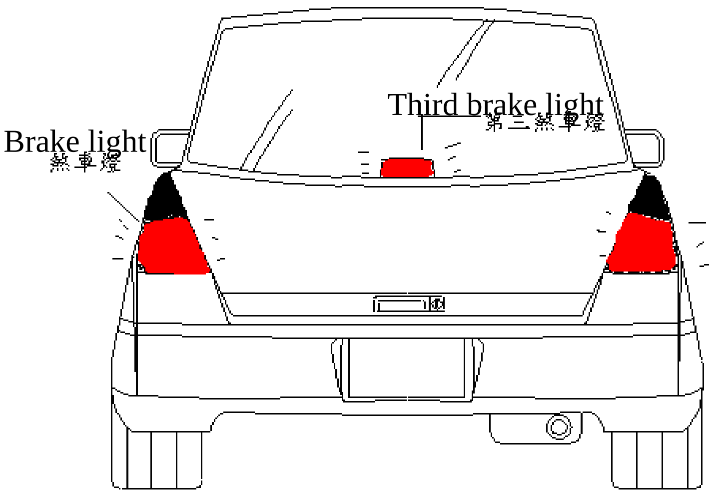

Figure 4 A general type of brake light

According to the above description, the parameters that expected to improve and not expected worsen are listed as follows:

(1) Parameters that Improve

a. EP27 Reliability (enhance third brake light functions)

b. EP37 Control of the degree of complication (used to control the condition of third brake lights)

c. EP18 Brightness（increase brightness）

(2) Not Expected Parameters that Worsen

a. EP36 Degree of complication on Installation (keep the structure simply)

b. EP13 Object steadiness (maintain the steadiness of third brake light)

c. EP33 Usage convenience (won't lower the usage convenience)

According to the above parameter characteristics and references on appendix, it forms a contradiction matrix (see Table 1).

Table 1 Contradiction matrix for refined third brake light

Parameter that Improve \ Parameter that Worsen		EP36 Control of the degree of complication	EP13 Object steadiness	EP33 Usage convenience
EP 27	Reliability	13,35,1		27,17,40
EP 37	Control of the degree of complication	15,10,37,28	11,22,39, 30	2 ,5
EP 18	Brightness	6,32,13	32,3,27	28,26,19

Table 2 shows the principles selected for designing third brake lights. Using Contradiction Matrix helps to get the innovative principles according to the demands for refining the third brake light.

Table 2 The principles selected for designing third brake lights

Demands for Improvement	Designing Principles	Responsive Solutions
Reliability（appearance）	IP1 Partition IP17 Moving to new space	Use multiple combinations and easily install and disassemble
Control of the degree of complication(enhance third brake light functions）	IP15 Dynamics IP10 Preliminary action IP28 Mechanics substitution IP11 Beforehand cushioning IP5 Merging	1. use useful object to merge third brake light such as sensor and make the third brake light show dynamic effect 2. use beforehand cushioning to remedy potential dangerous
Brightness(increase brightness）	IP32 Color changes	Use pigment or fluorescence elements to improve the visibility

The Concepts of Designing are as follows:

(1) Reliability (appearance): Apply the recommend principles, IP1 and IP17. Enlarge third brake light that enables a driver at the back make a quickly reaction under the condition that will not influence the driver to observe the angles at the back.

(2) Control of the degree of complication (enhance third brake light functions): Apply the recommend principles, IP15, IP10, IP28, IP11 and IP5, the concepts of designing in this research are as follows:

a. IP15: Third brake light is not keeping shine. It will be dynamic.

b. IP10: Place an object (sensor) that can be reacted at the most convenient time and place.

c. IP28: Merge third brake light, sensor, and brake pedal, and connect with dashboard to form a system.

d. IP11: Use brake horn to warn the cars both in the front and in the back when stepping on the brake sharply.

e. IP5：Merge above concepts.

(3) Brightness (increase brightness): Apply the recommend principles, IP32. Use LED to increase brightness.

3.2 The innovation conception of the third brake lights

The procedures of the innovation in this research are given in Figure 5. When a driver steps on the brake, the sensor and car signal control system will work, and brake lights and the volume LED third brake light will shine. Meanwhile, when a driver steps on the brake sharply in high speed for 3 to 4 seconds, the sensor will convey dashboard and horn and then make the sound.

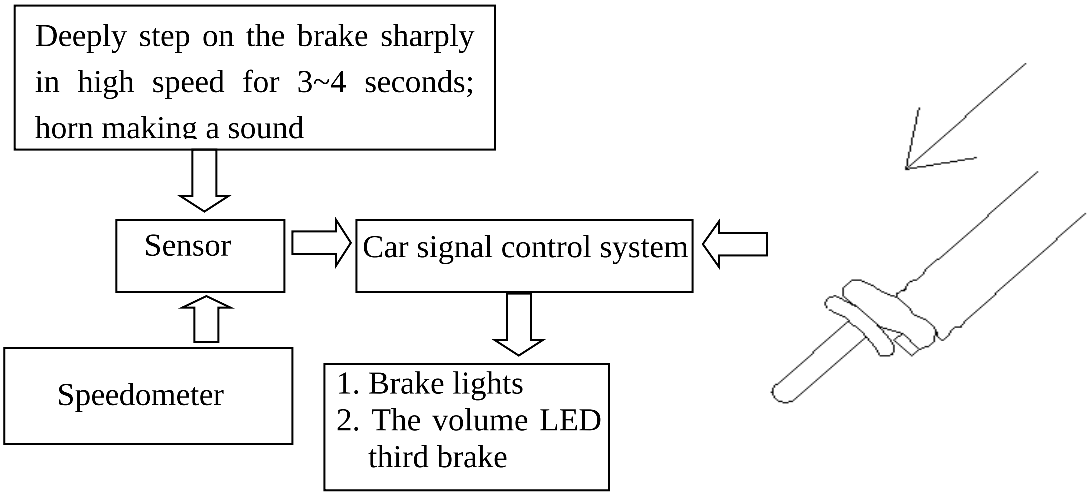

Figure 5 The procedures of the new style brake

The designing concepts in this research consist of the main power circuit, brake pedal sensor, volume LED lighting device and warning modules.

Brake pedal sensor device will be merged with brake pedal. Third brake light will make a response according to the degree of depth a driver stepping on brake pedal. Third brake light will all shine when a driver steps on the brake at the bottom.

Brake pedal sensor will be connected with a horn. The horn will ring to warn the vehicles in the front to keep out of the way when a driver brakes sharply in high speed for 3 to 4 seconds.

Volume LED is placed on the two sides of the original third brake light. It is arranged in an increment volume style. When a driver steps deeply on the brake pedal, it is easily recognized by a driver in the back. The reasons for choosing LED are as follows: LED is belongs to luminescence that has low power usage; its components have long life; it has no warm-up time; it reacts quickly and so on. In addition, the volume is small and it is easily to match with and apply to the units that needs to be the smallest and arrayal.

Power circuit will be connected with brake pedal sensor device, dashboard, volume third brake lighting device and horn.

This research uses “A continual third brake light safety device”. Figure 6 shows the connecting picture of a sensor. Volume LED lighting device is placed on the two sides of third brake light and will be connected with brake pedal sensor. It will shines according to the degree of depth a driver stepping on brake pedal. The structure of this device is just like a computer installs a microphone. The more deep a driver steps on the brake pedal, the more increment shine on two sides of LED lighting device. When a driver brakes sharply in high speed for 3 to 4 seconds, the sensor will be connected with a horn and make a sound. Meanwhile, the conditions of third brake light will show on the dashboard that a driver can know well.

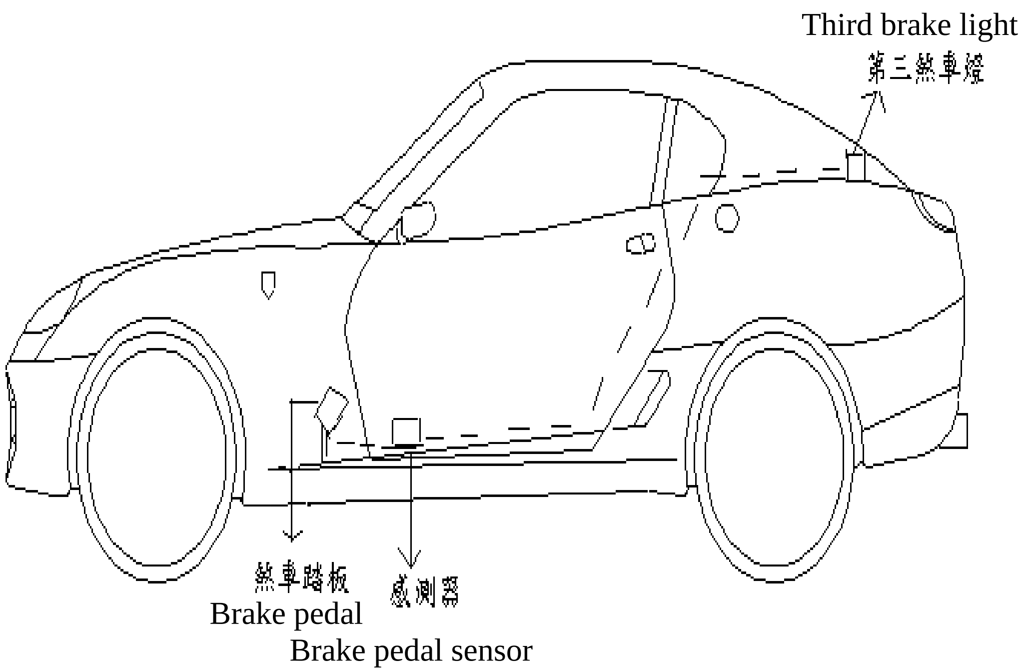

Figure 6 The connecting picture of a sensor

“A continual third brake light safety device” is shown as figure 7. Install volume LED which is 12 voltages each on the two sides of the original third brake light. Figure 8 shows that the degree of brake will be response on volume LED lighting device through a sensor. When the degree of brake is incrementally, volume LED lighting device will incrementally shine on the two sides. Volume LED lighting device will all shine on the two sides when stepping on the brake at the bottom.

Figure 9 shows that the sensor circuit in “A continual third brake light safety device” will be connected with Dashboard and drivers can easily know well the demonstration condition of the third brake light. Meanwhile, the sensor circuit makes the sound connect with a horn to warn the cars both in the front and in the back when a driver deeply step on the brake sharply in high speed for 3 to 4 seconds.

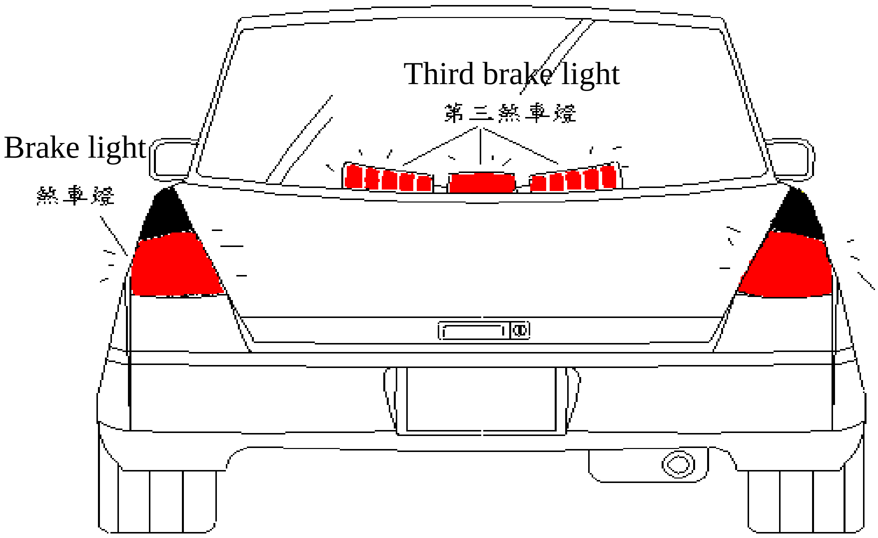

Figure 7　A continual style third brake light

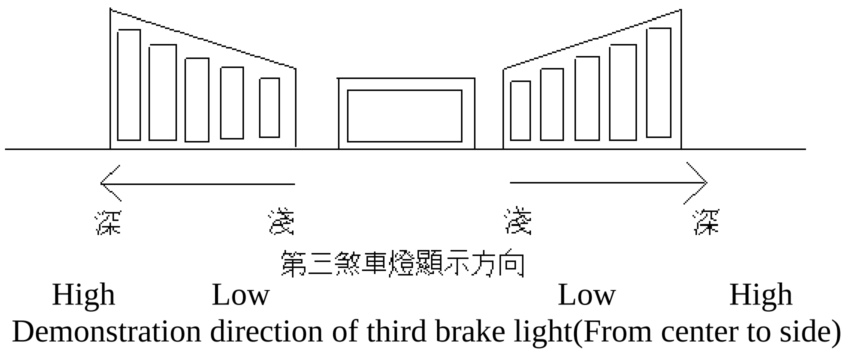

Figure 8 The demonstration of Volume LED lighting devise

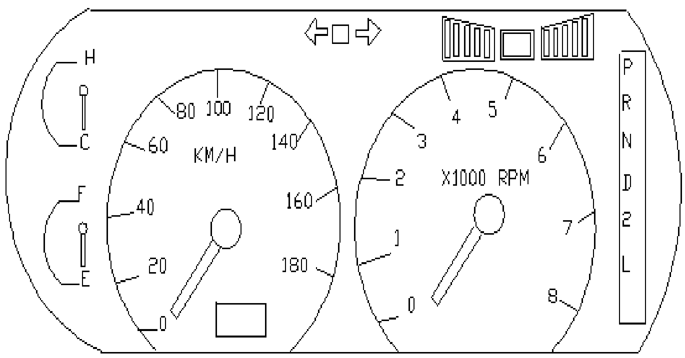

Figure 9 Dashboard monitor

4. Conclusions and Suggestions

This research provides an innovative concept that applied to refine third brake lights. It proposes a continual style third brake light safety device which focusing on the degree of brake. The degree of brake will be displayed on volume LED and then observed on the Dashboard. Meanwhile, when a driver steps on the brake for 3 to 4 seconds, the sensor will make the sound connect with a horn. This device provides a protection function for the vehicle both in the back and in the front. The contribution of this device is to improve the safety of vehicle.

The systematic method of TRIZ can provide a designing idea and efficiently solve problems. It also provides the researchers who are in development and research areas a useful designing device.

This research suggests that researchers can use TRIZ to solve systematic contradiction problems in engineering. Using TRIZ can gain possible solving principles but still need to consider both feasibility and cost.

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Paper ID: 108

Designing a Rescue Alarm Device for Vehicle Based on TRIZ Su-Field Analysis

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Abstract

There have been many reports from around the world of people dying inside overheated, airtight vehicles. If people are rescued early from vehicle, some of the tragedies could almost certainly have been avoided. In this study, a new feasible problem-solving process based on TRIZ Su-Field analysis model is constructed. There are two substances. Those trapped in the vehicle represent an objective substance termed S1 and the airtight vehicle represents a tool substance termed S2. A Mechanical filed, imprisoning people in vehicle, is termed M1. S2 is harmful to S1. Therefore, add the negative Mechanical filed termed M2 on S2 to help release S1 by opening the door of vehicle to avoid people imprison by vehicle. M2 is induced by sensor S3. S1 induces sensor S3 to turn on a rescue alarm device S4 to notify related rescuers for rescuing people from the vehicles in time. A set of innovative rescue alarm device designs for vehicles that are going through a systematic application process is proposed with patents and awards for them listed.

Keywords: airtight vehicle, induced rescue alarm device, patents and awards, people tied, Su-Field analysis

1. Introduction

1.1 Aims and Motivation of the Research

With the rapid pace of economic development, the automobile has become a major form of everyday transportation as well as a universal necessity. However, the steep increase in the numbers of cars has also brought a marked rise in traffic accidents and in the casualty toll. Traffic accidents figure in the top ten leading causes of death and are a cause of much personal and social woe and national economic damage.

Automobile tragedies are generally the result of careless behaviour. There have been, for instance, many cases around the world of young children being left locked as if trapped in hot airtight vehicles with fatal results. Newspapers in Taiwan report that between 1995 and 2005 designated vehicles taking children to and from kindergartens featured on average in 4.4% of annual traffic accident statistics. The average percentage for serious injury and death among children was 4.5 annually. Between 1992 and 1999, there was a series of 10 serious kindergarten vehicle accidents that took twenty-seven lives and the average of deaths and light injuries per accident was 2.7 and 13.3, respectively. A number of young children suffered asphyxia and dehydration in kindergarten vehicle accidents in April 1996 in Pintung, and in May 2004 and September 2005 in Taichung. Similar cases, a seven-year old boy and a five-year old girl trapped in the family car, occurred in 1999 in Miaoli County. In November 2006 in Hsinchu, a two-year old child walking near a kindergarten bus, out of the driver's line of sight, was killed when the bus crashed. In 2003 in the United States, there were many reported asphyxia deaths among young children left alone in overheated cars. In 2007 in Guangdong Province, China, there were four school vehicle asphyxia fatalities, and 2007 in Fukuoka, Japan, a two-year old child died from the same cause.

In the past in Taiwan, when kindergarten vehicle tragedies of this kind happened, the people found at fault were punished, some imprisoned, a number of kindergarten and day-care establishments were closed down, and sums of compensation between NT$8,350,000 and NT$9,200,000 changed hands.

The fact that each year in 1996, 2004 and 2005 three children died from asphyxia and dehydration in kindergarten vehicle accidents highlights the pressing need for providing the vehicles with appropriate security devices. The aim of this research, therefore, is to use a TRIZ Su-Field analysis model to design such devices and also to provide the basic concepts for developing patents.

As can been from the above discussion, there are many big unanswered questions concerning safety and kindergarten vehicles that must be faced and answered. It is very important to prevent such things happening again. There have been only few studies in this area of research. Therefore, the target here is the development of appropriate patents and improved rescue alarm devices.

2. Literature Review

2.1 Vehicle Safety

The automobile industry has seen constant upgrading and development, with overall enhancement in vehicle functions. However, there has also been a tragic increase in automobile accidents, making the search for effective reductions an issue of vital concern. Chai (2004) states that the goal of active vehicle management is to minimize the danger and damage that derive from automobile accidents and the consequent loss life and limb and waste of social resources. The aim also is to make driving safer on different roads and in different environments, while providing vehicles with the functions that users desire. The safety of vehicles needs to be checked more frequently and seriously.

The Taiwan Government Institution of Transportation recognizes the importance of safe driving and that the laws governing it need strengthening. For this reason, “the Safety Inspection and Certification System for Vehicles by type” for large-size automobiles was introduced on October 26th, 1996 and extended to other Vehicle types in succeeding years (Tseng, 2003).

2.2 TRIZ Su-field analysis model

Su-field analysis is a basic concept used to symbolize a technical system and identify its completeness and effectiveness. Recognized as one of the most valuable contributions of TRIZ, su-field analysis is able to not only model a system in a simple graphical approach and identify problems, but also offer standard solutions to improve the system.

According to TRIZ, the rationale of creating a su-field model is to set up a system whose ultimate objective to achieve a function. This normally consists of two substances and a field, as shown in Figure 1. The term S1 represents an object that needs to be manipulated and the term S2 a tool to act upon S1. Both substances can be as simple as a single element or as complicated as a big system with many components, each of which can also be explained by individual su-field models. The field is the needed energy to enable the interaction between the substances. The states of substances can be typical physical forms (e.g., gas, liquid and solid), interim or composite forms (e.g., aerosol, power, porous). Likewise, the field can refer to a broad range of energy, including mechanism, chemistry, physics, acoustics, optics and radiations.

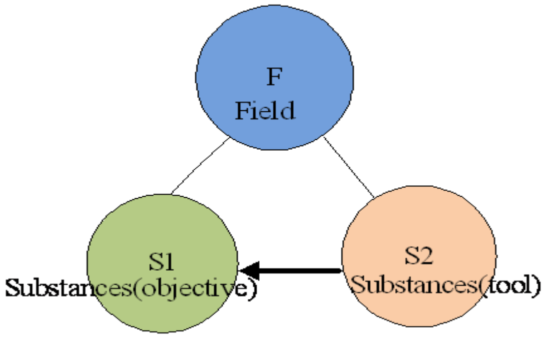

Figure 1 Basic Substances-Field Triangle Model

Genrich Altshuller and his colleagues, the creators of TRIZ, graphically represent a su-field model as a triangle. This is a simple and ingenious way to explain a technical system. On the assumption that the field is generated by a hidden substance, the triangle can be simplified into a dumbbell shape with the field indicated above the arrow and the relationship indicated beneath the arrow, as shown in Figure 2. There are five main types of relationship between the substances: useful impact, harmful impact, excessive impact, insufficient impact and transformation. Among them, useful and harmful interactions are the most common relationships.

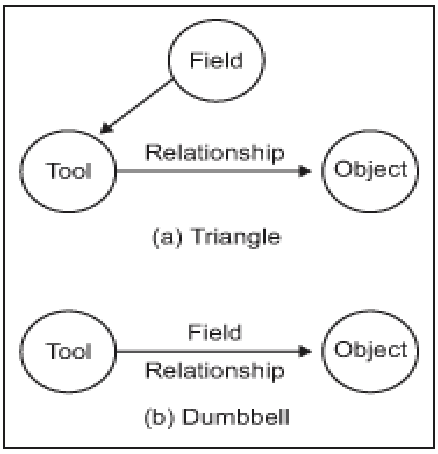

Figure 2 Basic Triangle and Dumbbell Substances-Field Model(Mao,et al 2007)

The su-field model is a fast and simple analytic tool for identifying problems in a system and providing insights that help with the evolution of the system. Once a model is created, su-field analysis can first tell if any of the three elements of the model is missing or if there are any undesired effects in the system. Then, it can indicate the direction for improving of the system. A complex system can be modeled using multiple connected su-field models. In general, there are four types of basic su-field models: 1) an effective complete system, 2) an incomplete system that requires completion or a new system, 3) a complete system that requires improvement to create or enhance certain useful impact and 4) a complete system that requires the elimination of some harmful or excessive impact. (Terninko, 2000; Mao,et al 2007)

3. Innovative Concept for a Rescue Alarm Device in a Vehicle

3.1 Su-field analysis

3.1.1 Case analysis of problems

Four cases are provided and their problems analyzed as follows:

1. Children suffered asphyxia and dehydration in kindergarten buses in April 1996 in Pintung, and in May 2004 and September 2005 in Taichung (all Taiwan). **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated, and the temperature inside was too high.**
2. Four children suffered asphyxia on school buses in 2007 in Guangdong Province, China. **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated and the temperature inside was too high.**
3. In 2003 in the United States, numbers of children left alone in cars died from asphyxia because of the high temperature inside. **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated and the temperature inside was too high.**
4. In 2007 in Fukuoka, Japan, a two-year old child on a bus suffered asphyxia. **Problems: The presence of the child was not noticed in time, the vehicle was not ventilated and the temperature inside was too high.**

3.1.2 Demand function

There are three demand functions, as follows:

1. **The presence of the children was not noticed in time. Demand function:** Need to find someone still in the vehicle in time
2. **The vehicle is not ventilated. Demand function:** Need to ventilate
3. **The temperature inside is too high. Demand function:** Need to lower the temperature

3.1.3 Model of the problem

If people are rescued early from vehicle, some of the tragedies could almost certainly have been avoided. As Figure 3 shows, the airtight vehicle, the tool substance, is represented by S2 and those trapped in the vehicle, the objective substance, are represented by S1. If S1 is imprisoned in S2, S1 might suffer asphyxia and dehydration. The Mechanical filed, imprisoning people in vehicle, is represented by M1. S2 is harmful to S1. The model of the problems is given in Figure 3.

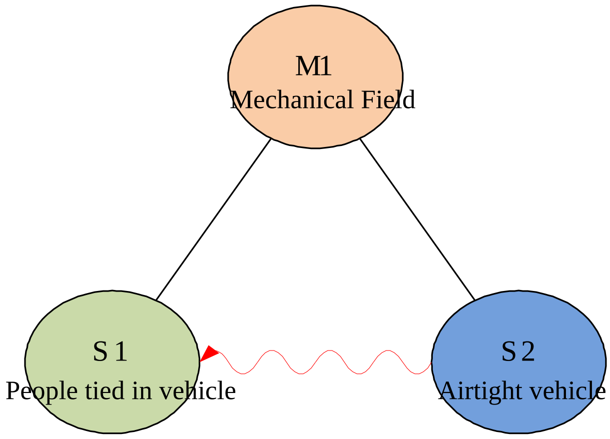

Figure 3 Model of problems that young children were imprisoned in kindergarten vehicle

3.1.4 Solution in the model

Figure 4 shows that the solution the model provides is to apply the transfer rule 4 of Su-Field analysis, that is, to add here the refined element, S3, to effectively eliminate harmful, redundant and unnecessary substances or fields. Therefore, this research adds the negative Mechanical filed termed M2 on S2 to help release S1 by opening the door of vehicle to avoid people imprison by vehicle. M2 is induced by sensor S3. S1 induces (Mechanical field) sensor S3, which passes through a circuit (Electric field) to trigger a rescue alarm device S4 (one or more of a variety of methods for rescue) to notify related rescuers for rescuing people from the vehicles in time. The rescuers turn on (M3: Negative Mechanical Field) S2 and rescues S1.

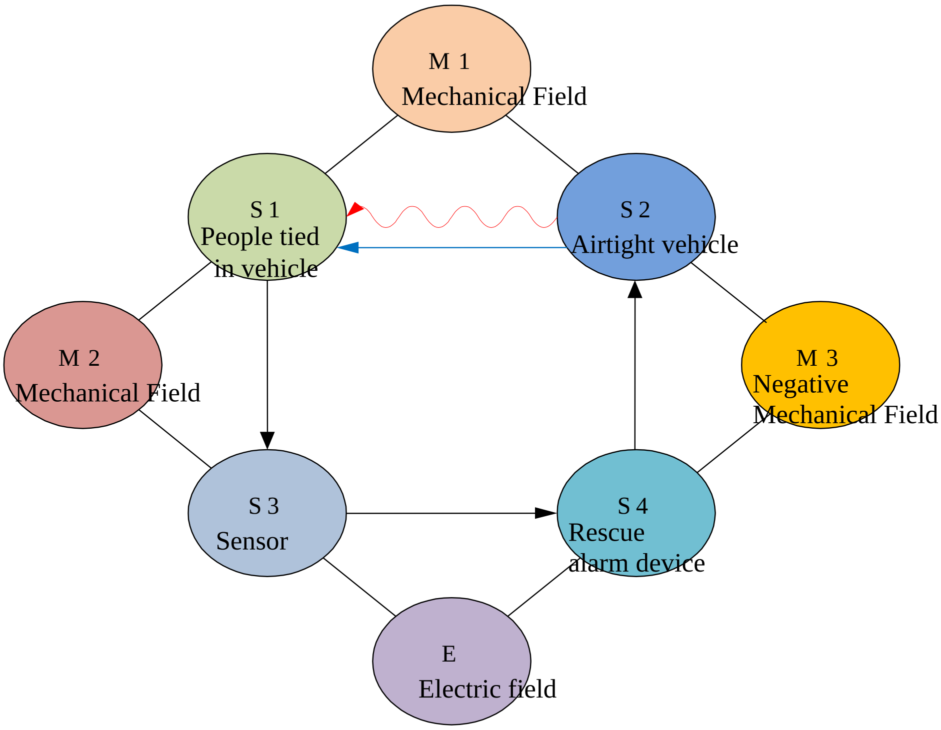

Figure 4 Model of solutions that young children were imprisoned in kindergarten vehicle

3.2 Rescue alarm device design for Kindergarten buses

The design covers two groups of devices: The first comprises sensors, such as for movement (shake or vibration), sound, tread, microwave, atmosphere, supersonic, infrared ray, or CO2 concentration. The second comprises **rescue** alarms, such as voice, light, air-waves, a sensor linked to an alarm, or a viewing or detecting device, such as a camera linked to a monitor to let the driver determine who or what is present in the vehicle. For example, when the vehicle is parked with its doors locked, the **rescue alarm** device becomes set on alert. Any noise made by a child left inadvertently on the bus will trigger the **rescue** alarm device, which will pass a message to the person in charge of the bus to notice people outside of the car and avoid possible danger. A patent search is underway at present to avoid violating any intellectual property rights during the processing of innovation analysis. The information collected and analyzed in Table 1 is undergoing a Taiwan patent search in the Intellectual Property Office, Republic of China. It shows the relationship between the rescue alarm device and sensors for kindergarten vehicles. In Table 1, "V" stands for "able to be researched and developed" , "—"stands for "unable to be researched and developed", and "X" stands for “someone’s patents”. Table 1 shows the relationship between rescue alarm devices and sensors for kindergarten school buses.

Table 1 The relationship between the rescue alarm devices and sensors for kindergarten school buses

		Rescue Alarm Device				
		Sound (horn)	Flash light	Wireless Electric Wave	Crystalloid Window	Breakdown Sign
Sensors	Shake	V	V	V	V	—
	Sound	V	V	V	V	—
	Pulling rings	V	V	V	V	—
	Tread	V	V	V	V	—
	Microwave	V	V	V	V	—
	Air pressure	V	V	V	V	—
	Supersonic	V	V	V	V	—
	Infrared rays	V	V	V	V	—
	CO_2 Concentration	V	V	V	V	—
	Complex	V	V	V	—	—
	Monitor	X	X	V	—	—
	Weight of passenger and car	V	V	V	—	—
	GPS	V	V	V	—	—
	None	—	—	—	—	V

3.2.1 Rescue alarm

Figure 5 shows a **rescue alarm** device in a kindergarten bus. When the engine is switched off and the vehicle parked and locked, a sensor inside is activated. So, for example, any noise made by a frightened child left inadvertently in the vehicle will trigger the sound-induced **rescue alarm** device. Or, if the child beats the window or crystalloid window, the shake-induced **rescue alarm** device is triggered. If any sensor is triggered, it will turn on the rescue alarm device and make a signal (sound, flash light, wireless wave, etc), and thus prolonging life and increasing chances of rescue for those trapped in the vehicle.

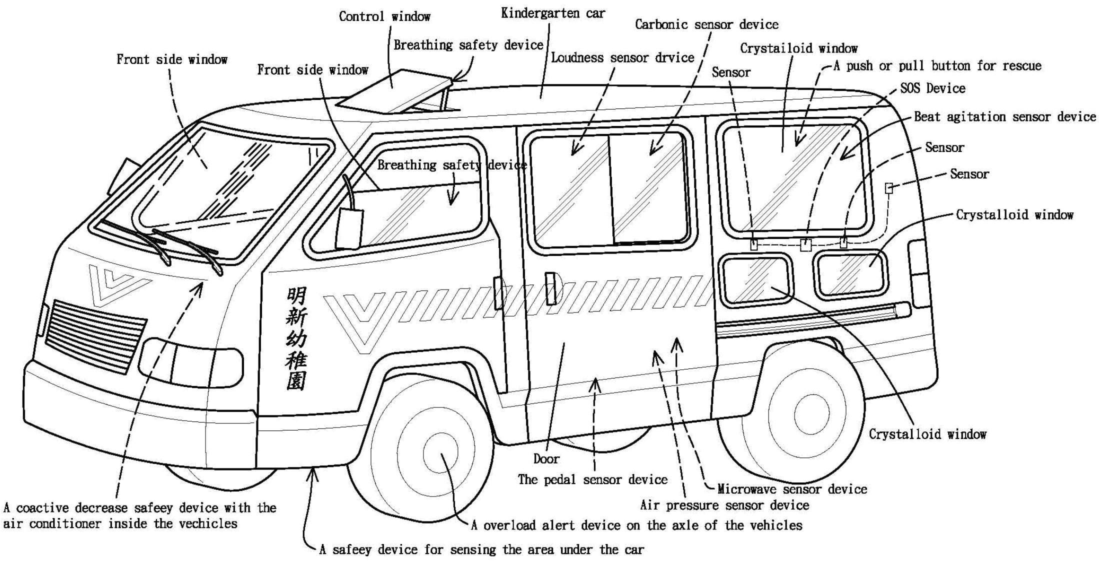

Figure 5 A rescue alarm device in a kindergarten buses

3.2.2 **Objectives for** Rescue Alarm **Devices in Vehicles**

These devices enhance and assure safety for children using kindergarten vehicles. In addition, they are suitable for deployment in vehicles that carry seniors, pregnant women and disabled or mentally challenged people.

3.3 Present Achievements

The following detailed information relates to seven **rescue alarm** device designs that have been approved or are awaiting the outcome of patent applications.

1. A kindergarten school bus with a sound-induced security device (R.O.C., I.P.O., Patent No, I244625)

The invention is to provide a kindergarten school bus's **sound-induced** security devices. When the bus is parked and its doors were closed, the **rescue alarm and** security devices will be on alert. If a child is still on the bus, any **noise** made by the child will trigger the **rescue alarm and** security device. The device will then **pass a message** to the person in charge of the bus and also open at least a window to avoid possible danger.

2. A Kindergarten school bus with a shake-induced security device (R.O.C., I.P.O., Patent No, M264160)

The invention is to provide a kindergarten school bus's **shake-induced** security devices. When the bus is parked and its doors are closed, the **rescue alarm and** security devices will be on alert. If a child is still on the bus, any **beat** made by the child will trigger the **rescue alarm and** security device. The device will then **pass a message**

(such as sound, flashing light, wireless electric wave, and etc.) to the person in charge of the bus and also open at least a window to avoid possible danger.

3. Vehicle's Tread-induced Security Device (R.O.C., I.P.O., Application No. I306067)

This invention is to provide a vehicle's tread-induced security device. It at least consists of a tread-conduction device and a rescue-signal device. The tread-conduction is set in a space of the vehicle and has a treadle with a spring. There's a conducting-board below the spring. The relative positions on the treadle and the conducting-board both have electric conduction. The tread-conduction device is set in a box and connected to the rescue-signal by a circuit. The power of the rescue-signal device is provided by the vehicle's power. When the doors of the vehicle are all closed and locked, and if a person in the vehicle treads the treadle, the person will trigger the **rescue alarm and** security device, the treadle will touch the conducting-board and makes the rescue-signal device start to send signals, and at least also open a window. Therefore, it will circulate the air, and people outside can find him as soon as possible and it can avoid any accident happened.

4. An induction air-flow safety device for the vehicles (R.O.C., I.P.O., Application No. M346545)

This utility mode is to provide an induction air-flow safety device for the vehicles. It comprises a supersonic and/or infrared sensor in the vehicles. The sensor is connected with a SOS device and the power of SOS device is supplied by the vehicles. After the power of the vehicles is turned off, the SOS device will be operated if the sensors induced someone needs help, the person will trigger the **rescue alarm and** security device. The SOS device will open at least a control window or vent hole so as to circulate the air and let someone know this situation to avoid the accident

5. Vehicle's CO_2 Concentration-induced Security Device (R.O.C., I.P.O., Application No. 095143243)

This invention is to provide a vehicle's CO_2 concentration-induced security device. There is a CO_2 induction device in the vehicle. The CO_2 induction device is connected to a rescue-signal device by a circuit. The power of the rescue-signal device is provided by the vehicle's power. When the doors of the vehicle are all closed and locked, and if the CO_2 concentration in the vehicle is higher than the limit value of the CO_2 induction device, the CO_2 induction device will make the rescue-signal device start to send signals, that will trigger the **rescue alarm and** security device and at least also open a window. Therefore, it will circulate the air, and people outside can find him as soon as possible and it can avoid any accident happened.

6. A kindergarten school bus with bells for help (R.O.C., I.P.O., Patent No.M293866)

The invention is to provide a kindergarten school bus's **bells-induced** security devices. When the bus is parked and its doors were closed, the **rescue alarm and** security devices will be on alert. If a child is still on the bus, any **pull or press to bell devices** made by the child will trigger the **rescue alarm and** security device. The device will then **pass a message** to the person in charge of the bus to avoid possible danger. When the security devices are triggered, at least the control window or vent holes will be opened that make air circulate and lower the high temperature to assure the life.

7. An induction safety device for the vehicles (R.O.C., I.P.O., Patent No. M337499)

This utility mode is to provide an induction safety device for the vehicles; it comprises a **microwave or atmosphere** sensors on the vehicles, the sensor is connected with the SOS device, the power of SOS device is supplied by the vehicles. After the electric door of the vehicles closed, the SOS device will be operated if the sensor induced someone needs help. The SOS device will **let someone know** this situation to avoid the accident.

3.4 Exhibitions and Awards

The above devices have featured in many exhibitions and gained awards, as follows:

1. Shown at "2006 Taipei International Invention Show and Technomart" at the Taipei World Trade Center (August 31-September 3). Patent title: "Young children's safety device in kindergarten buses". Awarded the most popular query group and individual prize among factory owners in the National Science Council Exhibition Hall.

2. Shown at "2008 Taipei International Invention Show & Technomart" (September 25-28). Patent title: "Young children's security device in kindergarten buses". Second prize as most popular at "Taipei International Invention Show & Technomart Invention Contest" in the Ministry of Education Exhibition Hall.

3. Shown at "2008 Research and Development Achievement Exhibition of Technological College in the Ministry of Education" on September 11, 2008. Patent title "Young children's Saver in kindergarten school bus", which was awarded the A level prize.

4. Shown at "2009 Taipei International Invention Show & Technomart" (September 24-27). Patent title: "Life-saving system in vehicles".

5. Shown at "2009 National Tsing Hua University IPs for Industrial Collaboration" (June 9). Patent title: "Travel agency safety creation design".

6. Shown at “Industrial Development Bureau, Ministry of Economic Affairs R.O.C.” (September 30, 2008). Patent title: “The rescue alarm and security devices in Travel Agency”.

7. Shown at “2008 Taipei International Invention Show & Technomart” (September 25-28). Patent title: “Shake-induced air-flow security device for kindergarten buses”. Gained Bronze Medal at the 2008 Taipei International Invention Show & Technomart invention contest (September).

4. Conclusions and Suggestions

People in many parts of the world die in hot airtight vehicles. If people are rescued early from vehicle, some of the tragedies could almost certainly have been avoided. In this study, a new feasible problem-solving process based on a TRIZ Su-Field analysis model was constructed. The airtight vehicle, the tool substance, was represented by S2 and those trapped in the vehicle, the objective substance, were represented by S1. S2 is imprisoned in S1. A Mechanical filed, imprisoning people in vehicle, is termed M1. S2 is harmful to S1. Therefore, the model of solution is applying the transfer rule 4 of Su-Field analysis to add a refined element S3 (sensor) to effectively eliminate harmful, redundant and unnecessary substances or fields. Therefore, this research adds the negative Mechanical filed termed M2 on S2 to help release S1 by opening the door of vehicle to avoid people imprison by vehicle. M2 is induced by sensor S3. S1 induces (Mechanical field) sensor S3, which passes through a circuit (Electric field) to trigger a rescue alarm device S4 (one or more of a variety of methods for rescue alarm) to notify related rescuers for rescuing people from the vehicles in time. The rescuers turn on (M3: Negative Mechanical Field) S2 and rescues S1.

This research used the systematic innovation method and provided several innovative designs for which patents were applied. Two invention patents and four new style patents have been received and one invention patent application remain in process. The above devices have featured in seven exhibitions and gained four awards. This research suggests that researchers can use TRIZ Su-Field to solve problems in engineering. Although in principle TRIZ Su-Field can be used to achieve solutions, feasibility and costs have still both to be considered.

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Paper ID: 109

Designing a Safety Device for Vehicle Based on TRIZ Su-Field Analysis

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Abstract

There have been many reports from around the world of people dying inside overheated, airtight vehicles. If the inside temperature could have been lowered in time, some of the tragedies could almost certainly have been avoided. In this study, a new feasible problem-solving process based on a TRIZ Su-Field analysis model is constructed. There are two substances. Those trapped in the vehicle represent an objective substance termed S1 and the airtight vehicle represents a tool substance termed S2. A thermal field, the fatal inside high temperature, is termed T1. S2 is harmful to S1. Therefore, if a negative thermal field, termed T2, is added, the inside temperature affecting S1 and S2 is lowered, and any fatalities from overheating, T1, are avoided. T2 is induced by sensor S3. S1 induces sensor S3 to turn on the safety device S4 and thus lower the inside temperature in time. A set of innovative safety device designs for vehicles that are going through a systematic application process is proposed with patents and awards for them listed.

Keywords: fatal hot airtight vehicle, induced lowering temperature safety device, patents and awards, Su-Field analysis.

1. Introduction

1.1 Aims and Motivation of the Research

With the rapid pace of economic development, the automobile has become a major form of everyday transportation as well as a universal necessity. However, the steep increase in the numbers of cars has also brought a marked rise in traffic accidents and in the casualty toll. Traffic accidents figure in the top ten leading causes of death and are a cause of much personal and social woe and national economic damage.

Automobile tragedies are generally the result of careless behaviour. There have been, for instance, many cases around the world of young children being left locked as if trapped in hot airtight vehicles with fatal results. Newspapers in Taiwan report that between 1995 and 2005 designated vehicles taking children to and from kindergartens featured on average in 4.4% of annual traffic accident statistics. The average percentage for serious injury and death among children was 4.5 annually. Between 1992 and 1999, there was a series of 10 serious kindergarten vehicle accidents that took twenty-seven lives and the average of deaths and light injuries per accident was 2.7 and 13.3, respectively. A number of young children suffered asphyxia and dehydration in kindergarten vehicle accidents in April 1996 in Pintung, and in May 2004 and September 2005 in Taichung. Similar cases, a seven-year old boy and a five-year old girl trapped in the family car, occurred in 1999 in Miaoli County. In November 2006 in Hsinchu, a two-year old child walking near a kindergarten bus, out of the driver's line of sight, was killed when the bus crashed. In 2003 in the United States, there were many reported asphyxia deaths among young children left alone in overheated cars. In 2007 in Guangdong Province, China, there were four school vehicle asphyxia fatalities, and 2007 in Fukuoka, Japan, a two-year old child died from the same cause.

In the past in Taiwan, when kindergarten vehicle tragedies of this kind happened, the people found at fault were punished, some imprisoned, a number of kindergarten and day-care establishments were closed down, and sums of compensation between NT$8,350,000 and NT$9,200,000 changed hands.

The fact that each year in 1996, 2004 and 2005 three children died from asphyxia and dehydration in kindergarten vehicle accidents highlights the pressing need for providing the vehicles with appropriate security devices. The aim of this research, therefore, is to use a TRIZ Su-Field analysis model first to design such devices and also to provide the basic concepts for developing patents.

As can been from the above discussion, there are many big unanswered questions concerning safety and kindergarten vehicles that must be faced and answered. It is very important to prevent such things happening again. There have been only few studies in this area of research. Therefore, the target here is the development of appropriate patents and improved rescue alarm devices.

2. Literature Review

2.1 Vehicle Safety

The automobile industry has seen constant upgrading and development, with overall enhancement in vehicle functions. However, there has also been a tragic increase in automobile accidents, making the search for effective reductions an issue of vital concern. Chai (2004) states that the goal of active vehicle management is to minimize the danger and damage that derive from automobile accidents and the consequent loss life and limb and waste of social resources. The aim also is to make driving safer on different roads and in different environments, while providing vehicles with the functions that users desire. The safety of vehicles needs to be checked more frequently and seriously.

The Taiwan Government Institution of Transportation recognizes the importance of safe driving and that the laws governing it need strengthening. For this reason, “the Safety Inspection and Certification System for Vehicles by type” for large-size automobiles was introduced on October 26th, 1996 and extended to other Vehicle types in succeeding years (Tseng, 2003).

2.2 TRIZ Su-field analysis model

Su-field analysis is a basic concept used to symbolize a technical system and identify its completeness and effectiveness. Recognized as one of the most valuable contributions of TRIZ, su-field analysis is able to not only model a system in a simple graphical approach and identify problems, but also offer standard solutions to improve the system.

According to TRIZ, the rationale of creating a su-field model is to set up a system whose ultimate objective to achieve a function. This normally consists of two substances and a field, as shown in Figure 1. The term S1 represents an object that needs to be manipulated and the term S2 a tool to act upon S1. Both substances can be as simple as a single element or as complicated as a big system with many components, each of which can also be explained by individual su-field models. The field is the needed energy to enable the interaction between the substances. The states of substances can be typical physical forms (e.g., gas, liquid and solid), interim or composite forms (e.g., aerosol, power, porous). Likewise, the field can refer to a broad range of energy, including mechanism, chemistry, physics, acoustics, optics and radiations.

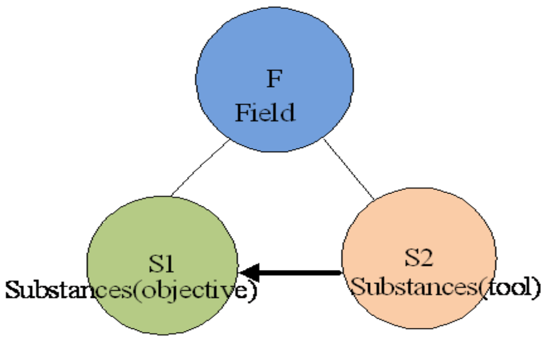

Figure 1 Basic Substances-Field Triangle Model

Genrich Altshuller and his colleagues, the creators of TRIZ, graphically represent a su-field model as a triangle. This is a simple and ingenious way to explain a technical system. On the assumption that the field is generated by a hidden substance, the triangle can be simplified into a dumbbell shape with the field indicated above the arrow and the relationship indicated beneath the arrow, as shown in Figure 2. There are five main types of relationship between the substances: useful impact, harmful impact, excessive impact, insufficient impact and transformation. Among them, useful and harmful interactions are the most common relationships.

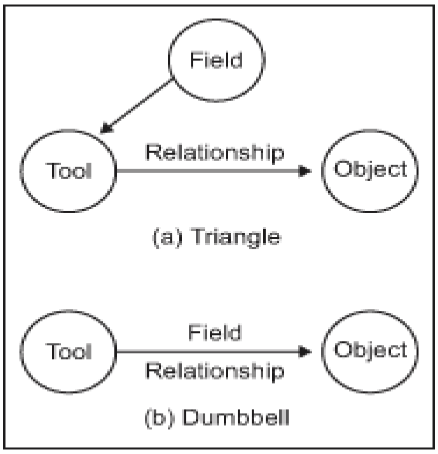

Figure 2 Basic Triangle and Dumbbell Substances-Field Model(Mao,et al 2007)

The su-field model is a fast and simple analytic tool for identifying problems in a system and providing insights that help with the evolution of the system. Once a model is created, su-field analysis can first tell if any of the three elements of the model is missing or if there are any undesired effects in the system. Then, it can indicate the direction for improving of the system. A complex system can be modeled using multiple connected su-field models. In general, there are four types of basic su-field models: 1) an effective complete system, 2) an incomplete system that requires completion or a new system, 3) a complete system that requires improvement to create or enhance certain useful impact and 4) a complete system that requires the elimination of some harmful or excessive impact. (Terninko, 2000; Mao,et al 2007)

3. Innovative Concept for a Safety Device in a Vehicle

3.1 Su-field analysis

3.1.1 Case analysis of problems

Four cases are provided and their problems analyzed as follows:

1. Children suffered asphyxia and dehydration in kindergarten buses in April 1996 in Pintung, and in May 2004 and September 2005 in Taichung (all Taiwan). **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated, and the temperature inside was too high.**
2. Four children suffered asphyxia on school buses in 2007 in Guangdong Province, China. **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated and the temperature inside was too high.**
3. In 2003 in the United States, numbers of children left alone in cars died from asphyxia because of the high temperature inside. **Problems: The presence of the children was not noticed in time, the vehicles were not ventilated and the temperature inside was too high.**
4. In 2007 in Fukuoka, Japan, a two-year old child on a bus suffered asphyxia. **Problems: The presence of the child was not noticed in time, the vehicle was not ventilated and the temperature inside was too high.**

3.1.2 Demand function

There are three demand functions, as follows:

1. **The presence of the children was not noticed in time. Demand function:** Need to find someone still in the vehicle in time
2. **The vehicle is not ventilated. Demand function:** Need to ventilate
3. **The temperature inside is too high. Demand function:** Need to lower the temperature

3.1.3 Model of the problem

As Figure 3 shows, the airtight vehicle, the tool substance, is represented by S2 and those trapped in the vehicle, the objective substance, are represented by S1. If the temperature in S2 increases, S1 might suffer asphyxia and dehydration. The thermal field, the fatal hot temperature, is represented by T1. S2 is harmful to S1. The model of the problems is given in Figure 3.

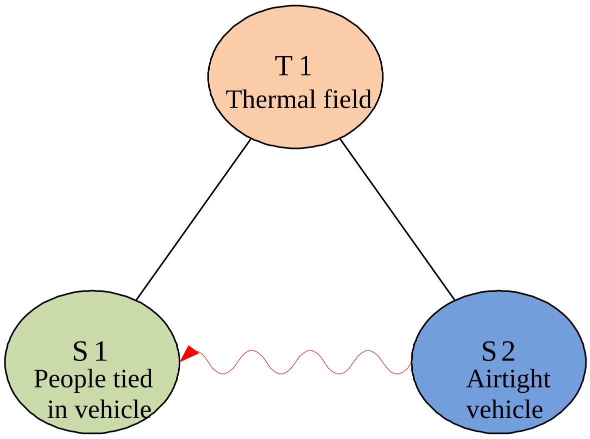

Figure 3 The model of problems that young children were killed by asphyxia and dehydration in kindergarten buses

3.1.4 Solution in the model

Figure 4 shows that the solution the model provides is to apply the transfer rule 4 of Su-Field analysis, that is, to add here the refined element, S3, to effectively eliminate harmful, redundant and unnecessary substances or fields. Therefore, this research adds the negative thermal field T2 to lower the temperature between S1 and S2 and thus avoid people dying from too high temperature. T2 is induced by sensor S3. S1 induces (Mechanical field) sensor S3, which passes through a circuit (Electric field) to trigger safety device S4 (one or more of a variety of methods for lowering temperature) to lower the temperature inside the vehicle in time.

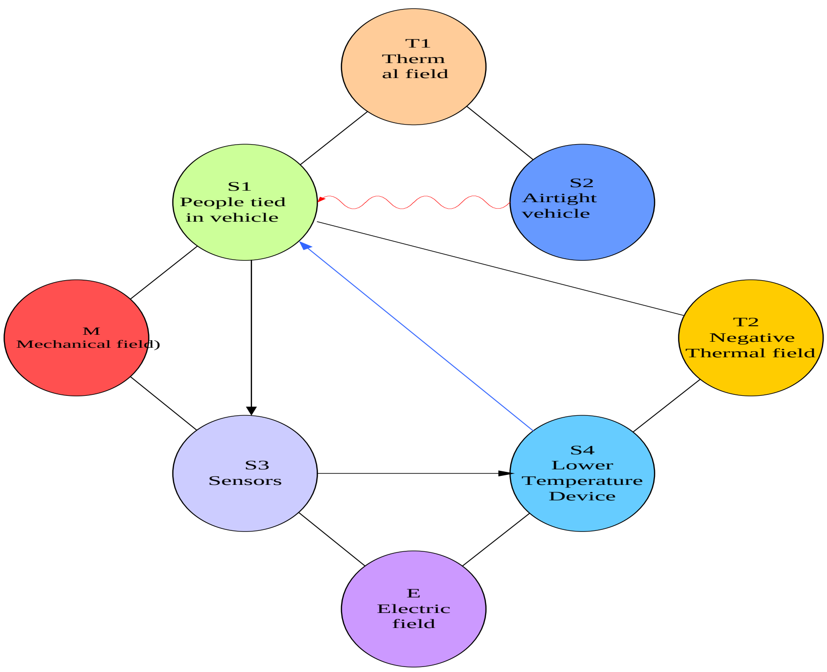

Figure 4 The model of solutions that young children were killed by asphyxia and dehydration in kindergarten buses

3.2 Safety device design for kindergarten buses

The design covers two groups of devices: The first comprises sensors, such as for movement (shake or vibration), sound, tread, microwave, atmosphere, supersonic, infrared ray, or CO2 concentration. The second comprises security devices, such as to cause a window to open, to switch on air conditioning or a fan to lower the inside temperature, a sensor linked to an alarm, or a viewing or detecting device, such as a camera linked to a monitor to let the driver determine who or what is present in the vehicle, or a device to warn whether the vehicle is overloaded. For example, when the vehicle is parked with its doors locked, the safety system becomes set on alert. Any noise made by a child left inadvertently on the bus will trigger the safety device, which will in turn cause at least one window to open and avoid possible danger. A patent search is underway at present to avoid violating any intellectual property rights during the processing of innovation analysis. The information collected and analyzed in Table 1 is undergoing a Taiwan patent search in the Intellectual Property Office, Republic of China. It shows the relationship between the safety device and sensors for kindergarten vehicles. In Table 1, "V" stands for "able to be researched and developed" , "—"stands for "unable to be researched and developed", and "X" stands for "someone's patents". Through a systematic processes, a set of innovation designs is proposed. Table 1 shows the relationship between safety devices and sensors for kindergarten school buses.

Table 1 The relationship among the safety devices and sensors for kindergarten school buses

		Safety Device			
		Open Side Window (vent hole)	Open Electric Fan	Air Conditioning	Sunshade
Sensors	Shake	V	V	V	V
	Sound	V	V	V	V
	Pulling rings	X	V	V	V
	Tread	V	V	V	V
	Microwave	V	V	V	V
	Air pressure	V	V	V	V
	supersonic	V	V	V	V
	Infrared rays	V	V	V	V

	CO_2 Concentration	X	V	V	V
	Complex	V	V	V	V
	Monitor	X	V	V	V

3.2.1 Lower the temperature

Figure 5 shows a safety device in a kindergarten bus. When the engine is switched off and the vehicle parked and locked, a sensor inside is activated. So, for example, any noise made by a frightened child left inadvertently in the vehicle will trigger the sound-induced security device. Or, if the child beats the window or crystalloid window, the shake-induced security device is triggered. When either or both of these safety devices are triggered, a control window or vent hole opens or the air conditioning or an electric fan switches on to circulate air/lower the temperature, thus prolonging life and increasing chances of rescue for those trapped in the vehicle.

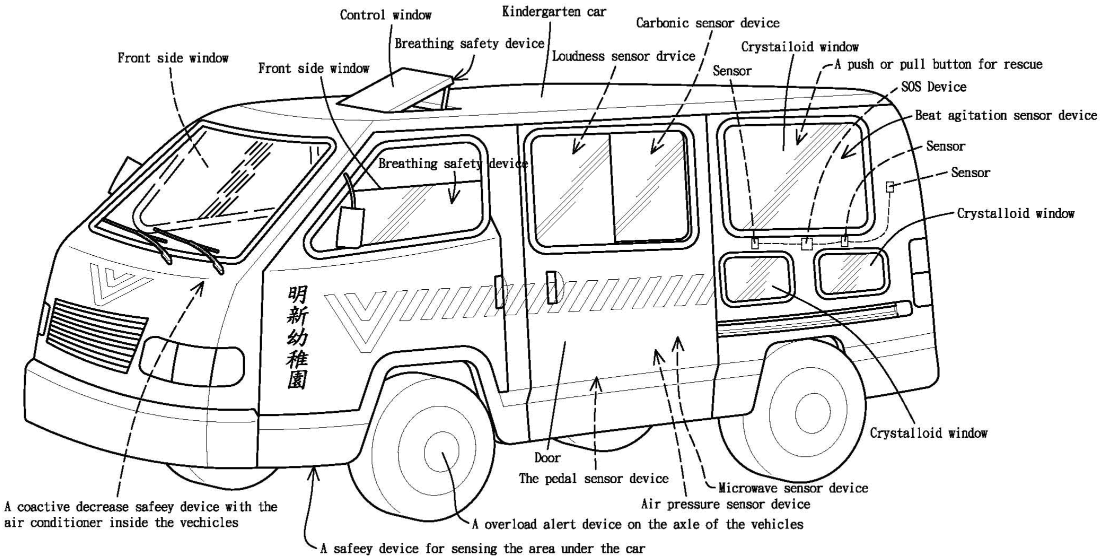

Figure 5 Young children’s safety device in kindergarten school buses

3.2.2 Objectives for Safety Devices in Vehicles

These devices enhance and assure safety for children using kindergarten vehicles. In addition, they are suitable for deployment in vehicles that carry seniors, pregnant women and disabled or mentally challenged people.

3.3 Present Achievements

The following detailed information relates to six safety device designs that have been approved or are awaiting the outcome of patent applications.

1. Shake-induced air-flow security device for kindergarten buses (R.O.C., I.P.O., Patent No, I295249)

This constitutes a shake-induced air-flow security device for kindergarten vehicles. When it is parked with doors locked, the security device is set on alert. Any movement made by a child inadvertently left on the bus will trigger the security device, which in turn will transmit a message to the person in charge and also cause at least one window to open to allow ventilation.

2. Sound-induced air-flow security device for kindergarten buses (R.O.C., I.P.O., Patent No, I298300)

This constitutes a sound-induced air-flow security device for kindergarten vehicles. When the bus is parked with doors locked, the security device is set on alert. Any noise made by a child still on the bus, will trigger the security device, which in turn will transmit a message to the person in charge and also cause at least one window to open to allow ventilation.

3. Tread-induced Security Device for Vehicles (R.O.C., I.P.O., Application No. I306067)

This constitutes tread-induced security device for vehicles. It features at least a tread-conduction device and a rescue-signal device. The first, consisting of a treadle with a spring and below that a conducting board, electrically wired together, is placed in the desired position in the vehicle. The whole device is in box that is linked to the rescue-signal device by a circuit, the power for which is provided by the vehicle. With the vehicle doors all closed and locked, anyone inside stepping on the treadle and in turn the conducting-board will trigger the rescue alarm and **security** device and cause it to transmit a signal and also open at least one window. This will allow ventilation, while summoning people outside to come and rescue those inside as soon as possible.

4. Induction air-flow safety device for vehicles (R.O.C., I.P.O., Application No. M346545)

This constitutes an induction air-flow safety device for vehicles. It comprises a supersonic and/or infrared sensor in the vehicle. The sensor is linked to the SOS device, the power for which is supplied by the vehicle. After the power of the vehicles is turned off, the SOS device will be activated if the sensors detect that help is needed as a result of the rescue alarm and **security** device being triggered. The SOS device will open at least a control window or vent hole to allow air to allow ventilation and also alert someone outside that there is a situation.

5. CO2 Concentration-induced Security Device for Vehicles (R.O.C., I.P.O., Application

No. 095143243)

This constitutes a CO_2 concentration-induced security device for vehicles. Situated inside the vehicle, the device is connected to a rescue-signal device by a circuit, the power for which is provided by the vehicle. With the vehicle doors all closed and locked, if the CO_2 concentration inside exceeds a set limit, the CO_2 induction device will be triggered, causing a rescue signal to be transmitted and at least one window to open. This will allow ventilation, while summoning people outside to come and rescue those inside as soon as possible.

6. A safety device to coactively decrease the temperature in vehicles (R.O.C., I.P.O., Application No. 097109945)

This constitutes is a safety device that coactively decreases temperature in vehicles. Linked to sensors inside the vehicle, it serves as an SOS device. No matter whether the vehicle power is switched on or off, the SOS device is activated as soon as any sensor detects that help is needed and activates the device to decrease the inside temperature.

3.4 Exhibitions and Awards

The above devices have featured in many exhibitions and gained awards, as follows:

1. Shown at “2006 Taipei International Invention Show and Technomart” at the Taipei World Trade Center (August 31-September 3). Patent title: “Young children’s safety device in kindergarten buses”. Awarded the most popular query group and individual prize among factory owners in the National Science Council Exhibition Hall.

2. Shown at “2008 Taipei International Invention Show & Technomart” (September 25-28). Patent title: “Young children’s security device in kindergarten buses”. Second prize as most popular at “Taipei International Invention Show & Technomart Invention Contest” in the Ministry of Education Exhibition Hall.

3. Shown at “2008 Research and Development Achievement Exhibition of Technological College in the Ministry of Education” on September 11, 2008. Patent title “Young children’s Saver in kindergarten school bus”, which was awarded the A level prize.

4. Shown at “2009 Taipei International Invention Show & Technomart” (September 24-27). Patent title: “Life-saving system in vehicles”.

5. Shown at “2009 National Tsing Hua University IPs for Industrial Collaboration”

(June 9). Patent title: “Travel agency safety creation design”**.**

6. Shown at “Industrial Development Bureau, Ministry of Economic Affairs R.O.C.” (September 30, 2008). Patent title: “The rescue alarm and security devices in Travel Agency”.

7. Shown at “2008 Taipei International Invention Show & Technomart” (September 25-28). Patent title: “Shake-induced air-flow security device for kindergarten buses”. Gained Bronze Medal at the 2008 Taipei International Invention Show & Technomart invention contest (September).

4. Conclusions and Suggestions

People in many parts of the world die in hot airtight vehicles. The crucial cause is the excessively high temperatures that can be reached inside. If these can be lowered in time, such tragedies can be avoided.

In this study, a new feasible problem-solving process based on a TRIZ Su-Field analysis model was constructed. The airtight vehicle, the tool substance, was represented by S2 and those trapped in the vehicle, the objective substance, were represented by S1. If the temperature in S2 increased, S1 might suffer asphyxia and/or dehydration. The thermal field, the fatal hot temperature, was represented by T1. S2 is harmful to S1. Therefore, the solution provided by the model was to apply transfer rule 4 of Su-Field analysis and add a refined element S3 (sensor) and thus effectively eliminate harmful, redundant and unnecessary substances or fields. The added negative thermal field, T2, lowered the temperature between S1 and S2 and avoided fatalities caused by the high temperatures. T2 was induced by sensor S3. S1 induced (Mechanical field) sensor S3 to pass through a circuit (Electric field) and turn on the safety device, S4 (a variety of methods for lowering temperature), which then lowered the inside temperature in time.

This research used the systematic innovation method and provided several innovative designs for which patents were applied. Three invention patents and one new style patent have been received and two invention patent applications remain in process. The above devices have featured in seven exhibitions and gained four awards. This research suggests that researchers can use TRIZ Su-Field analysis to solve problems in engineering. Although in principle TRIZ Su-Field analysis can be used to achieve solutions, feasibility and costs have still both to be considered.

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Paper ID: 111

Growth and Development: Two Aspects of Technical System Evolution

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Abstract

For more objective study of different aspects of Technical System's evolution the concept "processes of growth" and "processes of development" have been introduced. Indicators for identification and differentiation of these interdependent components of the technical evolution have been selected and systemized. Application of such approach leads to clarification of Technical System evolution goals and criteria of their achievement.

Keywords: evolution, growth, development, Technical System, TRIZ.

1. Introduction

Evolution of various systems often has common characteristics and analogous aspects. In many instances for deep investigation of evolution processes, it is useful to separate evolution's process into two interconnected components - growth and development.

For analysis of evolution of biological systems such subdivision into growth and development is well-known and looks quite natural and understandable. R. Ackoff (1986) initially introduced the distinction between growth and development for the complex social systems and validated efficiency of this separation.

According to R. Ackoff(1986) "Growth and development are not the same thing. Neither is necessary for the other. A rubbish heap can grow but it does not develop. Artists can develop without growing. Nevertheless, many managers take development to be the same as growth. Most efforts directed at corporate development are actually directed at corporate growth".

Useful and productive way of TRIZ tools improvement is the purposeful borrowing and adaptation of analogies from natural and social systems. However, we observed limited number of attempts to use this differentiation such an approach for the evolutionary analysis of technical systems (TS). Firstly this viewpoint of techno-evolution was applied in author's paper (N.Feygenson, 2005). Next steps of improving this approach described in manuscript (N.Feygenson, 2008) and in article (N.Feygenson, A. Kynin, 2009)

Goals of this paper are introducing fundamental concept of growth and development for Technical System's Evolution and illustration it's applicability for practices.

2. Basic notions

Definition of "*growth*" is as follows: with growth prevails increasing in the size or number of components of the system, often accompanied by an increase of the specific parameters of the system. At the level of "population" of technical systems, growth is reflected in increasing the number of technical systems, which commercially available for application.

When "*development*" takes place it primarily increased as the number of multivarious functions and/or their level of performance. This is an increase in reliability, durability, ease of use and in number of functions, which oriented to components of super-system. Development is accompanied by a reduction in resource's consumption, emission of harmful ingredients into the environment.

Factors and parameters of evaluation of growth are well-known and almost obvious. The level of development evaluation is principally multidimensional and requires a meaningful, often non-trivial analysis.

Describing these aspects of evolution from a marketing standpoint, the growth is filling a well-defined market niche with the maximum efficiency. The development is mainly the establishment of the structure, parameters and adaptation functions of the Technical System for a new niche. Another possible kind of appearance of development is the resource mobilization for possible impacts on the boundaries of the existing niches with a view to their expansion, moving into other neighboring niches. In other words, growth can be summarized as a component characterizing the process of the propagation of the technical system in the market niche, development - as a preparation for such propagation.

We propose these descriptive definitions only as working term into scopes of our research. There is not “gospel truth” and these definitions could be improved in future explorations. We summarized suggested generic description at Table 1.

Table 1. Differences between growth and development

Level of description	**Characteristics of process:**	
	Growth	**Development**
Syper-system 2	Occupation of the specific market niche	Recognition of new market niches and preparation for their expansion
Super–system 1	Increasing quantity of the same/similar TSs	Increasing number of functions oriented to components of super-system. Decreasing harmful actions to environment
Technical System	Changing in size and/or number of TS’s elements	Improvement TS’s structure and/or of level of performance for the intra-system functions. Increasing TS’s reliability, durability, efficiency of resources’ utility

It is clear that the proposed separation of growth and development is actually the identification and idealization of two sides of general tendencies of TS’s evolution. In real conditions, the processes of growth and development are combined in time and integrated. According R.Ackoff, (1986) “Growth and development do not have to conflict; they can reinforce each other”. However, is important and interesting to identify an evolution tendency, which is prevailing at this current period. In this case, we can quite clearly to assess observable and remote results of technical system’s improvement.

3. Characteristics of growth and development

For more accurately diagnose the processes of growth and development the differences in the notions of growth and development were systematized and considered from different points of view – see Table 2.

More over, several examples of application were described and discussed. These examples are from different industry’s area: automotive, railway, computer etc.

Table 2. Comparative characteristics of growth and development

Comparative characteristics	Growth	Development
General attributes		
What demands are met	Satisfaction is clearly manifested needs of the Super-system in the widest possible scale	Meeting the not always obvious demands, including own demands and demands of others systems
Relation to the choice of options, opportunities	Implementation in already defined direction. Replication TS for widespread utilization in existing abilities.	Improvement diversity of TS's options and creation of new criteria for its selection. Development Includes several interrelated processes and increases the variety of possible evolution ways.
Process direction	Growth is unidirectional process. It is extremely difficult to implement growth in the few directions	Development can be directed or spontaneous.
TS complication	Minimum complication of TS. Sometimes TS simplification for overcomes barriers to mass implementation (so named "Crossing the Chasm").	Creating an orderly and manageable complexity for TS's flexibility and variability
The results of the process that is mainly reflects this aspect of evolution	Efficiency in short-term understanding. TS pervasiveness increases, therefore increases in profits by means of the manufacturing and exploitation of the TSs.	The quality of the operation of individual subsystems and TS as a whole. Support the stability of work, ease of use of TS. Increasing profit but sometimes indirectly through the subsequent growth.
Effect on the stability of the evolution	Growth uses opportunities for the sustainable evolution. Forced growth could cause instability.	Development prepares the conditions for a sustainable evolution

Attitude to resources	Full use of few most important and most ready for use resources. Lack of resources can restrict growth.	Efficient use of resources. Ability to create and develop (new) resources, improve resource efficiency Lack of resources cannot limit the development. Highly developed TS less dependents on resources
Interrelationship of aspects		
The relative "autonomy" of aspects	TS can grow without development and without increasing the TS's value. Growth of TS's "population" can occur without significant changes in the TS's parameters.	Development can be not accompanied by a (significant) growth.
Mutual assistance processes	Growth can be a initiator and supporter for development Growth uses currently achieved level of development and realize its potential impact.	Development prepare the conditions and possible purposes for following balanced growth
Possible negative interactions	Growth can cause uneven development Growth can lead to an intensification of several problems. For solving this category of problems it is necessary to develop TS.	Insufficiently focused development may not lead to the subsequent growth
Coordination in time	The growth is the following stage after development	Development can be promoted by the results of growth and prepares following growth.

Restrictions and limits		
Outside TS	The resources availability, interactions with other TSs and man.	Lack of knowledge for creation new functions, the synthesis of combinations of new structures and functions
Inside TS	Exhaustion capacities of the existing structure to increase the growth parameters	Exhaustion capacities of the structures to improve existing functions
Upper limit	TS can be too large	TS cannot be over-developed
Inter-restrictions on the processes	Growth may be limited by existence of insufficient development of TS's subsystems. Uneven development inhibits growth.	Development, which not correlated with subsequent growth has limited usefulness and does not increase the stability of the evolution.

Here are some examples that illustrate the applicability and illustrate the usefulness distinguish the growth and development in the evolution of technical systems.

Example 1.

Henry Ford paid attention to the development of the concept car for mass consumption - the development of simple reliable construction, conveyor technology, standardization, etc. This was a stage of development. These problems of development were not obvious and trivial. Then came the stage of growth – i.e. the mass production famous model-T Ford.

But the following growth required further development of technical system "automobile".

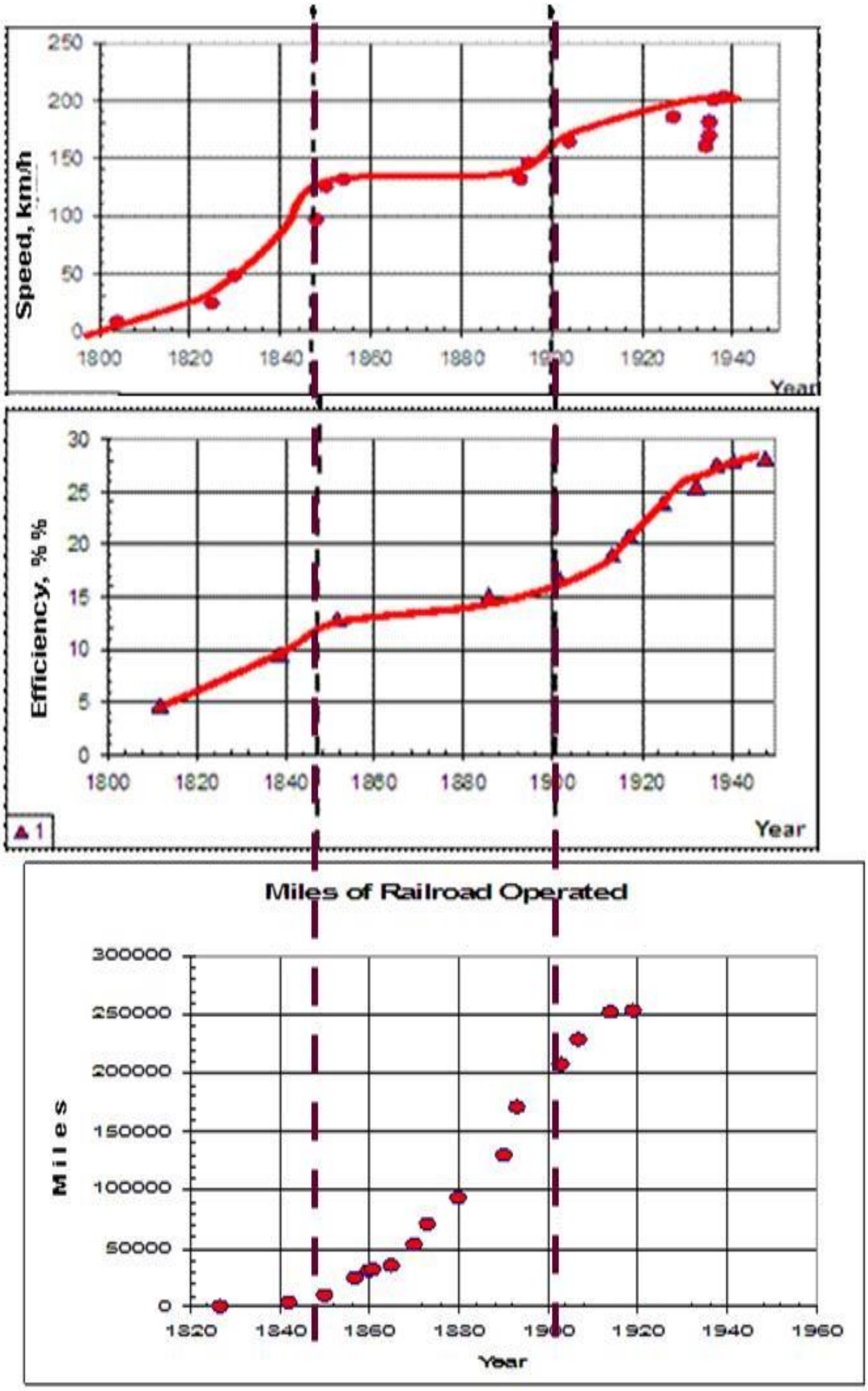

Figure 1. Characteristics of growth and development of railways with steam engine (Feygenson N., Kynin A.,2009)

Example 2.

Let consider the evolution of railroads which used steam engine. This example based on the presence of reliable data on the development of TS and related systems. As seen from the data presented in Fig. 1, in the period from 1840 to 1900 such characteristics as maximum speed and efficiency of steam-powered locomotive remained almost unchanged. But the length of the exploited railways increased dramatically during the same period. Figure 1 presents data on the U.S., a similar increase was observed at the same time in United Kingdom. Development has been suspended, but the growth has been intense until 1900. Then came the phase dominated by development, including the use of new varieties of principle of operation instead of steam engine. Similar processes of combination of growth and development are observed in the analysis of the evolution of ships.

Example 3.

Hewlett - Packard Notebooks confidently led in sales in 2007 in the class of business - notebook (data from *IDC*, Petukhov P.A). Achieved this leadership by carefully attending to the secondary functions i.e. keyboard protection from the liquid spill, robust case, the protective coating of wear parts, information security, *Ambient Light Sensor,* etc. In our point of view, this is the development of TS by adapting to the demands of users of safety, reliability, ease of using. Other key parameters (memory capacity, RAM, display size, weight etc.) are almost identical for other notebooks of this class. This example shows how development through improving the additional functions leads to growth of selling notebook’s "population".

So, given examples illustrate the application of these concepts for various TS, confirm their usefulness in the analysis of evolutionary dynamics. Possible ways to further improvements and applications of this concept are considered in work (Feygenson N., 2008)

We applied this concept in practical TRIZ-consulting projects. At initial stage we clearly define main project’s orientation. Depending on the project’s center of attention we chose the appropriate TRIZ tools. During the final stage of the consultation suggested ideas are classified according to their focus on growth or development of TS.

4. Conclusions

1. Provided, systematized and illustrated basic concept that describes the different but interrelated aspects of technological evolution - the growth and development of the technical systems.
2. The practical importance of using this concept is the ability to evaluate the realistic objectives and results of planned progress into the technical systems evolution.

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S-Curve as a Model for Description of Technical System Development

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Abstract

It is well-known that there are similar stages in development of different kinds of Technical System while their life-cycles. The repetitive three main stages were named as “infancy”, “rapid growth” and “maturity”. The changing of any performance parameter in time may be displayed by some curve which looks as the sign “S”. In literature this kind of curve very often named as “S-curve”. If the position of some system on the S-curve is known, then it becomes possible to predict the future development of the system and choose the optimal direction for the system’s improvement. But real development of system’s parameter follows to S-shaped very rare. Some methods for determination of the performance parameters and classification of the technical systems, which correspond to S-shape curve of development, are proposed in this article.

Keywords: TRIZ, S-curve, parameters, development.

1. Introduction

Many inventors would like to know how to predict the future development of a Technical System (TS). In general, Trends of Technical System Evolution could be used for this type of prognosis. These trends are the basis of the Theory of Inventive Problems Solving (TRIZ) (G. Altshuller 1973).

It was shown in TRIZ that there are similar stages in development of different kinds of TS while their life-cycles. Changing of any performance parameter in time can be easy displayed with so called “S-curve”. The typical “S-curve” presented on Figure 1.

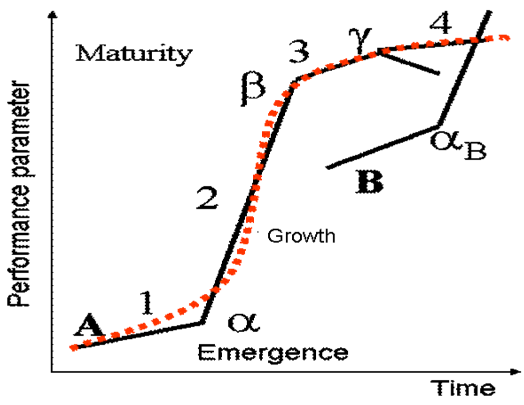

Figure 1. The dependence between performance parameter and creation time for the T.S. (G. Altshuller 1973).

It is well-known that S-curves may be used for prognosis of the system development (Martino 1972). Unfortunately, very often the real dependences differ from S- shape and in literature there are no recommendations about choice of performance parameters. For these reasons using of S-curve for purposes of prediction may be impeded.

The goal of this work was systematization and classification of the “life stages” curves for different Technical Systems. The authors included in the article consideration of a few different kinds of TS, namely:

- transport systems (ships, railway, cars);
- electronic devices (monitors and TV, printers);
- light sources;
- energy sources.

Based on results of investigations, the authors offered model of classification which may be useful in making forecast of systems development. The preliminary results of these investigations were introduced firstly on the TRIZ-Fest (Kynin 2009). Usually, the real development of TS parameters in time has some timeouts. The possible causes of these timeouts were already considered in our previous work (Kynin 2008).

Very often some improving in the main TS’s parameter (main function) we try to connect with increasing of TS’s Ideality. The Ideality (I) is the relation between sum of the useful functions (∑F) and the sum of expenditures (harmful function) (∑C):

$$I = {\sum F}\Big/{\sum C}\,. \qquad (1)$$

We assume, and maybe it sound surprising at the first glance, that the curve of “life stages” may have S-shape only in the case when the parameter of this curve is not correlated with Ideality. But what parameter may be not correlated with Ideality?

2. Record-breaking systems

Let’s consider so called “record-breaking systems” – these are the Technical Systems with strongly marked main parameter which usually produced in unique sample or in very restricted number of samples, for example, racing car. It main parameter is speed – the designers of this car try to increase speed regardless to all another - expense, comfort of driver, noise and so on. Ideality of racing car is not so high according to classical definition. But, really, the curve of maximum speed for racing car in time looks as the classical S-curves. The same we can see for the experimental airplanes designed for record-breaking altitude on Figure 2.

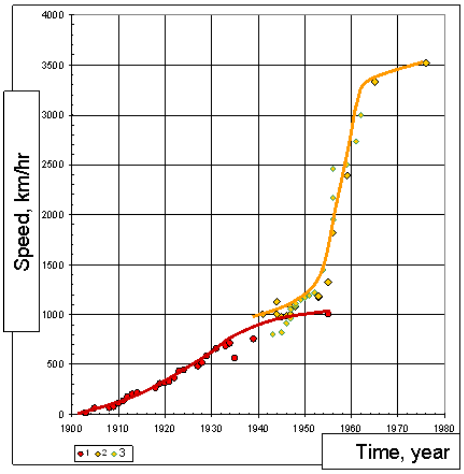

Figure 2. The dependence between speed and creation time for the different airplanes: Record piston airplane (1), Record jet airplane (2), Record USSR airplane (3) (Timeline airspeed record, Jakovlev 1982).

3. Substitutional systems

It was also disclosed that classical S-curve may be used for displaying new systems which substitute old systems but use the same (or with very insignificant changing) Super-system elements. We’ll name them as “substitutionary system”. For example, steam locomotive, diesel locomotive and electric locomotive use the same rail cars, rails, railway stations and so on, and their development is in good correlation with classical S-curve.

The dependences between speed and creation time for steam and diesel are presented on Figure 3.

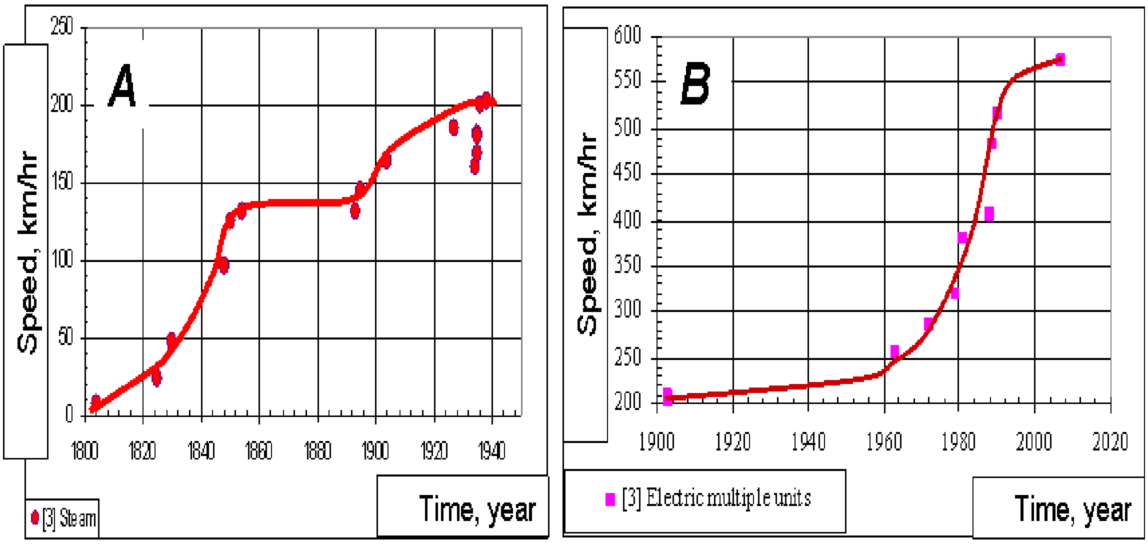

Figure 3. The dependence between speed and creation time for the steam (*A*) and diesel (*B*) (Land speed record for railed vehicles, Land speed record for railed vehicles).

4. Systems with "opposite" parameters

The development of real systems is not uniform. Usually the system's designers try to improve only one or very few parameters and forget, for a while, about all others. For example, it was a time when car designers try to increase engine power only (maximal speed and car's dynamic) and didn't think about fuel consumption, noise, contents of exhaust gases and so on. But after a time it would be necessary to improve these parameters. Moreover, some of these parameters are "opposite" to initially improved parameter. For example, to suppress engine noise we use muffler which decreases engine power. In other words, in this case we have "contradictive" parameters. It was found that if we choice a characteristic of contradictive parameters as a measure for system estimation then description of system's development will follow, as rule, to S-curve.

The dependence between performance parameters and creation times for CRT monitors is presented on Figure 4.

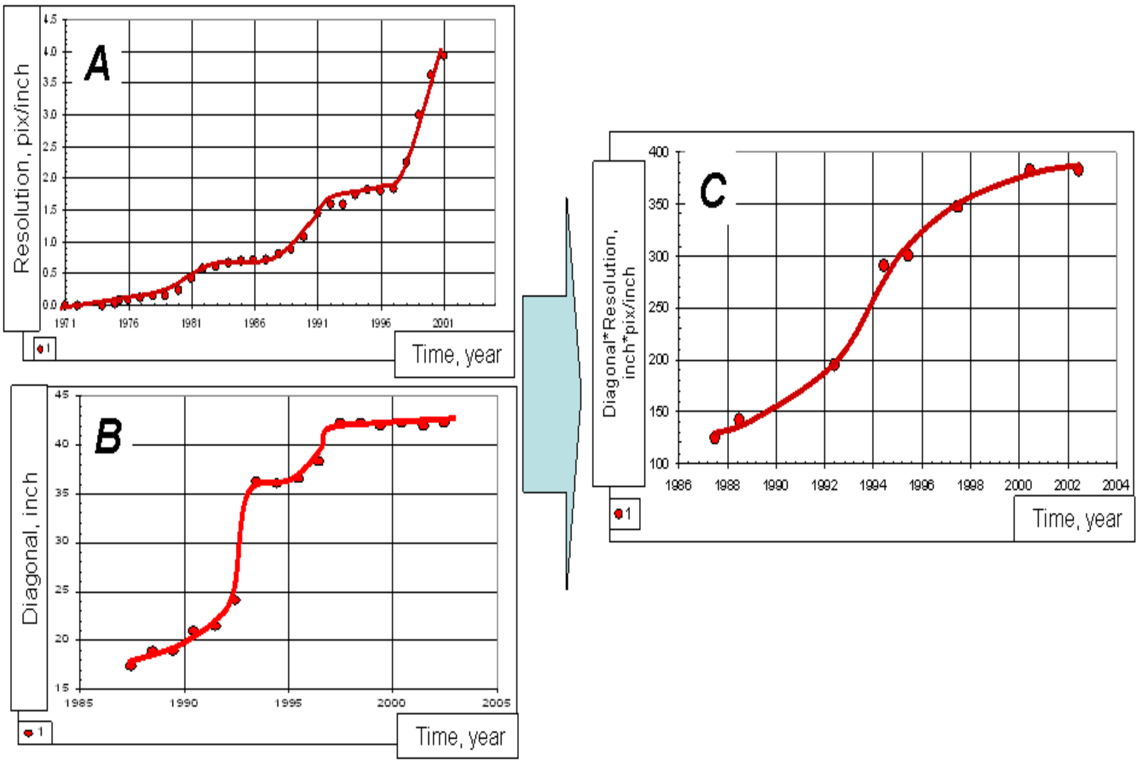

Figure 4. The dependence between performance parameters and creation times for CRT monitors: Resolution (*A*), Diagonal (*B*) (Sood, 2005) and complex parameter (*C*).

5. Efficiency

It was also specified that if the performance parameter is a ratio between main characteristic of the system and the energy expenses then the life-cycles of this system usually looks like "S-curve".

The dependence between efficiency and creation time for the incandescence lamps is presented on Figure 5. Here efficiency means ration of main parameter – measure of illumination (Lm) – and energy expenses for light production (Wt).

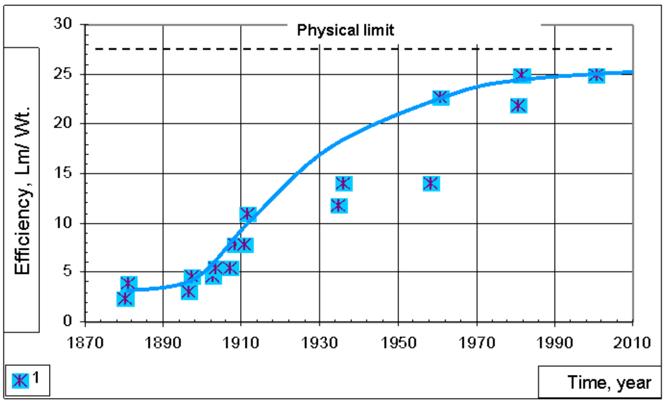

Figure 5. The dependence between efficiency and creation time for the incandescence lamps (Sood, 2005).

6. Envelope curves

Very often we consider “system family” - it is the systems with the same assignment, but using different principles of operation. The common development of “system family” according to chosen parameter can be done with “envelop” curve (Ayres 1969). Moreover, development of each system in “system family” may differ from classical S-shape but “envelop” curve has S-shape always. The dependence between efficiency of different engines and creation time is presented on Figure 6

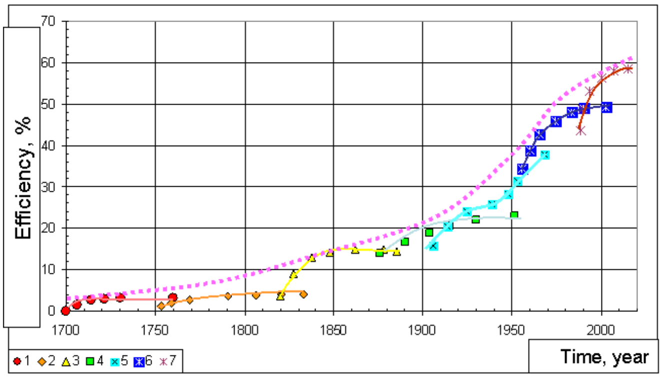

Figure 6. The dependence between efficiency and creation time for the engines: Newcomen (1), Watt (2), Cornish (3), triple extension (4). Turbines: Parsons (5), high pressure (6) and gas (7), and envelope curves (Energy Needs).

Conclusions

1. Real dependences of system’s single parameter development in time may be described with S-curve very rarely.

2. Behavior of the parameters following to S-shape curve may be used for the next types of systems:

- Record-breaking;
- “Substitutional”;
- With “opposite” parameters;
- Envelop curve for “system family”

3. S-shape curve may be also used for description of complex parameter such as efficiency and so on.

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Paper ID: 113

Resolution of physical contradictions with use of second-order phase transitions

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Abstract

This article discusses resolution of physical contradiction by second-order phase transition using. In a number of cases contradictory conditions of operational zone could be provided. Examples were found in leading areas of technology.

Problem

Main part of ARIZ-85-C is formulation and resolution of physical contradictions. One of effective tools is “11 Inventive principles for resolution of physical contradictions” [1]. Four of them are based on phase transitions (PT), allowing to provide the contradictory conditions of the operational zone.

Traditionally, the analysis of the operational zone includes consideration of the three aggregate state of matter (solid, liquid and gaseous) and corresponding PT. Second-order PT are considered occasionally (the only exception – ferromagnetic transition through the Curie point).

Proposed approach

Second-order PT can effectively resolve physical contradictions in the operational zone. PT is the transformation of a thermodynamics system from one phase to another when external conditions change (temperature, pressure, magnetic and electric fields). Usually that is an abrupt change in physical properties during of continuous change of external parameters.

There are two types of PT. First-order PT – when density/concentration are changed and heat is released or absorbed. Second-order PT – when density, entropy and thermodynamic potentials do not have jump changes, but heat capacity, compressibility, coefficient of thermal expansion are changed abruptly.

The main advantage of second order phase transitions is a very wide set of parameters which can vary. Some of these transitions are described in the physical effects databases and can be used for contradictions resolving. For example, shape memory effect is well known and is widely used for contradictions resolving. However, most of interesting phase transitions haven't included into databases yet. In additional, this area of science is developing rapidly, new info appears continuously. Therefore, may occur the situation you have to find required PT yourself.

The idea of this PT search is quite simple, mini-algorithm consists of three steps:

1. To identify the "controversial" parameter
2. To find a PT where this parameter changes
3. To "embed" this PT into the technical system

Practical examples:

1. Application of the supercritical fluid and passing through supercritical state crossing

What is a supercritical fluid (SCF)? As a certain combination of temperature and pressure above the critical value, the substance goes into a special state - supercritical fluid. It isn't usual difference between the liquid and gaseous state in the supercritical state. The density of SCF is close to the density of ordinary liquids and the coefficient that characterizes the molecular transfer is large and is close to the gas coefficient [2].

Example of SCF properties using: At present, aerogel based materials are increasingly used. They are used as a heat insulator, carriers of catalyst, sorbent and filter materials, etc. Gel synthesis is a simple technological operation. But the gel drying was considered impossible for many years. Because of surface tension forces broke the structure of the gel during drying. We should resolve the contradiction:

- the solvent should turn into the gas from the liquid stage, i.e. a boundary between liquid and gas **should exist**

-capillary forces exist at this boundary, they destroy the structure of the gel, i.e. boundary between liquid and gas **should not exist**

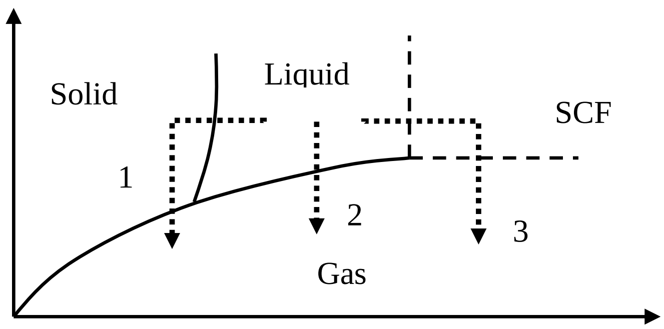
The problem was solved in 1931 by using of the supercritical state passing through. In this case, the pressure, and then the temperature rise above the critical. Solvent becomes a supercritical fluid. Then the pressure is slowly decreased. The solvent passes into the gaseous state and is completely removed from the gel. Boundary between liquid and gas in this case doesn't form. Contradiction is resolved. Consider the process in detail.

In general, there are three ways on the phase diagram to remove solvent from the product (Pic. 1).

Described above undesirable effects occur when using the path 1 (the transition from liquid to gas). There is boiling or evaporation of the solvent from the free surface.

It is possible to organize the process using the path 2. In this case, the solvent is firstly frozen and then sublimated under reduced pressure. This process is called freeze-drying. It is widely used in industry when drying at high temperature is undesirable. Contradiction is resolved. However, a lot of problems occur during the freezing. These problems are associated with the solvent crystals formation.

Finally, it is possible to organize the process using the path 3 – passing through supercritical state crossing. In this case, the pressure, and then the temperature rise above the critical. Then the pressure reduces slowly (at constant heating). The solvent is completely removed from the product. The boundary between liquid and gas in this case doesn't form. Contradiction is resolved, additional problem doesn't arise.



Pic. 1. Passing through supercritical state crossing.

2. Glass transition in polymer

Glass transition in polymer is the transition from the highly elastic form into the solid glassy state. Physical nature of glass transition in polymers is the same as in low molecular weight liquids. But the mechanism of the process has some peculiarities (molecular motion in the glassy and highly elastic states of the polymer). Ehrenfest's thermodynamic equations are suitable for glass transition in polymer (they describe the parameters of the system on the opposite sides of the phase transition). This allows to include the glass transition in polymer into the list of second-order phase transitions.

As an example of practical application we can consider the gas diffusion through the amorphous polymer. Diffusion rate is changed dramatically when passing through the glass transition temperature. If the temperature is above the glass transition, there are additional diffusion paths for the gas diffusion. At a temperature below the glass transition, polymer structure becomes more compact and diffusion requires high activation energy. Thus, temperature changes allow to control the rate of diffusion of gases through polymeric membranes

3. Effect of percolation on fractal

Effect of percolation on fractal originally was studied for problem of percolation of oil through porous rocks. The simplest model of this effect is an abrupt change of the permeability with small changes in porosity. Then, this effect have been studied in relation of current flow in disordered conducting media such as adhesives filled with conductive powder. Abrupt change of conductivity of the fractal structure can be observed when you change the concentration of conductive particles, and when you change the distance between them. The latter method is used for current limited device (CLD) production [3]

While the current is small, a bit of heat is generated inside the CLD. This heat can be dissipated without a significant increase of CLD temperature. With current increasing heat generation increases too, the CLD heats up. Due to the thermal expansion the distance between the conductive particles increases. The internal resistance of the CLD increases abrupt, this limits the current. After CLD cooling conductivity is restored.

The device has an interesting feature. Two second order phase transitions are used together. First – effect of percolation on fractal. It is used to provide the main function of the CLD. Second – glass transition in polymer. When temperature is above the glass transition temperature, coefficient of thermal expansion of the polymer increases several times. It makes the effect of current limitation more sharply.

4. Phase transition mesophase-isotropic melt.

The essence of this effect is a strong (in order) change the viscosity at a relatively small (15-20C) temperature changes. The effect is observed in multicomponent mixtures of low molecular weight polymers [4].

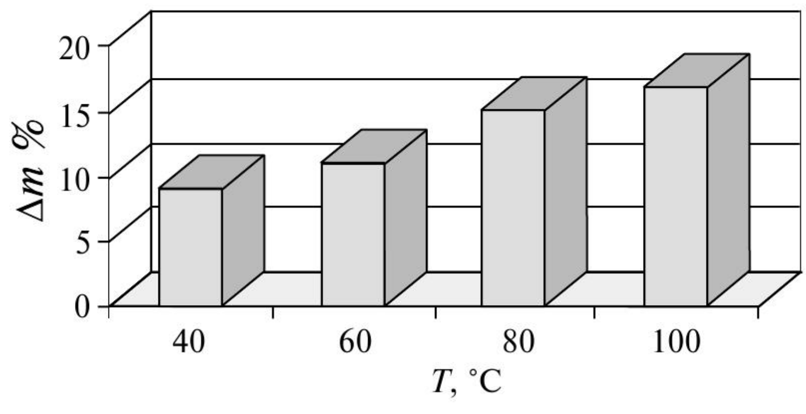
The nature of the effect is rather complicated. Broadly speaking, if there is a mixture of two low molecular weight polymers with a low mutual solubility, in a certain temperature range, one of the polymers may pass into a specific mesomorphic state. In this state it forms matrix that determines the rheological characteristics of the mixture. With small temperature increase the mesophase melts and mixture viscosity decreases sharply.

This effect provides the possibility of effective control the viscosity of the working body in different systems. We can effectively solve technical contradictions associated with the need of changing the viscosity under resources limitations.

5. The joint use of two phase transition for the resolution of contradiction

Technology of porous polymer production by processing in supercritical CO_2 is sufficiently well known. However, when we try to process workpiece of variable thickness, technical contradiction occurs. The process of saturation is determined by the diffusion of supercritical CO_2 into the depth of the polymer. Different parts of the workpiece absorb different amount of CO_2 and after heating have different porosity. We can withstand the workpiece in CO_2 for a long time to complete the process of diffusion. But in this case the resulting porosity will have maximum porosity.

If we need a product with middle or low porosity, contradiction is resolved by using the glass transition in polymer. Absorption of CO_2 occurs only in amorphous polymer, crystalline regions practically don't absorb CO_2. We can change the ratio of crystalline and amorphous phases in the polymer by changing the temperature of treatment. Working temperature allows to specify the necessary level of porosity of the material (Pic.2).



Pic. 2 Dependence of the amount of absorbed CO2 on the temperature of processing. Sample material – ABS. Process conditions: pressure – 250 bar, processing time – 60 minutes, on the vertical axis – change in mass as a percentage of the original sample [5].

Conclusions

Use the second order phase transitions for the physical contradictions resolving are proposed. The idea's effectiveness is demonstrated by practical examples. A simple three steps mini-algorithm is proposed.

The problem is a synthesis of the systems of several phase transitions. Authors intend to develop the work in this direction.

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Paper ID: 116

Determination of Optimal Factor Settings for a Pharmaceutical Filling Process by Mixed-Level Factorial Design

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Abstract

Product and process variations can be costly to manufacturers in terms of high rework expenses, scrap, and inspection. In this paper, the variability of a generic pharmaceutical filling process was studied. Four factors were investigated in the production process. First, process capability analysis was conducted. The significance of the process factors and their interactions were determined using Design Expert. Our ultimate goal is to develop the optimal level settings of controllable factors to minimize the quality loss caused by the deviation of process mean from the target value (nominal fill weight), and the variations in fill weights. Mixed-level factorial design was carried out. The optimal level settings of the process factors were obtained for high and low viscosity products. As presented in this paper, significant quality improvement in the filling process can be achieved by reduction in fill weight variations. The approach may be applied to other similar filling processes.

Keywords: Factorial Design, Fill Weight Variation, Parameter Design, Optimization, Pharmaceutical Filling Process.

1. Introduction

Pharmaceutical manufacturers are regulated to meet fill weight specifications for liquid bottle medicine. The filling process must perform consistently over time to be capable of meeting this requirement. This paper investigates a liquid-medicine filling process at a pharmaceutical manufacturer where medicine bottles are produced continuously at a high speed. The medicine weight filled in each container must meet or exceed a specified label claim weight. A filling machine dispenses the product into containers. The characteristic of products for the filling operation is the fill weight (response variable), and is assumed to be a random variable with a certain probability distribution. Although the company decides and sets the target or nominal value for the fill weight, the variation in the amount of medicine dispensed into each container by the same filling equipment will adversely affect the quality and also the cost (Philips and Cho 2000, Tang and Lo 1993). The variations are caused by the design of the filling process, skills of operators, environment, machine and the physical properties of the product (Usher, Alexander and Duggins 1996, Taylor 1991).

Sampling plan, control charts, regression analysis and experimental design are typical tools for quality improvement of filling processes, to identify the sources of fill-weight variations, to determine the optimal process mean (Anis 2003, Misiorek and Barnett 2000), and then to reduce the process variability. Earlier work in this area includes Burr (1949), Springer (1951), and Bettes (1962). They considered the problem of determining the optimal process mean with specified upper and lower specification limits while taking into consideration of economic aspects, and thus to reduce the total cost. Nelson (1979) later extended Burr's work by developing a graphical method to select the optimal settings.

Hunter and Kartha (1977) developed a model to determine the optimal target value of an industrial process so as to minimize the expected loss. Nelson (1978) found an appropriate function, which may be used to find a better approximate optimal solution. He also included a plot of errors. A generalization of this model was presented by Bisgaard, Hunter, and Pallesen (1984), where the authors developed a procedure for selecting optimal values for the process mean as well as the variance. They eliminated the assumption made in Hunter and Kartha (1977) that all under-filled items are sold at a fixed price. They considered a situation where under-filled items are sold for a price that is proportional to the amount of ingredient in the container.

This paper deals with the problem of the determination of the factor settings that optimize the process mean (e.g., reduce the deviation of the average fill from the target value), as well as minimize the variability in a pharmaceutical filling operation. $4^1 x 2^3$ mixed-level factorial design is used. For more details about mixed level factorial design, see Wu and Hamada (2000), Montgomery (2005). Analysis of variance (ANOVA) was performed on the fill weights to determine the optimal condition of the filling process. Significant improvement was observed in terms of minimizing the deviation of the average fill from the target value, as well as reducing the variability around the process mean. For the reason of confidential and proprietary information of the company, as set in an agreement with the company before conducting this project, all data in this study are coded to a certain scale.

2. Problem definition and assumption

As stated earlier, this paper focuses on a pharmaceutical filling process. A lower limit is specified for the filling process and the manufacturing company is required to meet the fill weight specification. Under-filled containers put the company at risk with the liability due to FDA regulations (i.e., companies may face a recall or a serious fine). Therefore, pharmaceutical companies tend to use a process mean much higher than the target value to reduce the risk of producing under-filled units, consequently to ensure the better conformance to specification. However, using higher process mean or over-filled strategy results in substantial loss to the manufacturer (Tan 1990) due to the high expense of medicine. A typical problem for generic pharmaceutical production is to find the optimal level settings for the controllable input variables that can optimize the process mean (i.e., make the process mean equal to or as close as possible to the target value) while minimizing the variability in the fill weight. The output characteristic of the filling process is the fill weight denoted by y or response variable. It can be assumed to have a normal distribution with mean μ and variance σ^2, or $N(\mu, \sigma^2)$.

3. Schematic model of the filling process

Based on brainstorming and group discussion of company's employees involved in the specific process, factors that might affect the fill weight variation were identified as:

- Line speed (number of bottles filled per minute).
- Product Viscosity.
- Production Shift
- Height of Solution in the filler bowl (HSFB)

If interactions of three or more factors are assumed negligible, the statistical model of the characteristic of the filling process is given by:

$$y_{ijklm} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + \delta_l + (\tau\delta)_{il} + (\beta\delta)_{il} + (\gamma\delta)_{kl} + \varepsilon_{ijklm} \qquad (1)$$

Where i = 1, 2, 3, 4; j, k, l = 1 or 2 and m = 1, 2, … 21; Also,

y_{ijklm} represents an observed fill weight at specific level setting of process parameters
μ represents the overall mean of the filling process
τ_i represents the effect of the ith level of line speed
β_j represents the effect of the *j*th level of product viscosity
γ_k represents the effect of the *k*th level of production shift
δ_l represents the effect of lth level of HSFB.
ε_{ijklm} represents the random error.
$(\tau\beta)_{ij}$, $(\tau\gamma)_{ik}$, $(\beta\gamma)_{jk}$, $(\tau\delta)_{il}$, $(\beta\delta)_{il}$, and $(\gamma\delta)_{kl}$, are interaction effects of respective factors.

An illustration of the filling process can be depicted in Figure 1. The signal factor and the control variables are the factors to be chosen for the optimal levels settings for the filling process to minimize the process variation and the mean deviation from the target. In Figure 1, signal factor is the viscosity of the product, because the viscosity can be expected but our engineers cannot control its different levels. The viscosity of a product is determined during the in-process phase and at the completion of the batch. The uncontrolled noise factors are fill heads (21 fill heads or filling stations on a rotary filling machine), wear and tear of equipment, changes in the packaging environment, such as changes in temperature, and humidity. Figure 1 depicts the schematic model of the filling process.

4. Discussion of factors

Controlled variable: A controlled variable is one that a manufacturer can control and as a result, can alter the amount used in the product or process design. We need to find the optimal level settings for the minimization of noise factor's effects on the response variable y. Controllable variables in this process:
Line Speed: The line speed is a quantitative parameter. It is the number of bottles filled per minute (bpm). The line speed is a controlled factor. It was adjusted several times during a pilot study to learn the settings that impacts fill weight variation.
HSFB: Height of solution in the filler bowl or holding tank. Adjusting the float bar and a sensor mounted on top of the filler bowl controls the amount of product in the filler bowl. Two levels can be assigned to this factor (high and low). The quantity of product in the filler bowl affects the pressure in the filler.

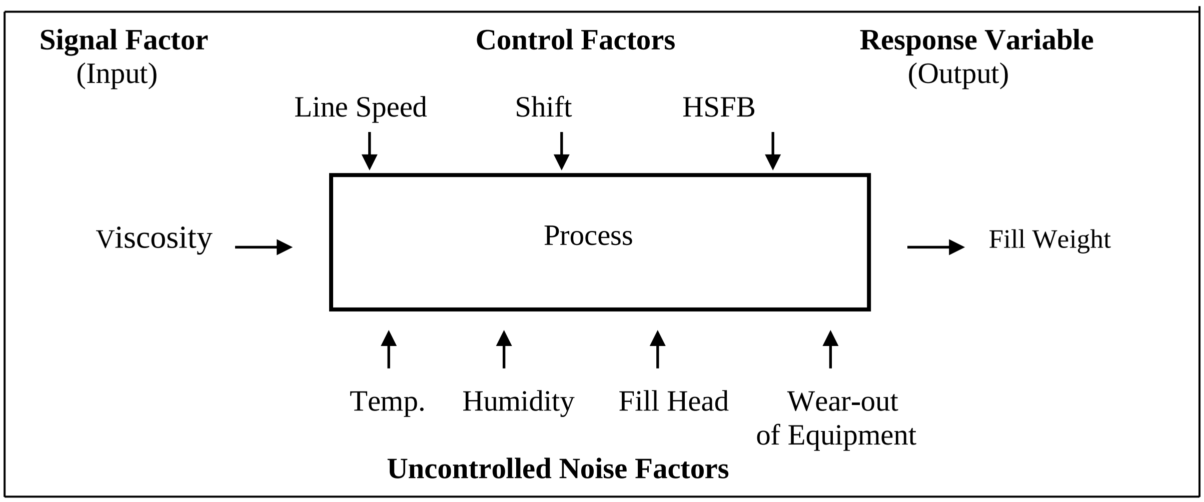

Figure 1. Schematic model of the filling process

Signal Factors: A special factor, with a range of settings, which is controlled by the user of the product to make use of its intended function. It is used in dynamic experiments (see Chen and Kapur 1997). An example of signal factor in this research is viscosity. Product *v*iscosity is the resistance of fluids to flow (i.e., the thickness of the liquid). Viscosity is determined by the nature of the product (medicine). As mentioned earlier, viscosity tests are performed on some batches during in-process and finished product. The classification of product viscosity is depicted in table 1.

Table 1. Product viscosity and their levels

Medicine Product	Viscosity Range (Level)
A, B, C, & D	Low (below 200 cps)
E	High (above 200 cps)

Production Shift: Operator knowledge, Setup, over or under adjustments (Improper fill head adjustments) and running damaged nozzle.
Noise factors that we cannot control in this research include:

- *Environment changes* such as temperature and room humidity. During the manufacturing process of a batch, the temperature of the jacket surrounding the mixer is controlled by the presence of cooling water running through the mixer jacket, if desired. Otherwise the mixer runs at the ambient temperature. Temperature is treated as a noise factor.
- *Fill heads***:** there are 21 fill heads that can fill bottles simultaneously on the rotary fill machine. There may exist variations of these fill heads in inside diameter, valve leakage, & other dimensional variations due to usage.
- *Wear out of equipment* as a result of equipment usage.

All these factors are summarized in a cause and effect diagram in Figure 2, which can show the relationship between a variation effect and the various factors. The experiment is arranged so that the levels of viscosity are kept constant as long as possible. Table 2 gives the control factors and their levels. In this study, we used a 4^1x2^3 mixed-level factorial design to accommodate the restriction of production line set-up. One factor has 4 levels and three other factors have 2 levels for each. As shown in Table 2, there are four different levels that are assigned to line speed; while viscosity, shift, and the height of solution in the filler bowl (HSFB) has two levels each. A full factorial design of these levels combinations resulted in 32 experimental conditions (experimental runs).

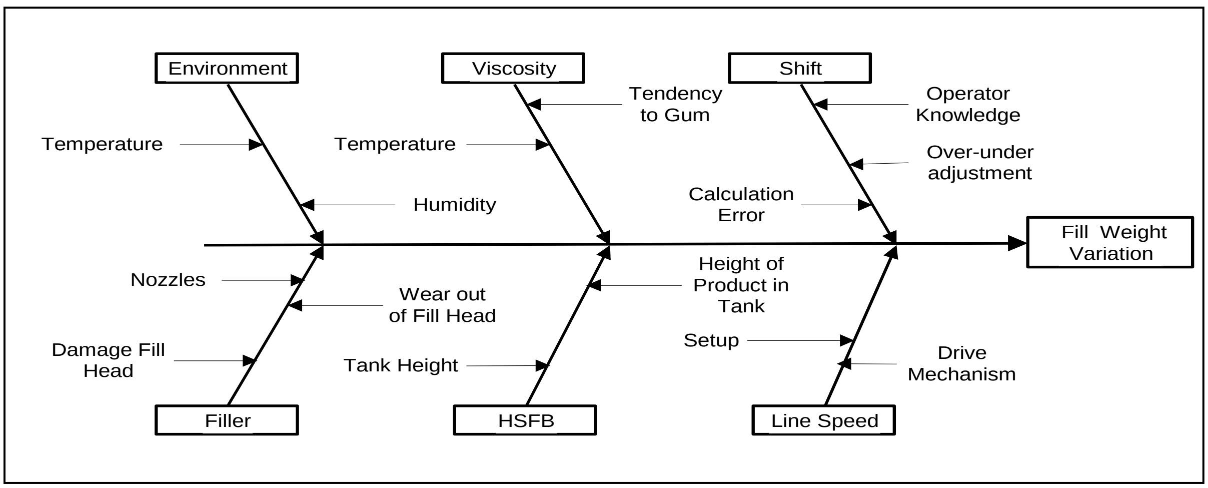

Figure 2. Cause and Effect Diagram (Analysis of Possible Causes to Fill Weight Variability)

Table 2. Control factors and their levels for the mixed-level factorial (4^1x 2^3) design.

Line Speed (X_1)	Viscosity (X_2)	Shift (X_3)	HSFB (X_4)
(4 Levels)	*(2 Levels)*	*(2 Levels)*	*(2 Levels)*
(50) = 1	10 – 200 (low =1)	1	Low = 1
(65) = 2	Above 200 (high=2)	2	High = 2
(80) = 3			
(94) = 4			

To evaluate the loss to the company due to the deviation from the target value, Taguchi's quadratic loss function is considered in this study:

$$L(y) = k(y-T)^2 \qquad (2)$$

The expected quality loss is given by:

$$E[L(y)] = k[\sigma^2 + (\bar{y} - T)^2] \qquad (3)$$

where L(y) is the loss caused by a deviation from the target measure T of a product quality characteristic y, and k is a numerical constant transferring the quadratic value of the deviation to a monetary scale, which can be calculated by A_0/Δ_0^2, and

A_0 = loss caused by a product out of specification;
Δ_0 = (USL – LSL)/2
USL = Upper specification limit
LSL = Lower specification limit

To evaluate the quality loss to the company, we used the following data (coded) obtained during the packaging operation for product *A*.
Given: LSL = –5.3, T = –1.9, USL = 6.2, σ^2 = 2.5308, Mean = 3.1381, A_0= \$2.00
Then Δ_0^2 = $[(6.2 - (-5.3))/2]^2$ = 33.0625, k= \$2.00/33.0625 = 0.060
Using Equation (3), the expected quality loss to the company is:
$E[L(y)]=0.060[2.5308+(3.1381-(-1.9))^2]$= \$1.67 per unit on average.

Figure 3 shows the process capability chart for the filling process of product *A*. From the chart it can be observed that the mean of the process is centered at 3.1381, and not on the target value. The standard deviation is 1.5909. The histogram extends beyond the upper specification limit. This implies that some units were filled above the upper specification limit. Any deviation from the target incurs a loss. C_{pk} value of 0.63 is lower than the desired minimum value of 1.33. Additionally, C_{pm} = 0.21 indicates the process is not centered and goes beyond the upper specification limit. As a result, the process had a great room for quality improvement.

6. Specifications of the 32 experimental runs for this research

The mixed level design worksheet in Table 3 was generated with a Minitab software package. The worksheet depicts a single four-level factor and three two-level factors we intend to study. Although the number of levels for the factors is different, as shown in table 2, it can be seen from table 3 that the four-level factor "line speed" is proportionately balanced. We used the design worksheet for the mixed level experimental run. In Table 3, the process factors are displayed in columns 5 through 8.

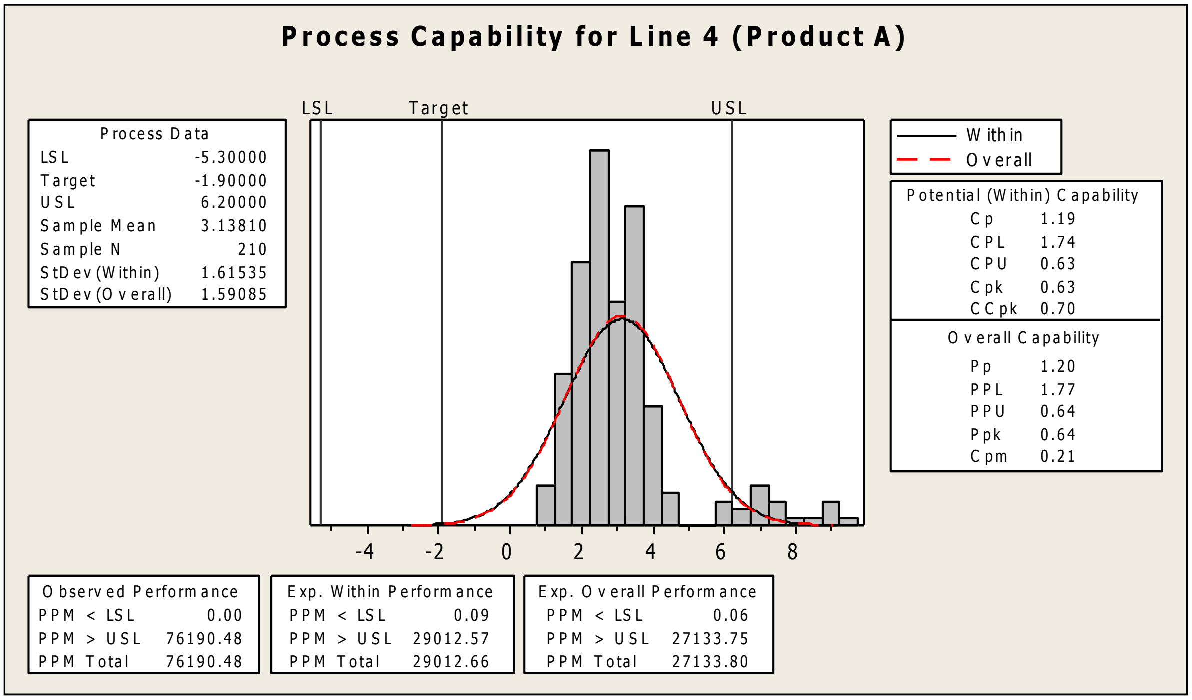

Figure 3. Process capability chart for the filling process of product A

7. THE EXPERIMENTS AND DATA COLLECTION

The four factors are carried forward from table 2 to table 3 and this specifies 32 runs for the design. The following approach was used for this experiment. The production line was setup according to the level of each factor shown in table 3. For instance, for the first row of table 3, the entry in column 5 is 1, the entry in column 6 is 2, the entry in column 7 is 1 and the entry in column 8 is also 1, so run 1 has:

Factor x_1 *at* level 1; Factor x_2 *at* level 2; Factor x_3 *at* level 1; Factorx_4 *at* level 1

The filling machine should be run for a while so as to attain a steady state condition. The filling machine contains 21 fill heads, so 21 samples from each filling circle (1 unit from each fill head) were collected from each experimental run, twenty-one samples were collected from the first experimental run. A total of 672 (21 samples by 32 experimental runs) samples were collected from the entire experimental runs. We were able to collect so many samples because weighing the samples is not destructive and the samples can be put back in line for use. In addition, weighing a bottle takes very little time. We used the same approach for experimental runs 2 through 32, for each run given the factor levels as in Table 3. During each experimental run, samples were collected from each fill head. The data (coded) in Table 4 are fill weights of the samples collected from the 32 runs or factor level combinations as depicted in Table 3. At the completion of the experiment, we used Design-Expert software package to analyze the data collected and then draw conclusion from the analysis.

Table 3. Design worksheet in standard order for the mixed level factorial design.

Std Order	Run Order	Center Pt	Blocks	Line Speed Levels	Viscosity Levels	Shift	HSFB
5	1	1	1	1	2	1	1
6	2	1	1	1	2	1	2
8	3	1	1	1	2	2	2
10	4	1	1	2	1	1	2
16	5	1	1	2	2	2	2
11	6	1	1	2	1	2	1
21	7	1	1	3	2	1	1
4	8	1	1	1	1	2	2
2	9	1	1	1	1	1	2
26	10	1	1	4	1	1	2
18	11	1	1	3	1	1	2
30	12	1	1	4	2	1	2
9	13	1	1	2	1	1	1
14	14	1	1	2	2	1	2
23	15	1	1	3	2	2	1
3	16	1	1	1	1	2	1
29	17	1	1	4	2	1	1
12	18	1	1	2	1	2	2
28	19	1	1	4	1	2	2
15	20	1	1	2	2	2	1
7	21	1	1	1	2	2	1
13	22	1	1	2	2	1	1
19	23	1	1	3	1	2	1
25	24	1	1	4	1	1	1
22	25	1	1	3	2	1	2
20	26	1	1	3	1	2	2
27	27	1	1	4	1	2	1
17	28	1	1	3	1	1	1
24	29	1	1	3	2	2	2
32	30	1	1	4	2	2	2
31	31	1	1	4	2	2	1
1	32	1	1	1	1	1	1

Total experimental run = 32 treatment combination

8. Statistical analysis of data and interpretation of results

At the completion of the mixed-level factorial experiment, models were fitted to the data generated by all 32 experimental runs. The ANOVA (analysis of variance) test of the General Linear Model procedure available in the Design-Expert was used to analyze the significance of the factors and their interactions. In this section we summarize and analyze the data from the mixed-level factorial experiments. Statistical and graphical evaluation of the data is presented. In the final stage of the analysis of the data, we used Design-Expert software package to predict the optimal factor settings, or to obtain the best level combination of controllable factors for both high and low viscosity products. In Figure 4, it can be observed that line speed and HSFB have positive main effects; that is, increasing these variables will increase the average fill. However, there is a nonlinear effect of line speed. As the line speed goes from 80 to 94 bpm the average fill drops.

Table 4. Fill weight obtained from the mixed level factorial experiments.

Fill Head #	Run #											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	78.1	78.1	78.7	76.4	78.7	76.9	77.4	76.2	75.8	78.3	78.8	78.3
2	77.6	77.1	78.6	75.4	78.6	76.2	77.0	75.8	75.3	78.8	78.8	77.1
3	78.1	77.8	77.9	75.9	77.7	76.7	77.3	76.2	75.7	78.4	79.0	78.1
4	77.8	74.1	77.5	75.6	77.0	76.4	78.8	76.1	75.5	78.9	79.1	74.6
5	78.4	77.9	79.3	76.1	78.9	76.4	78.6	76.5	76.0	78.8	79.0	78.1
6	78.0	77.7	78.9	75.8	78.9	77.1	76.6	77.1	75.8	78.8	78.9	78.0
7	76.2	77.8	79.0	75.7	78.9	76.7	76.7	76.7	75.6	78.9	79.2	78.0
8	78.0	77.8	79.1	75.7	79.1	77.6	77.5	76.8	75.8	78.6	79.0	78.0
9	76.3	77.9	79.1	76.1	78.1	76.9	77.9	76.5	75.5	74.7	76.1	75.9
10	75.5	77.7	79.1	75.5	77.9	76.6	77.6	76.6	75.6	78.8	75.6	77.8
11	78.6	77.8	79.4	75.9	78.7	76.5	79.2	76.3	75.7	79.3	79.2	76.7
12	77.8	78.2	79.4	76.0	79.1	76.9	77.2	76.9	75.8	78.8	79.2	77.7
13	78.2	77.4	77.1	76.0	76.5	76.4	76.6	76.3	75.9	79.2	78.6	74.4
14	78.5	77.6	77.0	76.0	76.8	76.9	76.5	76.8	75.6	78.9	79.2	78.0
15	78.1	78.0	79.0	75.5	77.9	76.4	75.8	76.5	75.5	78.8	79.1	78.2
16	78.3	78.8	79.0	75.9	78.1	76.6	75.7	76.6	75.9	78.6	79.6	79.1
17	78.8	78.3	79.1	76.4	78.4	77.0	76.9	77.2	75.8	79.0	79.2	78.7
18	78.6	77.8	79.1	76.1	77.9	77.4	78.3	77.5	75.9	79.0	79.2	78.0
19	79.0	78.3	79.5	76.5	79.4	77.0	80.0	77.1	75.8	78.9	79.7	78.0
20	77.5	77.8	79.6	75.9	79.3	77.9	81.0	76.9	75.9	79.0	79.3	76.9
21	77.4	77.7	78.8	76.0	78.6	76.8	79.6	76.7	75.8	79.1	79.3	77.8

Table 4 (Continued)

Fill Head #	Run #											
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	78.8	80.8	78.3	76.8	78.0	76.8	76.8	78.4	77.7	78.0	76.7	78.6
2	78.8	80.7	77.8	76.3	77.4	76.5	76.2	77.8	79.5	78.0	76.2	78.1
3	78.1	79.9	77.6	76.7	76.4	76.5	76.8	76.3	76.7	76.6	76.6	78.8
4	78.7	79.6	78.2	76.3	77.6	76.6	76.6	75.8	76.3	77.1	76.5	78.5
5	78.5	77.1	77.9	76.6	80.2	76.7	76.6	77.8	74.7	80.0	76.6	78.8
6	78.9	79.7	78.1	77.3	77.6	77.1	77.1	77.2	76.8	76.8	77.1	78.6
7	78.3	80.9	76.2	76.8	76.7	77.5	76.7	77.4	79.7	76.0	76.8	78.4
8	78.5	81.0	78.0	77.0	78.5	77.5	77.1	79.5	78.1	78.3	77.3	78.5
9	78.6	80.3	77.1	77.0	77.5	77.0	77.2	76.6	75.0	78.0	76.8	78.5
10	78.7	77.6	76.0	76.7	77.7	76.7	76.7	75.0	76.4	77.8	76.5	78.5
11	78.6	79.4	78.3	76.5	80.7	76.7	76.5	77.5	76.0	79.9	76.5	78.7
12	78.8	76.5	76.3	77.1	77.5	77.1	77.1	78.0	77.3	77.8	77.2	78.8
13	78.9	76.2	77.7	76.5	77.3	76.7	76.2	78.7	78.2	77.8	76.4	78.7
14	78.9	75.2	78.5	77.1	77.0	76.9	77.2	77.8	78.2	77.0	77.0	78.8
15	78.9	77.7	77.4	76.3	76.4	76.8	76.4	75.9	76.5	76.2	76.3	78.6
16	78.7	81.0	75.6	76.7	73.7	76.9	77.0	77.8	76.0	74.5	76.6	78.6
17	78.7	80.1	77.8	77.1	75.9	77.4	77.0	80.8	77.6	75.0	77.0	78.8
18	78.8	78.8	77.0	77.5	77.0	77.4	77.3	80.7	81.2	76.0	77.5	78.6
19	78.8	81.1	77.9	77.1	78.8	77.6	77.2	77.1	76.5	79.8	77.0	78.6
20	78.9	80.2	77.4	77.2	81.9	77.2	76.9	75.9	76.4	81.4	77.0	78.4
21	78.4	78.3	79.3	76.7	82.0	76.9	76.8	80.1	79.6	81.5	76.6	78.5

Table 4 (Continued)

Fill Head #	Run #							
	25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
1	79.7	79.5	76.8	78.7	79.0	79.9	78.1	78.5
2	78.1	79.1	76.3	77.9	79.9	79.4	78.0	77.8
3	76.7	79.8	76.6	78.4	77.1	79.0	78.4	78.1
4	77.4	79.7	76.5	78.2	79.1	77.2	78.4	78.1
5	80.4	79.7	76.6	78.6	80.0	79.7	78.4	78.4
6	77.1	79.7	77.0	78.4	80.4	80.2	78.5	78.2
7	76.7	79.7	76.8	78.1	77.4	79.4	77.7	78.1
8	77.0	79.9	77.0	78.3	79.4	78.3	77.6	78.4
9	77.1	79.3	77.0	78.2	78.2	80.1	76.2	78.2
10	78.2	78.5	76.8	78.5	76.2	79.7	76.1	78.3
11	80.7	79.0	76.7	78.4	75.9	74.7	77.8	78.2
12	77.6	80.0	77.3	78.5	74.6	75.2	77.6	78.5
13	77.6	79.7	76.5	78.6	76.2	73.7	78.6	78.4
14	76.5	79.8	77.0	78.7	75.2	75.3	78.5	78.3
15	76.1	79.7	76.5	78.5	80.7	82.0	78.4	78.5
16	76.3	80.2	76.9	78.6	81.6	81.2	78.5	78.4
17	75.1	79.7	77.2	78.7	79.8	77.8	78.7	78.5
18	75.8	79.7	77.3	78.4	77.1	80.7	78.6	78.4
19	77.3	78.3	77.0	78.5	80.2	80.1	77.7	78.3
20	81.6	78.4	77.1	78.2	80.6	80.0	78.0	78.1
21	81.9	79.7	76.7	78.2	80.4	80.3	78.4	78.3

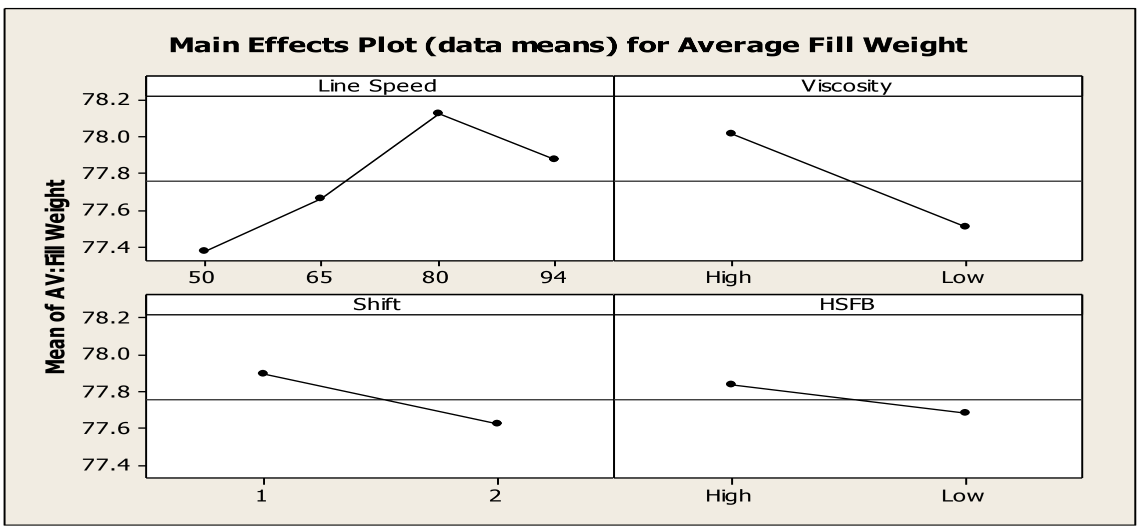

Figure 4. Main effects plot of mean response.

Figure 5 shows cube plots of average fill weight and standard deviation obtained from the mixed factorial design experiment for factors: line speed, and shift. From the plot, we can see that the maximum standard deviation occurs at the corner point for shift 1, line speed 94 bpm for high-viscosity product, and the minimum standard deviation occurs when line speed is 50 bpm and shift is 1 for low-viscosity product. Thus, for both low and high viscosity products, running the filling process at low line speed on shift 1 produces the minimum variability in the filling process.

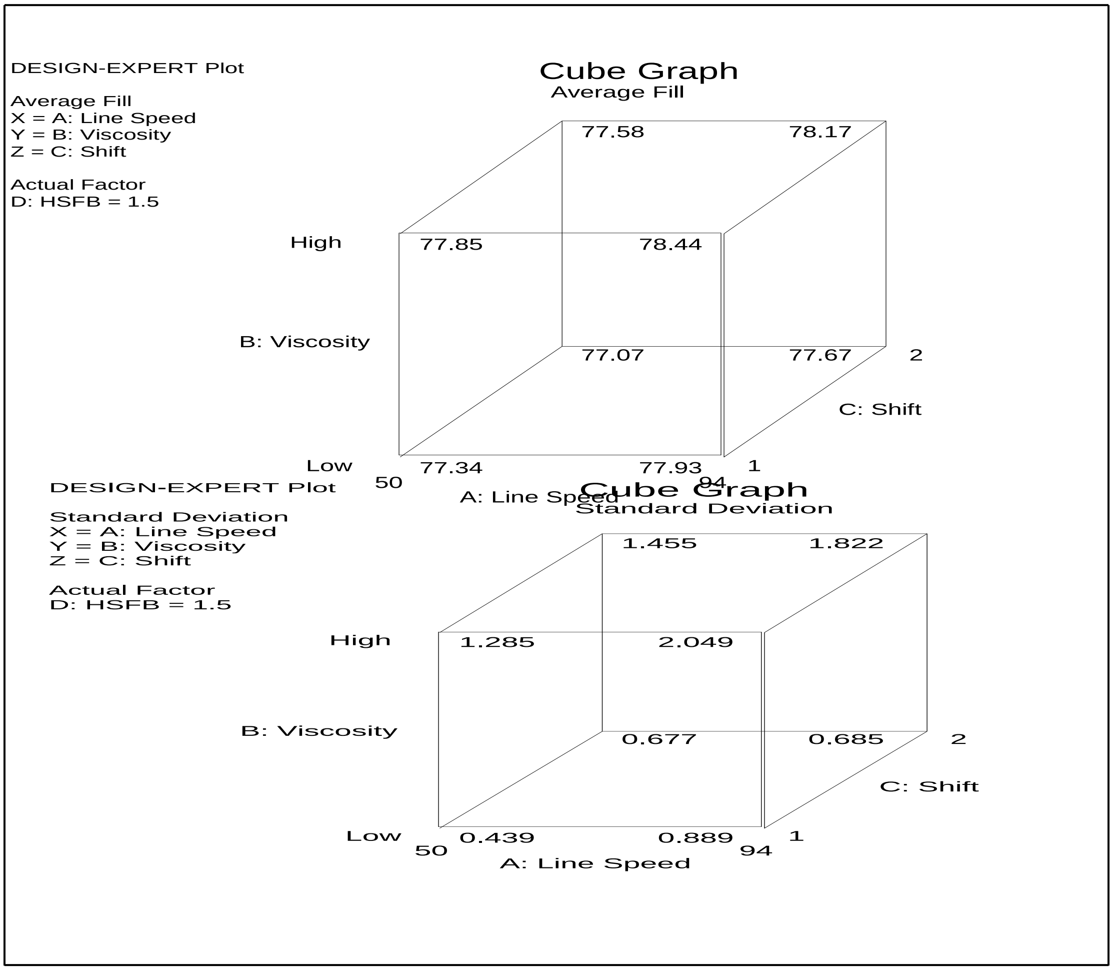

Figure 5 depicts cube plots for mean response and standard deviations.

Figure 6 is a graphical representation of contour and surface response plots for the average fill as a function of line speed and viscosity while both HSFB and shift are fixed at level 2. These plots were obtained from the fitted model (for response surface, see Shah, Montgomery and Carlyle 2004). From both plots, it can be observed that the average fill increases as line speed increases.

In addition to these plots, we also fit the models (by using Design Expert) for the response y, standard deviation and variation of the data in Table 4 obtained during the mixed level factorial experiment (See Equations 4 through 6). The models include linear and two-factor interaction terms. The quadratic, cubic and higher interaction terms are aliases (Table 5). The fitted model can be used to predict the individual response for various levels settings.

Process mean:

$$\hat{y} = 81.4962 + 0.0386x_1 - 0.3740x_2 - 3.0357x_3 - 4.4761x_4 - 0.02571x_1x_2 - 0.00893x_1x_3 + 0.01792x_1x_4 + 0.9375x_2x_3 + 0.8875x_2x_4 + 1.3375x_3x_4 \quad (4)$$

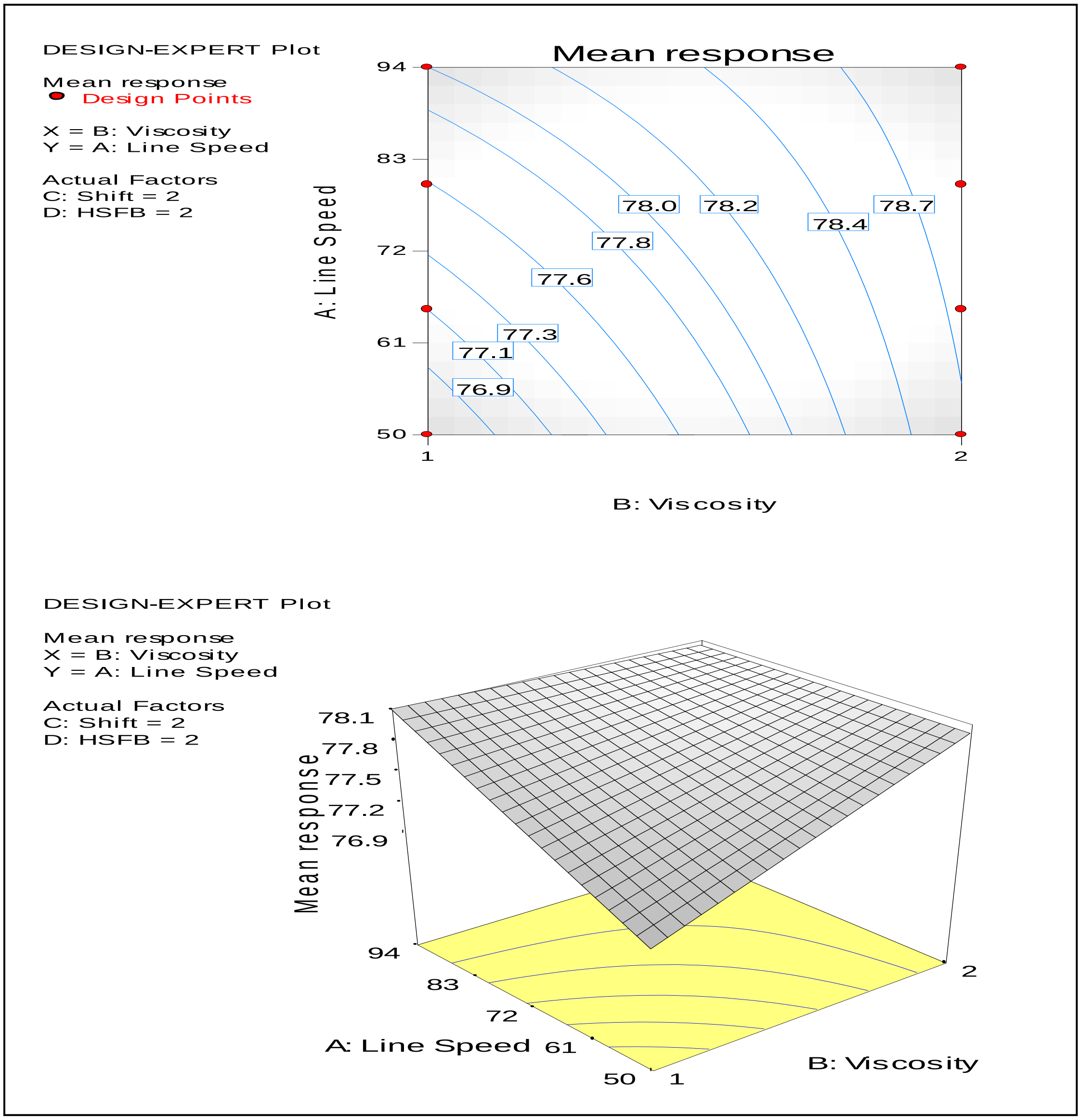

Figure 6. Contour and response surface plots.

Standard Deviation:

$$\sigma = 0.110 - 0.0127x_1 + 0.875x_2 + 0.348x_3 - 1.04x_4 + 0.00730x_1x_2 - 0.0099x_1x_3 + 0.0172x_1x_4 - 0.0717x_2x_3 - 0.200x_2x_4 + 0.320x_3x_4 \quad (5)$$

Variance

$$\sigma^2 = 6.47 - 0.0848x_1 - 0.557x_2 - 1.34x_3 - 5.03x_4 + 0.0354x_1x_2 - 0.00977_1x_3 + 0.0502x_1x_4 + 0.0574x_2x_3 + 0.239x_2x_4 + 1.32x_3x_4 \quad (6)$$

Where x_1 is Line Speed; x_2 is Viscosity; x_3 is Shift and x_4 is HSFB. The x_1x_2, x_1x_3, x_1x_4, x_2x_3, x_2x_4, and x_3x_4 terms are the interactions, with ignoring the cubic and higher-order interactions terms.

9. ANOVA for the mixed level factorial experiment

Design-Expert software package was used to analyze the data from the mixed level factorial experiment using the desirability function approach. Table 5 depicts the ANOVA table obtained for the average fill weight versus the variables (line speed, HSFB, Shift and Viscosity). The desirability approach was used to find the operating conditions for the most desirable response value, i.e., the response with the minimum deviation from the target value. We obtained the optimal parameter settings for both low and high viscosity products from the table. From Table 5, solution 1 has the highest overall desirability for both high and low viscosity products. Tables 6 and 7 give the optimal parameter settings for low and high viscosity products depicted in table 5. The table shows only partial information from the computer output. To verify the optimal parameter settings as predicted by the Design-Expert software package, confirmatory experiments (using the optimal factor settings given in Tables 6 and 7, respectively) were performed. Two hundred and ten samples were taken from each of the confirmatory runs. The result of the confirmation test shows a good match between the predicted and actual data.

Table 5. Computer Output from Design Expert for Fitting a Model to the data in Table 4.

Response: Mean response

Sequential Model Sum of Squares

Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**		**Prob > F**
Mean	1.935E+005	1	1.935E+005			Suggested
Linear	4.40	4	1.10	1.34	0.2808	
2FI	9.21	6	1.53	2.48	0.0565	Suggested
Quadratic	0.53	1	0.53	0.85	0.3670	Aliased
Cubic	5.24	8	0.66	1.09	0.4293	Aliased
Residual	7.20	12	0.60			
Total	1.935E+005	32	6047.35			

Final Equation in Terms of Actual Factors:

Mean response =	
81.5	
+0.0386	* Line Speed
-0.374	* Viscosity
-3.04	* Shift
-4.48	* HSFB
-0.0257	* Line Speed * Viscosity
-0.00893	* Line Speed * Shift
+0.0179	* Line Speed * HSFB
+0.938	* Viscosity * Shift
+0.888	* Viscosity * HSFB
+1.34	* Shift * HSFB

Table 5 (Continued)

Solutions Number	Line Speed	Viscosity	Shift	HSFB	Mean response	Desirability	
1	**94**	**2**	**1**	**2**	**78.2**	**0.929**	**Selected**
2	94	2	1	2	78.2	0.920	
3	94	2	1	1	78.2	0.918	
4	89	2	1	2	78.1	0.917	
5	94	2	1	2	78.2	0.909	
6	90	2	1	2	78.2	0.902	
7	94	2	1	1	78.1	0.896	
8	80	2	1	2	78.0	0.883	
9	77	2	1	2	77.8	0.820	

9 Solutions found

Constraints Solutions Number	Line Speed	Viscosity	Shift	HSFB	Mean response	Desirability	
1	**80**	**1**	**2**	**2**	**78.0**	**0.923**	**Selected**
2	80	1	2	2	78.1	0.923	
3	94	1	2	2	78.1	0.922	
4	94	1	2	2	78.1	0.922	
5	94	1	1	2	78.2	0.921	
6	80	1	1	1	78.0	0.920	
7	94	1	1	1	78.1	0.919	
8	80	1	1	2	77.9	0.918	
9	94	1	1	2	78.2	0.911	
10	94	1	1	1	78.3	0.902	

10 Solutions found

Table 6. Recommended Optimal factor settings for high viscosity (level 2) products

Line Speed	HSFB	Shift
94 bpm	2	1

Table 7. Recommended Optimal factor settings for low viscosity (level 1) products

Line Speed	HSFB	Shift
80 bpm	2	2

10. Conclusion

In this paper, experimental and mixed level factorial design was used to study and find the optimal process parameter setting. Quality loss function and process capability analysis were also used to evaluate the current variability of a generic pharmaceutical filling process. The significance of the impact of the process factors and their interactions were determined through ANOVA based on a 4^1x2^3 mixed level factorial design. This mixed-level factorial design of 32 experimental runs was performed and Design-Expert software package was utilized to obtain the best levels for controllable factor settings as in Tables 6 & 7 that optimize the process for both high and low viscosity products. The confirmatory runs indicate a good match between the predicted results.

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Paper ID: 117

Invention Principles and Contradiction Matrix for Semiconductor Manufacturing Industry : Chemical Mechanical Polishing

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Abstract

The classical contradiction matrix (CM) and inventive principles (IPs) developed by Altshuller were based on patents from traditional industries in the 1950s. Evidences showed that the classical contradiction matrix and inventive principles are not quite suitable for newer high-technology industries such as semiconductor industry due to the fact that the fundamental physics of operating principles are different. To date, no research has developed any CM and IP specifically suitable for the semiconductor industry. This research, as the first step of efforts to develop suitable CM and IP for semiconductor industry using patents from Chemical Mechanical Processing (CMP) equipment and processes in the semiconductor industry. By focusing on a particular industry, we can develop a more suitable CM and IP for that particular industry and with less number of patents needed to review. The results show that a newly established preliminary CM based on merely 120 patents from 1999 to 2006 can interpret 77% of the inventive principles in a set of new patents. This is a significant improvement over the original Altshuller's original CM which can only interpret 46% with 40,000 patents studied. In addition, during this study, two existing principles were revised to reflect a broader application and three new inventive principles were identified.

The contributions of this research include: 1) Revising the traditional engineering parameters to be consistent with semiconductor industry including the addition of 7 new parameters; 2) Identifying 3 new IPs and modifying 2 IPs for CMP processes; 3) Establishing a triplet representation to model any patent to facilitate future analytical studies of the contradiction matrix and IPs.

Keywords: Contradiction matrix; Inventive principles; Theory of Inventive Problem Solving; Chemical Mechanical Processing; Semiconductor industry

1. Introduction

TRIZ is a Russian acronym of "Teoriya Resheniya Izobreatatelskikh Zadatch" approximately translated into English as "Theory of Inventive Problem Solving'. The body of knowledge was originally established by a Russian Inventor Genrich Altshuller starting from 1946. Among the many tools Altshuller established, the Contradiction Matrix and Inventive Principles is the most used tool for systematic innovations. The usage of and the relationships among the various TRIZ tools including the contradiction Matrix and Inventive Principles was identified by [Sheu 2007]. Altshuller and his partner studied two hundred thousand patents and concluded that all inventions are results of solving contradictions and that contradictions are the blocking stones of all inventive improvements. Based on this theory, Altshuller classified engineering problems into contradictions between 39 parameters and identified 40 inventive principles. Contradictions are classified based on the pairs of improving parameters and worsening parameters. Each type of the pair of contradiction may have some corresponding inventive principles which were found to be effective in solving that particular type of contradiction based on past patents. However, Darrell Mann found that Altshuller's contradiction Matrix can only interpret 48 percent of newer mechanical design patents [Mann 2002]. In this study, the authors found that Altshuller's Matrix which was the result of studying two hundred thousand patents can only interpret 46% of the Chemical-Mechanical Processes (CMP) in semiconductor industry while the matrix established by the authors out of some 120 patents from 1990's can interpret 77% of the CMP patents [Sheu 2007]. This indicates that the effectiveness of the contradiction matrix is application specific and different industries may need to establish their own specific matrices due the different working principles in fundamental physics/chemistry between industries.

The study also established an augmented parameter set and the prototype of the contradiction matrix for the Chemical-Mechanical Polishing processes and equipment.

2. Previous Work

2.1 The Classical Contradiction Matrix

The well-known classical contradiction matrix consists of 39 engineering parameters on the left and upper sides of the matrix. An abbreviated version is shown in Table 1 and the full version can be found in many TRIZ books including [Mann 2007]. The Matrix maps the technical problem modeled by contradiction represented by corresponding "improve" and "worsen" parameter set to Inventive principles to help people solve the problem.

Table 1. The Contradiction Matrix

		Parameter Which Gets Worse			
		1.Weight of moving object	2.Weight of stationary object	…	39.Productivity
Parameter To Be Improved	1.Weight of moving object				35,3,24,37
	2.Weight of stationary object				1,28,15,35
	…				
	39.Productivity	35,26,24,37	28,27,15,3		

2.2 Suitability of the Contradiction Matrix

This is witnessed by this research that the interpretability of the classical matrix is only 46% on the chemical-mechanical polishing patents. [Mann 2002] also reported a mere 48% applicability on the mechanical patents. [Mann 2006] re-did the matrix for software industry because of the same reason. For the semiconductor industry, it is therefore needed to re-do the matrix if the concept of contradiction matrix and inventive principles is to be used.

Altshuller's Classical Matrix was developed in the 1950's using patents from traditional mechanical systems. Recent studies indicated that the suitability of using the classical matrix to solve recent engineering problems may be limited.

Darrell Mann(2002) chose 130 patents from mechanical systems in the American and European patents to verify the suitability of the classical CM. The principle proposed by the classical CM can only interpret 48% of the 130 recent patents. The conclusion Mann's research team made was that the classical matrix was assembled from electro-mechanical patents more than twenty years ago. Therefore, the more recent advances were not intractable by the classical matrix. The results of this study suggest that, for mechanically oriented problems, the recommendations by the classical matrix will be right just under half of the time. Therefore, Darrell Mann and his team in [Mann, etc. 2003] used the same idea of contradicting parameters and inventive principles to established Matrix 2003 based on the analysis of 150,000 patents issued between 1985 and 2003. Three types of matrices were established: The new technical matrix, the business matrix, and the Information Technology (I.T.) matrix. Unlike many empty cells in the Classical Matrix, the Matrix

2003 have no empty cells. In the new technical matrix, the number of parameters was increased from 39 to 48. In the Business Matrix, 31 parameters were used. In the I.T. Matrix, there were 21 parameters. The number of corresponding inventive principles remains as 40 though the ways to interpret each inventive principle are customized for different types of matrices. The established new matrices were also coded in Matrix+ software [Matrix+] to automate and facilitate the matrix applications.

Sheu (2007) suggested that a major factor for the unsuitability of Classical Matrix on the newer industries is that the working principles of the underlying fundamental physics or chemistry for different industries/applications may be quite different. Therefore, the matrix solutions developed from certain industries probably will not work well across different industries when their underlying working principles are quite different. For example, a manager from semiconductor industry in Taiwan described to the author their repeated disappointment in using the classical Altshuller's matrix to solve their problems. The problem can be solved by developing specific set of CM and IP based on that specific type of industry or application. Some domain-oriented CM such as Software Matrix, Business, Eco-innovation, Biological, Nano-technology are either proposed or being developed by Mann. So far, no one has developed any CM in the semiconductor industry especially in the Chemical-mechanical Polishing area.

3. Research Method

3.1 Overview of the Method

Believing that semiconductor industry will need a different parameters and correspondence between the contradictions and their corresponding inventive principles, this study focused on the establishment of prototype contradiction matrix for semiconductor industry. Based on discussions with industry managers, the chemical-mechanical polishing processors (CMP) was selected for establishment of first prototype matrix. 120 patents between 1999 and 2006 were used to extract relevant parameters, invention principles, and their correspondences. The following conclusions were drawn:

1. The original 39 engineering parameters are not adequate for the CMP process /equipment. Additional parameters were identified. Some parameter names were changed to reflect the terminology used in the semiconductor industry.
2. A couple different inventive principles were identified.

The research approach consists of the following steps:

Step 1：Select target for study. Chemical Mechanical Polishing equipment and processes were selected after consulting with a few managers of a leading semiconductor manufacturer.

Step 2：Locate patents of the target application. Patents between 1999 and 2006 were randomly selected for establishment of parameter set and contradiction matrix. Moreover, patents in 2007 were selected for testing of the established contradiction matrix.

Step 3：Modeling of the patent characteristics conducive to this analysis is described in Section 3.2. Each patent is reviewed and characteristics extracted based on the set model.

Step 4：Establishment of the engineering parameters and prototype contradiction matrix specifically for the CMP equipment and processes. Identification of possible new inventive principles used in the CMP patents.

Step 5：Testing and comparing the CMP matrix and the Altshuller matrix for their effectiveness in interpreting the randomly selected CMP patents from year 2007.

Step 6：Testing the validity of the experiment as described in Section 4.3.

3.2 Patent Modeling in Array Format

A set of Arrays is established to represent any patent so that unified format to represent patents can be used enabling a systematic process of study. Refer to Figure 1, a patent can be represented by:

1) A “Problem Array” which is composed of an “Improve Array” and a “Worsen Array” uniquely specifying the problem situation which the patent intends to solve;

2) A “Solution Array” which indicates the inventive principles used to solve the problem by this patent.

The Problem Array and the Solution Array then form the Patent Characteristic Array (PCA) which uniquely represent the patent in this format.

For example, a patent used to improve the conflict represented by parameter #1 (improving) and parameter #10 (worsening) using inventive principle # 20 will have the #1 spot on the “Improve array”, #10 spot on the “worsen array”, and #20 spot on the solution array turned on (1) and the rest spots turned off (0). The PAC can also use to represent the patents solving contradictions of multiple “improve parameters” and multiple “worsen parameters” with multiple inventive principles. For example, a patent using #3, 5, 7 inventive principles to solve the problem of improving #10, 15, 20 parameters will cause the worsening #6, 8, 10 parameters will have the #3, 5, 7 spots of the Solution Array, #10, 15, 20 spots of the “Improve array”, and #6, 8, 10 of the “Worsen array” turned on and the rest spots turned off. In addition to the crisp 0/1 values, real numbers or fractional values can also be introduced to the spots in the arrays to represent uneven improvement/worsening on different parameters and uneven application of the different inventive principles. Fuzzy values can also be introduced to better represent the situations in the real-world problems.

With the patent modeling we can qualitatively represent any patent and pave the way for future correlation studies between the problem array and solution array. Based on the Patent Characteristic Array, A Patent Summary Form, as described in Table 2 is used to record all the essence for the patent.

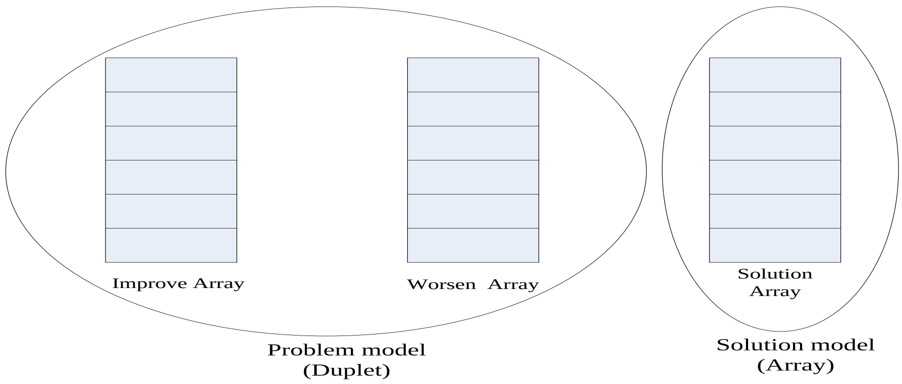

Figure 1. A Patent Array

3.3 Sampling Approach

Granted patents from the Republic of China (Taiwan) and the United States are studied. 120 granted patents in the CMP area randomly selected from the year 1999-2006 are used to establish the prototype contradiction matrix. Another 16 granted patents (22 cases) in the same CMP area in 2007 are used as test samples for the goodness of the Matrix.

Table 2: Patent Summary Form

<table>
<tr><td>ID</td><td></td><td>Patent Title</td><td colspan="4"></td></tr>
<tr><td>Main function</td><td colspan="6">⓪</td></tr>
<tr><td>Expected benefits</td><td colspan="6">⓪</td></tr>
<tr><td rowspan="3">Parameter improved</td><td colspan="2">Para. Name</td><td colspan="4">Original situation/value</td></tr>
<tr><td colspan="2">①</td><td colspan="4">②</td></tr>
<tr><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td rowspan="3">Parameter worsen</td><td colspan="2">Para. Name</td><td colspan="4">Worsening situations</td></tr>
<tr><td colspan="2">③</td><td colspan="4">④</td></tr>
<tr><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td rowspan="3">Solution by this patent</td><td colspan="2">Relevant parameters</td><td colspan="4">Values of parameters</td></tr>
<tr><td colspan="2">⑤</td><td colspan="4">⑥</td></tr>
<tr><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td rowspan="3">Contradiction</td><td>↑</td><td>↓</td><td>Principles used</td><td>↑</td><td>↓</td><td>Principle</td></tr>
<tr><td>⑦</td><td>⑧</td><td>⑨</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Patent briefing (features of the patent)

⑩</td></tr>
</table>

3.4 Identified New Parameters and Inventive Principles

It was clear that the original Altshuller 39 parameters are not sufficient for the CMP processes and its equipment. In particular, the following parameters are common in the CMP field yet can not be appropriately or fully represented by the traditional parameter set of either classical Matrix or Matrix 2003:

- surface asperity (roughness)
- availability
- Uniformity
- Cleanness

- Scratch
- Harmful chemical effects
- Yield /quality

Even though yield maybe related to reliability and scratch/harmful chemical effects maybe related to system generated harmful effect, the practitioners of semiconductor industry generally consider them as different parameters and monitor/control them separately. The fundamental physical/chemical principles between harmful mechanical effects such as scratch and the harmful chemical effects are quite different. They warrant separate treatments in the industry. They are also more consistent to the terminology used by the semiconductor industry.

These parameters were added to the original Altshuller's parameter set. The revised parameter set and the classical parameter set are listed in Table 3:

Table 3:The Engineering Parameters-Classical Matrix v.s CMP based Matrix

Classical Matrix		CMP based Matrix		Classical Matrix		CMP based Matrix	
No.	parameter	No.	parameter	No.	parameter	No.	parameter
1	Weight of moving object	1	Weight of moving object	21	Power	21	Power
2	Weight of stationary object	2	Weight of stationary object	22	Loss of energy	22	Loss of energy
3	Length of moving object	3	Length of moving object	23	Loss of substance	23	Loss of substance
4	Length of stationary object	4	Length of stationary object	24	Loss of information	24	Loss of information
5	Area of moving object	5	Area of moving object	25	Loss of time	25	Loss of time
6	Area of stationary object	6	Area of stationary object	26	Amount of substance	26	Use of consumable
7	Volume of moving object	7	Volume of moving object	27	Reliability	27	a. Reliability b. Quality/Yield
8	Volume of stationary object	8	Volume of stationary object	28	Accuracy of measurement	28	Accuracy of measurement
9	Speed	9	Speed	29	Accuracy of manufacturing	29	Accuracy of manufacturing
10	Force	10	Force	30	External harm affects the object	30	External harm affects the object
11	Stress or Press	11	Stress or Pressure	31	Object-generated harmful factor	31.a	Harmful chemical reactions
12	Shape	12	Shape			31.b	Cleanness (Particle count)
13	Stability of object	13	Stability of object			31.c	Scratch
14	Strength	14	Strength			31.d	Uniformity

15	Duration of action by a moving object	15	Duration of action by a moving object			31.e	Object-generated harmful factor
16	Duration of action by a stationary object	16	Duration of action by a stationary object	32	Manufacturability	32	Manufacturability
17	Temperature	17	Temperature	33	Ease of operation	33	Ease of operation
				34	Ease of repair	34	Ease of repair
18	illumination intensity	18	Illumination intensity	35	Adaptability	35	Adaptability
19	Use of energy by moving object	19	Use of energy by moving object	36	Complexity of device	36	Complexity of device
20	Use of energy by stationary object	20	Use of energy by stationary object	37	Difficulty of detecting and measuring	37	Difficulty of detecting and measuring
				38	Level of automation	38	Level of automation
				39	Productivity	39	Productivity
						40	Surface roughness/Asperity
						41	Availability

Among the above parameters, 31.a through 31.d were finer classification of parameters which makes it consistent with the industry's concern and terminology. Parameters 40 and 41 were also added.

In classifying the principles used in the studied patents into appropriate inventive principles, it was found that there are situations which can not sensibly fit into any of the Altshuller's existing 40 inventive principles. This may indicate new inventive principles found. For example, some patents are primarily based on clever and non-obvious mechanical structure/mechanism or geometric manipulations to get innovative solutions. Some are based on chemical reactions which can not be considered as the existing strong oxidant, composite material, or inert atmosphere which contain chemical contents. Therefore, the authors consider the "mathematical formulation/transformation" and "chemical reactions" are plausible new inventive principles. In addition, principle # 40, composite materials was renamed to "Using new materials". The new set of suggested inventive principles and the classical inventive principles set are listed as Table 4: The patents applying these new principles are listed in section 4.4.2.

Table 4:The Inventive Principles -Classical Matrix vs CMP based Matrix

Classical Matrix		CMP based Matrix		Classical Matrix		CMP based Matrix	
Inventive Principle		Inventive Principle		Inventive Principle		Inventive Principle	
1	Segmentation	1	Segmentation	21	Rushing through; Skipping; Hurrying	21	Rushing Through; Skipping; Hurrying
2	Extraction, Taking out	2	Extraction, Taking Out	22	Convert harm into benefit; Blessing in disguise, Turn lemons into lemonade	22	Convert Harm into Benefit; Blessing in Disguise, Turn Lemons into Lemonade
3	Local quality	3	Local Quality	23	Feedback	23	Feedback
4	Asymmetry	4	Asymmetry	24	Intermediary, Mediator	24	Intermediary, Mediator
5	Consolidation, Merging	5	Consolidation, Merging	25	Self-service	25	Self-Service
6	University / Multi-functionality	6	University / Multi-functionality	26	Copying	26	Copying
7	Nesting / Nested doll	7	Nesting / Nested Doll	27	Cheap disposables, Cheap short-living objects	27	Cheap Disposables, Cheap Short-Living Objects
8	Counterweight , Weight compensation, Anti-weight	8	Counterweight , Weight Compensation, Anti-Weight	28	Replacement of mechanical system, Mechanics substitution; Another sense	28	Apply / Use different field
9	Prior counteraction, Preliminary anti-action, Preliminary counteraction	9	Prior Counteraction, Preliminary Anti-Action, Preliminary Counteraction	29	Pneumatics and hydraulics	29	Pneumatics and Hydraulics
10	Prior action, Preliminary action	10	Prior Action, Preliminary Action	30	Flexible membranes or thin film, Flexible shell or thin membranes	30	Flexible Membranes or Thin Film, Flexible shell or Thin membranes
11	Beforehand compensation; Beforehand cushioning, Cushion in advance	11	Beforehand Compensation; Beforehand Cushioning, Cushion in Advance	31	Porous material	31	Porous material
12	Equipotentialit y	12	Equipotentiality	32	Color changes	32	Color Changes
13	The other way round ; Do it in reverse, Inversion	13	The other way round ; Do it in reverse, Inversion	33	Homogeneity	33	Homogeneity
14	Spheroidality; Curvature, Curvature increase	14	Spheroidality; Curvature, Curvature Increase	34	Discarding and recovering, Rejecting and regenerating	34	Discarding and Recovering, Rejecting and Regenerating
15	Dynamics, Dynamicity, Dynamic parts	15	Dynamics, Dynamicity, Dynamic Parts	35	Parameter changes; Transformation of properties, Transformation of physical and chemical	35	Parameter Changes; Transformation of Properties, Transformation of Physical state of an Object

					states of an object		
16	Partial, Overdone, or Excessive action	16	Partial, Overdone, or Excessive Action	36	Phase transition	36	Phase Transition
17	Another dimension; Transition into a new dimension, Dimensionality change	17	Another Dimension; Transition into a New Dimension, Dimensionality Change	37	Thermal expansion	37	Thermal Expansion
18	Mechanical vibration	18	Mechanical Vibration	38	Accelerated oxidation, Strong oxidants, Use strong oxidizers	38	Accelerated Oxidation, Strong Oxidants, Use Strong Oxidizers
19	Periodic action	19	Periodic Action	39	Inert environment, Inert atmosphere	39	Inert Environment, Inert Atmosphere
20	Continuity of useful action	20	Continuity of Useful Action	40	Composite material	40	New materials
						41	Chemical (re)actions
						42	Mechanical structure/mechanism or geometric designs
						43	Mathematical formulation/transformation

The number 40 inventive principle is an extension of Altshuller's existing principle, Composite materials. The numbers 41,42 and 43 were added by this research.

3.5 Establishment of Contradiction Matrix for Chemical Mechanical Polishing

Based on randomly selected limited number of patents in CMP industry between 1999 and 2006 and the parameters/invention principles as mentioned before, a new prototype contradiction matrix specific for the CMP applications was established. Three matrices were compared in their effectiveness to interpret the 16 randomly selected CMP patents (22 cases) from year 2007. The matrices are: 1) Altshuller's classical matrix; 2) The CMP-based prototype Matrix by this research; and 3) the combination of the 1) and 2) matrices – the combined matrix.

The results are described in Section 4 below.

4. Results

4.1 Using Matrices to interpret the CMP patents

The authors used traditional Altshuller matrix to interpret the test set of CMP patents. The results can be classified into the below situations:

(1) Based on the appropriate contradicting parameters at least one of the identified inventive principles can interpret the principle(s) used in the patent. An example is Kim (2005) case. (United States Patent no. 5893796)

(2) The principles identified by the Traditional Matrix failed to interpret the subject patent:

Case 1：None of the Altshuller's existing parameters can fit the key contradicting parameters in the patent. For example, availability and surface asperity are used in the industry but no parameter in the classical parameter set can represent them. In this case, the classical matrix is totally un-applicable. Xu's (2004) case is one of them.(WIPO patent no. PCT/US2002/040941)

Case 2：No appropriate inventive principle can interpret the patent. It appears that some of the patents in the CMP field can not be completely interpreted by the existing 40 inventive principles. A couple of inventive principles were identified for these situations. They are: Use chemical reactions and use mechanical mechanism or geometric design. Robert (1999) case is one of them. (WIPO patent no. PCT/US1999/007418)

Case 3: There are appropriate engineering parameters and appropriate inventive principles to interpret the patent. Yet, the Classical Matrix does not provide the right correspondence between the corresponding contradiction and inventive principle(s). Anthony's patent (2005) is one of thess cases. (United States Patent no.6712670)

Table 5 shows the results of using Altshuller's classical matrix to interpret the CMP patents studied in this research. It appears that using the classical matrix can only interpret the modern CMP patents successfully in 46% of the cases. This rate is similar to using the classical matrix to interpret modern mechanical patents in Darrell Mann's (2002) report. On the contrary, the effectiveness of using the prototype matrix provide solely by CMP patents from 1999 to 2006 can interpret 77% of the CMP patents in 2007 even though the number of patents used to establish the CMP matrix, 120, is much lower than the number of patents (more than 40,000) to establish the Altshuller classical matrix. The reason for this situation is clear that the fundamental working principles for the CMP applications are drastically different from that of the patents Altshuller used because they are from different industries. Detail comparison of the performance of Classical matrix v.s CMP matrix and the combined matrix of CMP and Classical matrix is shown in Table 5.

Table 5: Performance of classical matrix v.s CMP based matrix in interpreting the CMP patents.

	Classical Matrix	CMP based Matrix	Combined Matrix
Solely Lack of corresponding parameter(s)	21%	0%	0%
No proper inventive principle only	2%	0%	0%
No appropriate parameter & inventive principle(s)	12%	0%	0%
Matrix does not point to the right solution	19%	23%	9%
Matrix works	46%	77%	91%
Total	100%	100%	100%

4.2 New Engineering Parameters and Inventive Principles For CMP

Based on the research, it is found that the classical matrix is not ideal for CMP processes/equipment. A modified contradiction matrix is necessary for CMP. Thus, this study modified and added engineering parameters and inventive principles based on the classical matrix, as well as the results of relevant patent of CMP.

4.2.1 New Engineering Parameters

The new engineering parameters for CMP matrix are as follows:

26. Use of consumable

It refers to the consumption of consumables. The consumables in CMP are mainly slurry, polishing pads, and de-ionized water used for washing or dilution.

27a. Reliability

The attribute that the system performs its expected functions in an expected manner under expected conditions.

27b.Quality /Yield

There are multiple characteristics for quality. In the semiconductor manufacturing industry, it is often expressed as a yield.

31.a. Harmful chemical reactions

It refers to chemical reactions that cause undesirable results in the systems or objects.

31.b.Cleanliness

The state that impurities or contaminants exist in the system.

31.c Scratch

Scratches on the wafer surface can easily cause short circuit or other undesirable effects.

31.d. Uniformity (as a particular type of harmful factor)

It primarily refers to the uniformity of wafer (product) after polishing. This feature is particularly important in the semiconductor manufacturing industry. The purpose of CMP is to make the surface smooth and uniform. This also often relates to the uniformity of the slurry distribution, the force on wafer and the force on polishing pad.

31e.(Other)Object-generated harmful factor

This refers to any undesirable factors not covered by previous parameters. If we use only this parameter to indicate all harmful factors, the corresponding inventive principles indicated by the classical matrix often fail to reflect the principles used in the patents studied. To be more accurate, other engineering parameters related to the characteristics of CMP are added by this study. This parameter is used only when principle 31a to 31d cannot explain the problems.

40. Surface roughness/Asperity

The surface roughness of the polishing pad is very closely related to the polishing effect. After some usage, the surface of polishing pads loses its original asperity due to abrasion and residual byproducts, resulting in poor polishing performance. At this time, the polishing pads need to be re-adjusted or replaced.

41. Availability

$$Availability = \frac{E(Uptime)}{E(Uptime) + E(Downtime)}$$

(during the observed period usually one year or month)

Availability is very important in the semiconductor manufacturing industry where the equipment costs accounts for about three quarters of the manufacturing costs.

4.2.2 New inventive principles

Based on the above-mentioned studies, two of the original 40 inventive principles were augmented in their coverage and three additional inventive principles were identified. They are described as follows:

The revised two inventive principles:

28. Apply / Use different field(s) (was: mechanics substitution)

For fields that represent the system or force application can be divided into several field types such as: mechanical field/force, heating field/power, chemical field, electric field/power and magnetic field/force. It is now broader than the "mechanical system substitution” in that new fields can be added or used to replace the existing field to solve the problem.

40. Use different materials (was: Composite Materials)

It is determined that “Composite Materials” failed to cover the case when a purely different material is used to replace the existing material. The examples include conducting wire material is changed from aluminum to copper or tungsten, and the different chemical composition in the slurry. The natural extension of “Composite Materials” is “Different Material(s)”. “Different material(s)” can however include the original principle of “Composite Materials”.

The proposed three additional inventive principles are as follows:

41. New Chemical (Re)Actions

Chemical actions/reactions can be used to eliminate the undesirable substances or harmful substances in the system as well as to create a material or a desirable effect. Although principle 38, strong oxidants, also belongs to the scope of the chemical (re)actions, it fails to cover many other innovative problem solving method primarily based on novel chemical (re)actions. The authors decided to make “Chemical (re)actions” as an additional principle. Theoretically, this inventive principle may refer to all chemical (re)actions including process of oxidation. Because “Strong Oxidation” is already included in the set of original principles, this added inventive principle is then used to cover all chemical-action based inventive cases where existing principles fail to cover. Cases include the patent of BAJAJ, Rajeev (WIPO patent no. PCT/US1999/028816), which is applied to clean up the polishing pad surface together with the chemical reaction solution (dilute hydrochloric acid solution) in order to remove residues.

42. Apply geometric design or mechanical structure/mechanism

It refers to design/redesign of novel mechanical structure of the system or objects; (re)design of lines or angles, and geometrics, so as to amend the deficiency or loss of the original system. Example of this principle can be found in the patent of Davenport, Robert (WIPO patent no. PCT/US1999/007418). This patent is a device with the intermediate washing station, and it also uses the brushes made of Politex to assist in cleaning the slurry on the wafer surface, in order to obtain better cleaning result.

43. Apply a mathematical model/formulation/transformation

The manufacturing process of semiconductor is quite complex. Often times, solving a problem requires sophisticated mathematical analysis/computer calculation/simulations to find innovative solutions. There are patents of which the keys to the innovations were sophisticated mathematical analysis/computation/simulation where no existing inventive principle can interpret. Although some of the feedback data can be used to help analyze the problem, the feedback data only provide partial information to aid mathematical analysis. Additional data such as production plan, dispatching rules, system design, etc., are needed to feed into the mathematical model to produce innovative solutions. The key to the solution is not the data but the ability to perform the mathematical analysis. Therefore, this principle is distinctly different from the "principle 23 –feedback". One example of the inventive principle in action can be found in Miyano's patent (The Republic of China, patent no. 84117659), which is used to determine the physical quantity changing with the process, obtain the time series data, and detect the end of the process according to the time series data.

4.3 Statistical verification of the performance difference between the classical matrix and the CMP matrix

To compare the performance of classical matrix and the CMP based matrix on CMP problems, the study randomly selected 16 patents (22 cases) from 2007 to test their results. in the results are shown in Table 6. It shows that the Classical Matrix can only explain 46% of the test cases and the CMP-based matrix interpret 77% of the cases. It is noted that the classical matrix was based on the study of 40,000 cases while the prototype CMP matrix was constructed out of merely 120 CMP cases. This is NOT to say that the CMP matrix is better than the classical matrix. It only indicated that the CMP matrix is more effective in identifying inventive principles which are relevant to solving the CMP problems. Contradiction Matrices are basically out of empirical studies. Because the fundamental working principles underlying the patents studied by Altshuler and the patents studied by the CMP matrix are drastically different, it is no wonder that the CMP matrix is much more relevant than the classical matrix to solve the CMP problems. This support the argument that fundamentally different industries may need different matrix to be effective and efficient.

Table 6 The classical contradiction matrix and contradiction matrix for CMP works

No.	Patent Number	Classical matrix	CMP Based Matrix
1	7,210,981	○	○
2	I270436	○	○
3	I270128	×	○
3-1		×	○
4	I272998	×	○
4-1		○	×
5	200709893	○	○
5-1		○	○
6	200715393	×	×
6-1		×	○
7	200709895	○	○
8	200713548	×	○
8-1		○	×
9	I278062	×	○
10	I276509	○	×
11	I279286	×	○
12	I282363	×	○
13	I278033	×	○
13-1		×	×
14	I278929	○	○
15	I278377	○	○
16	I280175	×	○
ratio		10/22＝46％	17/22＝77％

○:The principles identified by the matrix were able to interpret the patent idea..

×: The principles identified by the matrix fail to interpret the patent idea.

The nonparametric Sign Test was applied due to the data limitation: sample size was lower than 30 and population parameter was unknown [Lehmann,1998]. The Sign test may be used to test the hypothesis that data is random, or has a specified mean. It may also be used to compare two pairs of samples on the null hypothesis that they are not significantly different. Very often, experiments are designed so that the results occur in matched pairs. In these cases the sign test can often be applied to decide between two hypotheses concerning the data. Performing a sign test involves counting the number of times when, say, the first score is higher than the second − designated by a “+” sign and the number of times that the first score is lower than the second −designated by a “–” sign.

The results of a Sign Test indicated that there was significant better in CMP based matrix than in classical matrix. As shown in Table 7, the feasibility of each case was listed.

Table 7 Signed Test

Case	CMP based Matrix	Classical Matrix	Difference	Case	CMP based Matrix	Classical Matrix	Difference
1	○	○	0	12	○	×	+
2	○	○	0	13	×	○	－
3	○	×	+	14	○	×	+
4	○	×	+	15	×	○	－
5	○	×	+	16	○	×	+
6	×	○	－	17	○	×	+
7	○	○	0	18	○	×	+
8	○	○	0	19	×	×	0
9	×	×	0	20	○	○	0
10	○	×	+	21	○	○	0
11	○	○	0	22	○	×	+

0: The matrix can be interpreted in the case.

+: The CMP based Matrix can be interpreted, but the classical matrix can’t be interpreted.

－: The CMP based Matrix can’t be interpreted, but the classical matrix can be interpreted.

If the consequence of the test was random, each trial would have an equal probability of 0.5 vs 0.5 for good or bad, respectively. The sample distribution was Binomial Distribution. Assume that Random Variable x represents the number of positive signs. The Probability Mass Function (p.m.f) was

$$f(x)=\binom{n}{x}(0.5)^{x}(0.5)^{n-x}=\binom{n}{x}(0.5)^{n} \quad , \quad x=0,1,2, \ldots ,n$$

When sample n and the number of positive were known, Binomial Distribution was used to calculate the probability:

$$\sum\binom{n}{x}(0.5)^{n}$$

Suppose the applicable median of the intensity of classical matrix is η_0, CMP based matrix is η_1 and the number of the positive sign is x. The Hypothesis Test is

$$H_0 : \eta_0 \geq \eta_1 \;;\; H_1 : \eta_0 < \eta_1$$

The result of the Signed Test is shown in the Table 7 (α＝0.05).

The results revealed that nine cases were demonstrated as the same performance. Three cases in the CMP based Matrix can't be interpreted, but ones in the classical matrix can be done. On the contrary, 10 cases in the CMP based Matrix can be interpreted, but ones in the classical matrix can't be interpreted. If the performance between Classical and CMP matrices was insignificant difference, numbers of sign "+" and sign "-" were calculated as the same probability. For example, if numbers of sign "+" equal to 10 and numbers of sign "-" equal to 3, probability can be calculated as:

$$x = 10,\ n = 13$$

$$p - value = P(x \geq 10 \mid p = 0.5)$$

$$P(x \geq 10 \mid p = 0.5) = \sum_{x=10}^{13} \binom{13}{x} (0.5)^x (0.5)^{13-x} = \sum_{x=10}^{13} \binom{13}{x} (0.5)^{13} = 0.0461 < \alpha = 0.05$$

In a hypothesis test, the null hypothesis $\eta_0 \geq \eta_1$ means the rejection region is on the tail of right hand side. Once the statistic value falls within the rejection region (p-value=0.0461 < 0.05), the null hypothesis is rejected. The result in this example showed that the hypothesis was rejected at significance level $\alpha = 0.05$. Thus, in the CMP cases, the applications in CMP based matrix can get more advantages than in classical contradiction matrix.

5. Summary and conclusions

In order to establish contradiction matrix suitable for semiconductor industry, the research started with matrix suitable for one of the critical processes in the semiconductor manufacturing, the chemical mechanical polishing. Prototype contradiction matrix for CMP process was established using 120 cases in CMP patents between 1999 and 2006. Some 16 sample patents (22 cases) in 2007 were used to compare the effectiveness of the CMP matrix and the classical matrix. The results showed that the Altshuller's classical matrix which is based on the study of more than 40,000 patents can only interpret 46% of the modern CMP patents while the prototype CMP matrix can interpret 77% of the CMP patents even though it is out of a study of some 120 patents. This further proves that the effectiveness of the contradiction matrix is industry specific if the underlying working principles of the problem to be solved is significantly different from the underlying working principles of the cases which the matrix was constructed from.

The contributions of this work include:

1. Establishing a prototype matrix suitable for CMP processes and further testifying that the effectiveness of the contradiction matrix is application specific.
2. Identifying 7 additional engineering parameters for the CMP applications. These parameters are also useful for other processes in the semiconductor manufacturing industry.
3. Identifying 3 additional inventive principles and augmented 2 inventive principles.
4. Establishing a model with problem array and solution array to uniquely define the problem and its corresponding solutions paving the way for future analytical analyses of the patents.

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Paper ID: 122

Study on Logistics System of Bohai Bay Ports Based on TRIZ

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Abstract

The main idea in this paper is to apply TRIZ to solve the high logistics cost and disorder competition between the core ports and branches， as well as the low efficiency of collection and distribution of cargoes in Bohai bay ports by analyzing technical contradictions, making conflict matrix and getting the innovative principles. After selecting innovative principles, the paper presents the thought which comprises of developing the regional port logistics cluster and constructing cross-regional logistics dispatching platform based on IT and network.
Key words: Innovation, Port Logistics, Technical Contradiction, TRIZ

TRIZ (The Theory of Inventive Problem Solving), which is proposed by Altshuller, has made great contributions into engineering technology innovation (Mann, 2001). Because of situational dependent and complexity, management problem can be seen as the innovative problem (Fey,Rivin,1997, Ruchti, 2003). When presenting 31 managerial standard parameters, it can analyze the management conflicts such as logistics problems more generally and accurately (Mann, 2001). After redefining the 40 innovative principles based on management innovation, it's possible to find ideal solutions to management problems (Farias, 2006). As the management problems are non-structural, solving management problems with TRIZ must be guided by systematic approach of management(Wen-yan, Run-hua, 2002).

The port logistics ,which essence is a part of global supply chain, has emerged many problems while developing. In this paper, the author utilizes TRIZ to analyze and solve problems. It describes problems emerged on logistics of Bohai bay ports in the beginning. Then analyzing the problems by means of 39 standard parameters and finding technical contradictions. Depending on technical contradictions, the conflict matrix is made and the innovative principles are obtained. Finally, the thought of problems solving is presented.

1. Describing the Problems

The region of Bohai Bay, which coastline is 5800 kilometers long, is located in northern China . There are about 60s ports and more than 760 kinds of berths distribute in the region of Bohai Bay. Three port groups exist in the region and they are Jing-jin-ji Port Group whose core port is Tianjin Port, Shandong Port Group whose core port is Qingdao Port and North-eastern Group whose core port is Dalian Port.

Many problems have arised in the development of Bohai Bay ports. In terms of functions of port logistics, the business of Bohai Bay ports homogenized quite seriously (Xiao-ming, Zhang-yi, 2007). The unclear functional position of ports and disorder competition between ports are outstanding problems in the development of port in China (Jin-jie, Chong-bin, 2008). Compared with some large ports at home and abroad, the efficiency of logistics in Bohai Bay ports is obviously lower. For example(Fan, 2006).

1.1 The description of problems

Problem 1: The cost of port logistics in each port group is high. The main costs of port logistics include investment in infrastructure, cargo transportation, cargo handling ect.

Each port in three port groups of Bohai Bay is carrying out redundant infrastructure construction including terminals, berths and waterway facilities. At the same time, the economy hinterland and the transportation market are highly overlapped. Consequently, the costs are high and can not be reduced effectively.

Problem 2: The disorderly competitions exist between the core ports and branches in each port group which have weaken the competitiveness of port group's regional logistics. Owing to geographical proximity, overlap of economy hinterland and transportation market, the unreasonable competitions including price wars arise among the core port and branches.

Problem 3: The efficiency of collection and distribution of cargoes in the whole Bohai Bay is low. Fierce competition exists among Tianjin Port, Dalian Port and Qingdao Port and they all positon themselves as the future shipping center. So three port logistics systems become isolated in constructing and utilizing shipping lanes and cargo transport networks.

It often occurs that waiting time before ships with cargoes entering the port is reduntant. In addition, transporting cargoes in unreasonable routes, loading and unloading cargoes too many times have also greatly reduced the efficiency of collection and distribution of cargoes.

1.2 Ideality Solution

The ideality solution in TRIZ theory can be interpreted as an ideal system state when the ratio between the sum of all the useful effects and the sum of all the harmful effects in a system reaches minimum. In this paper, the ideality solution of innovating logistics system of Bohai bay ports can be defined as follows. Firstly, the costs of port logistics is minimized. Secondly, disorder competitions are eliminated within each port group, while the structure of the port group is stable. Meanwhile, the efficiency of collection and distribution of cargoes in Bohai Bay achieve highest.

1.3 Available resource

Available resource is another key concept in TRIZ and it is the basis of problems solving. When innovating the logistics system of Bohai Bay ports, available resources mainly include as follows: a. The existing Logistics System and resources of Bohai Bay Ports. b. The support from the central government's policy to bulid the shipping center. c. The perfect technology of IT and network.

2. Analyzing the Problems

Technical contradiction indicates that another one or several parameters deteriorate while one parameter improves, or the useful effects of other parameters reduce while the harmful effects of one parameter reduces. The parameters used to analyze three problems described above by means of technical contradiction are listed in Table 1.

Table 1.Parameters used to analyze the problems

NO.	Parameter	NO.	Parameter
4	Length of stationary object	26	Quantity of substance/the matter
13	Stability of object's composition	30	Object-affected harmful factors
22	Loss of Energy	35	Adaptability or versatility
23	Loss of substance	36	Device complexity
25	Loss of Time	39	Productivity

2.1 The related parameters and technical contradictions in problem 1

The cost of port logistics in problem 1 can be indicated with the parameter No. 23 and 26. The system's useful functions can be represented by parameter No. 35 and 39. According to the definition of technical contradictions, improving 23 means to reduce the loss of idle equipments, substance and capital in operation. However, the productivity of port logistics will decrease then. Improving 26, which means to cut back the amount of infrastructure investments, will weaken adaptability to competition and decline productivity of port logistics. So there are three pairs of technical contradictions in problem 1: (23,39), (26,36), (26,39).

2.2 The related parameters and technical contradictions in problem 2

When analyzing problem 2, the parameters used are NO. 13, 30, 35 and 36. Improving 13, which indicates to enhance the stability, will make port group more complex. For instance, some coordinating agencies will be established. At the same time, improving 30, which means to reduce diversification investment of single port logistics in order to avoid market risk, will weaken the adaptability to a competitive environment. Here there are two pairs of technical contradictions: (13,36), (30,35).

2.3 The related parameters and technical contradictions in problem 3

The parameters used in analysis of problem 3 include NO. 4, 22, 25, 36 and 39. The efficiency of port logistics depends on efficiency of port handling, transportation, lanes density and length of routes etc. Once improving 4, which intend to shorten the shipping route in Bohai Bay, logistics structure may become more complex. Improving 25 which is to reduce the loss of time will increase input of energy and human. So is it when improving 39. Three pairs of technical contradictions exist when solving problem 3: (4,36), (25,22), (39,22).

The relation between three problems and its corresponding technical contradictions are illustrated in Figure 1.

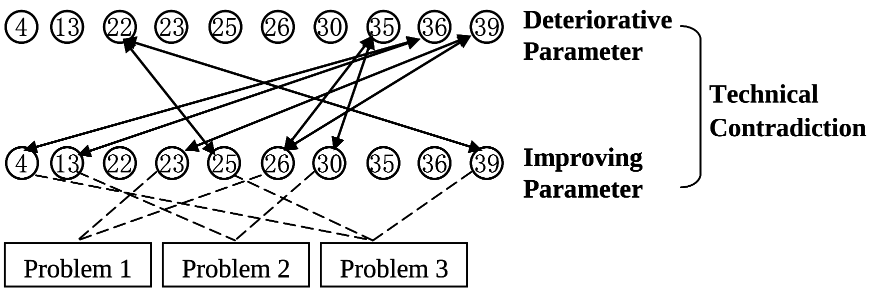

Figure 1. Problems and corresponding technical contradictions

3. Searching the Standard Solutions

According to TRIZ, conflict matrix can be made after technical contradictions are found. And standard solutions will also be obtained easily. As is shown in Figure 2.

Deteriorative Parameter

Improving Parameter	22	35	36	39
4			1 26	
13			2 22 26 35	
23				10 23 28 35
25	5 10 18 32			
26		3 15 29		3 13 27 29
30		11 22 31 35		
39	10 28 29 35			

Figure 2.Conflict Matrix

4. Selecting the Standard Solutions According to Practice

4.1 The solution of problem 1

In the light of Figure 2, the innovative principles for problem 1 solving include 3,10,13,15,23,27,28,29,35 and “Local quality” (3) is the most suitable. It refers to change an object’s or system’s structure from uniform to non-uniform (Retseptor, 2003).When it comes to port logistics costs, “Local quality” can be interpreted as changing the structure of port logistics costs from uniform to non-uniform. So the infrastructure and services in each port group should be transformed from synthesizing type (uniform) to professional type (non-uniform).

4.2 The solution of problem 2

The innovative principles used to solve this problem comprise 2, 11, 22, 26, 31, 35 and “Taking out” (2) is the best one. It means to single out the only necessary part (or property) of an object or system. When analyzing competition of ports logistics, “Taking out” can be interpreted that every port should retain its most competitive logistics services, and remove less competitive ones.

Guided by above two principles, problems are resolved preliminarily. However, all ports must be integrated in accordance with respective functional position to keep stability and competitiveness of logistics system. For that reason, the original logistics system in port group should be replaced by port logistics cluster which is a new kind of logistics system.

4.3 The solution of problem 3

The selected innovative principles in problem 3 solving are “Merging” (5), “Parameter changes” (35). “Merging” indicates to bring closer together identical or similar objects or systems. “Parameter changes” means to change an object’s or system’s physical state.

Guided by “Merging”, three port logistics clusters should join together and coordinate to use all resources to serve importers and exporters. The efficiency of collection and distribution of cargoes can improve significantly. But as mentioned above, it is impossible to merge three core ports in short term. So it is practical to use “Parameter changes” to construct a cross-regional logistics dispatching platform based on IT and network instead. Depending on this dispatching platform, three port logistics clusters can share resources and information just like one port logistics system.

5. The Innovative Thought of Logistics System of Bohai Bay Ports

On the basis of above analysis, the innovative thought of logistics system of Bohai Bay ports could be proposed and shown in Figure 3.

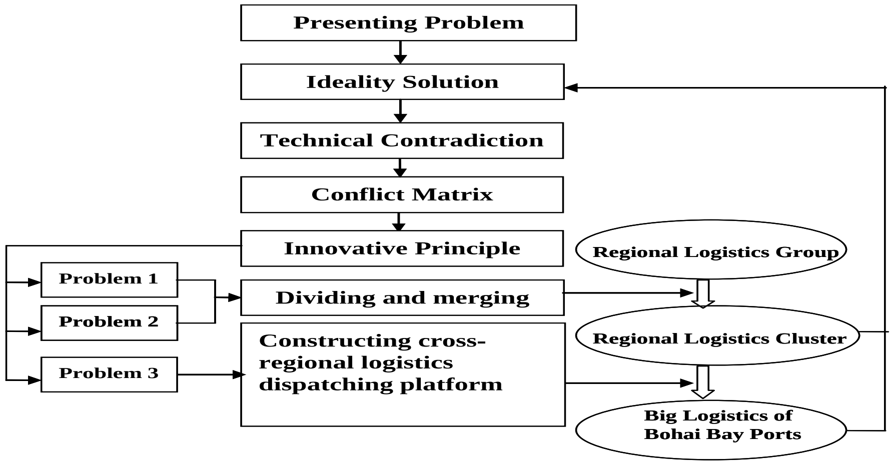

Figure 3. Roadmap of solving the problems based on TRIZ

5.1 Transforming regional logistics group to regional logistics cluster

According to the application results of TRIZ, every port in port group should be divided based on advantages in resources and function. Then merging them to form a port logistics cluster.

Port logistics cluster could be formed by the way of horizontal merger and vertical integration. On the one hand, the branch ports should be in coordination with core port to form a complete logistics chain in vertical. On the other hand, they could create their own distinctive logistics chain to complement or compete orderly with core port. It is true that the advantages of scale and specialization will be strengthened in this new port logistics modle.

5.2 Constructing cross-regional logistics dispatching platform based on IT and network

When three port logistics clusters are developed, constructing a logistics dispatching platform is necessary and practical. By this platform, three logistics clusters are joined together and cross-regional service can be realized. So compared with dispersive state, the same cargos can be served by three port logistics clusters which will improve logistics efficiency significantly.

To build the logistics dispatching platform, virtual technology(VT), EDI, E-port and other information technology are necessary. Through this dispatching platform, an open logistics information system which connects port and port, region and region, port and shippers, port and carriers will be constructed.

6.Conclusion

As is informed by Figure 3, the logistics of Bohai bay ports can be improved in efficiency and service quality according to the application of TRIZ. Providing that problems definitely defined and ideality solution acknowledged, the innovative management problems can be standardized and the efficiency of problem solving will be improved as well. Of course, the application of TRIZ to solve innovative management problems does not mature, a set of theory systems are expected urgently. In this theory system, standard parameters, innovative principles, Object-Field model and Effect base should based on and surpass the original contents. Meanwhile, computer is inevitable in sucessful application of TRIZ.

Acknowledgement

The topic of research is a part of the continuous study project of the human social science research base of Tianjin.

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Paper ID: 123

Study on Strategic Management and Innovation of Bohai-Circle Harbors

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Abstract:

TRIZ is a theory system applied to solve innovation problems. It has been widely used in innovation research, but any paper related to TRIZ-based strategic management on ports recourses has not been found. The paper analyses the problems existed in Bohai-circle harbors, such as serious repeated fundamental construction, low efficiency of resources utilization, then utilizes conflict matrix & corresponding innovation principles, and finally presents some strategic innovation ideas in ports construction.

Key words:

TRIZ; Conflict matrix; Port cluster; Systematic innovation; Bohai-circle habors

INTRODUCTION

TRIZ is the abbreviation of *Teorija rezhenija inzhenernyh zadach* in Russian.It is proposed by G.S.Altshuller from the former Soviet Union. In the beginning, it is only used in engineering areas. With intensive studies, TRIZ has been applied to business, management, education and other non-technical areas.

With the development of economic globalization and further intensified competition between ports, the port resource integration has become an inevitable trend in port development. In this paper, with the utilization of controdiction matrix and 40 principles of the invention, the TRIZ theory is firstly applied to the port resources strategy management.

Ⅰ. PROBLEMS OF BOHAI-CIRCLE PORT GROUP RESOURCES

1.1 For repeated plan and construction, resources waste a lot.

1.2 Disorderly competitions inside the port group cause the distribution of ports' resources and serious internal friction of resources, which decrease the competitive strength of the whole port group.

1.3 The proportion of the govermental investment in funding source is too high. Other channels are lacked.

Ⅱ. ANALYSIS BASED ON TRIZ

2.1 Problem-solving model based on TRIZ

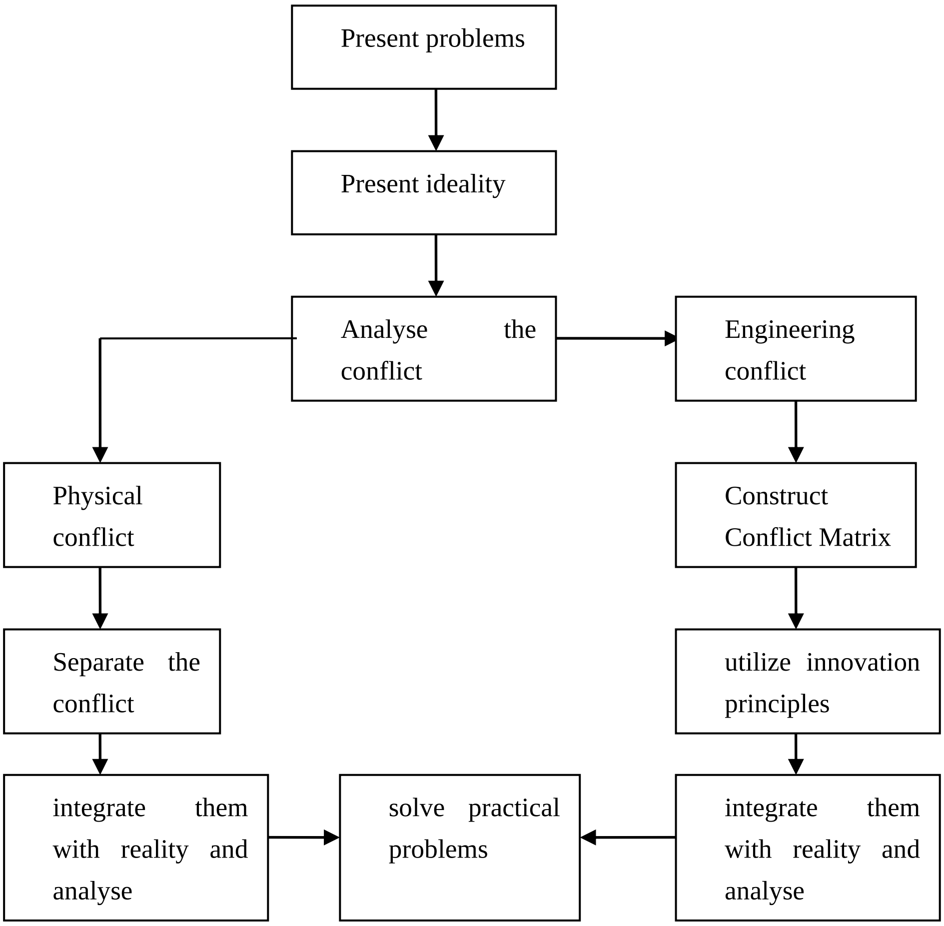

Figure 2. Problem-solving model based on TRIZ

2.2 Ideality

2.3 Construct conflict matrix and utilize innovation principles

2.3.1 Conflict analysis and the construction of conflict matrix

Table 1 Conflict Matrix

Improving Feature \ Worsening Feature		1	…	4 …		26	36	37	…	39
		Weight Of moving object	**…**	**Length … of stationa-ry object**		**Quantity of substance / the matter**	**Device complexity**	**Difficulty of detecting and measuring**	**…**	**Productivity**
1	**Weight of moving object**									
…	…									
13	**Stability of the object's composi-tion**						2，35，22，26	35，22，39，23		
…	…									
22	**Loss of Energy**					7，18,25				
…	…									
25	**Loss of Time**				30,24,14,5		6，29	18，28，32，10		
…	…									
33	**Ease of operation**						32，26，12，17			
…	…									
39	**Productivity**				30，7，14，26		12，17，28，24	35，18，27，2		

2.3.2 Utilization innovation principles

Find out the corresponding principles of the invention from the conflict matrix, and construct an application table of the innovation principles:

Table 2 Application of Innovation Principles

	Concrete Controdiction	Innovation Principles	Priority Selection	Concrete Meanings
1	（22，26）	7，18，25	7 Nested doll	……
2	（25，4）	30，24，14，5	5 Merging	……
3	（25，36）	6，29	6 Universality	……
4	（25，37）	18，28，32，10	10 Preliminary Action	……
5	（33，36）	32，26，12，17	32 Color Changes	……
6	（39，36）	12，17，28，24	24 Intermediary	……
7	（39，37）	35，18，27，2	35 Parameter Changes	……
8	（13，36）	2，35，22，26	2 Taking Out	……
9	（13，37）	35，22，39，23	35 Parameter Changes	……

Ⅲ. STRATEGIC MANAGEMENT IDEAS OF BOHAI-CIRCLE PORT GROUP RESOURCES BASED ON TRIZ

3.1.Construct the Port of Bohai, forming port cluster .

3.2. integration of resouces: three main port groups get listed jointly to absorb private capital and increase the amount of resources.

3.3. Optimize the distibution of resources and make every port's position clear to realize the complementary advantages of the whole port cluster.

3.4. Upgrade the levels of interal talent and technology, promote the information and management system, and increase the resources' service efficiency.

CONCLUTION

Based on Bohai-circle resources' situation, the paper firstly utilizes the TRIZ theory, finds out corresponding innovation principles from the conflict matrix, and present strategic innovation ideas, such as the construction of Port of Bohai, the joint listing of the 3 port clusters in Bohai port and etc. This is a strong proof that the TRIZ theory is applied to strategic management of port resources. Proposal of innovative strategic vision provides a reference for the government and enterprises.

As the port enterprises are still monopoly in China, and they are under great impact of administrative intervention by the government. Therefore, the details of resources integration need to specifically contact the reality in China for further discussion and study.

ACKNOWLEGEMENT

This topic of research is a part of the continuous study project of the human social science research base of tianjin.

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Paper ID: 136

Development and application of a patent-based design around process

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Abstract

Patent infringements have become an important issue for industries when developing products. Designing around existing patents of competitors is a task constantly faced by designers. New design problems, which are often a “local innovation” of an existing patent, are generated during the design-around process. The rules of patent infringement judgment present the major constraints to such design problems, and designers may have to sacrifice the performance of the product in order not to infringe on existing patents.

This research proposes a patent-based design process by systematically integrating patent information, the rules of patent infringement judgment, strategies of designing around patents, and innovation design methodologies. The purpose of the process is to generate a new design concept that is a slight variation of one of the concerned patents but does not infringe with existing patents. The basic idea is to consider patent infringement before engineering design concepts are actually generated.

This research also develops a design around tool based on the innovative patent-based design process can be divided into three major stages: (1) relation between technology and function; (2) sorting and (3) operation of the design matrix. The designer just need input the technology/function matrix, and he/she will get all problems about the design topic. The tool is easy to operate and it can present what is used in the design around method. Otherwise, the design around tool enhances the efficiency of product development, lower the possibility of patent infringements, and increase the patentability of results of innovation.

Key words: design methodology, patent infringement, design around, TRIZ

1. Introduction

Design process plays an important role in the success of a product's development. Design process influences performance, quality, cost, and the development time of the product. Systematic product design processes commonly seen in research literature or design textbooks often start with finding a need, specification development, conceptual design, detail design, and finally production. Such design processes are very useful for innovative design. Innovative design mythologies such as analogy, brain storming, and Theory of Inventive Problem Solving (TRIZ) are often used to generate engineering design solutions.

However, the design problem constantly faced by engineering designers across industries is how to design around existing patents [Glazier, 1990], which requires a completely different design approach and knowledge. This type of design problem is often a local innovation of an existing patent. The rules of patent infringement judgment present the major constraints to such design problems, and designers may have to sacrifice the performance of the product in order not to infringe on existing patents.

Although patent analysis has almost been a standard process in the early stage of product development in industry, few researches in design processes consider constraints in the form of existing patents or fully utilized the information obtained from patent analysis. Chen and Chen [2004] integrated the systematic design process and design patent protection mechanism to develop an adaptive design process. Zhang and Chen [2004] presented a process based upon the extension theory and TRIZ to design around patents and resolve conflictive problems. Chang et al. [2004] proposed an auxiliary methodology for creative mechanism design. This methodology is a systematic approach based on modification of existing devices for the generation of all possible topological structures of mechanisms to avoid existing designs that have patent protection.

Designing around techniques have been discussed in many textbooks. For example, Nydegger and Richards [2000] proposed three possible strategies for designing around an existing patent:

(1) Reduce the number of elements in the claims to satisfy the full elements rule.
(2) Use the method of substitution to make the accused subject matter different from the techniques disclosed in the claims to prevent literal infringements.
(3) Substantially change one of the constitutive requirements of way/function/result to prevent infringements according to the doctrine of equivalents.

These designing around techniques provide a good guideline for avoiding patent infringement. Note that each of the methods described above presents a new design problem to be solved. Innovative design methodologies are still needed to generate real engineering solutions for the new design problems.

This research proposes a patent-based design process by systematically integrating patent information, the rules of patent infringement judgment, strategies of designing around patents, and innovation design methodologies. The purpose of the process is to generate a new design concept that is a local variation of one of the concerned patents instead of a completely innovative design, but does not infringe with existing patents. The basic idea is to consider patent infringement before engineering design concepts are actually generated.

Figure 1 shows the conceptual flowchart of this patent-based design process. To start with, the designer conducts standard patent search and analysis to identify the related patents to be designed around and to collect functions and core techniques of each related patent. Each patent is then symbolized by a “design matrix” converted from the design parameters (DPs) and functional requirements (FRs) of the patent. This design matrix representation is inspired by the Axiomatic Design methodology proposed by Suh [2001], which will be described in later sections.

The design matrices of the patents can be manipulated mathematically. Rules of infringement judgment and design around strategies can be converted into mathematical operators applying on the design matrices. In this research, a design-around algorithm is developed to generate a new design matrix that does not infringe with design matrices of existing patents. There can be many design matrices that satisfy the constraints. In our algorithm, the design matrix which is the smallest variation of one of the design matrices of existing patents to be designed around will be chosen first. The new design represented by this design matrix will also be a local variation of an existing patent. The design matrix is then transformed back into a real engineering design problem.

The whole process is integrated into a computerized “Design-Around Tool (DAT)”. By inputting the DPs and FRs of thee patent to be designed-around, the designer can obtain a series of design problems to be solved, sorted by the extent of variation to the existing patent.

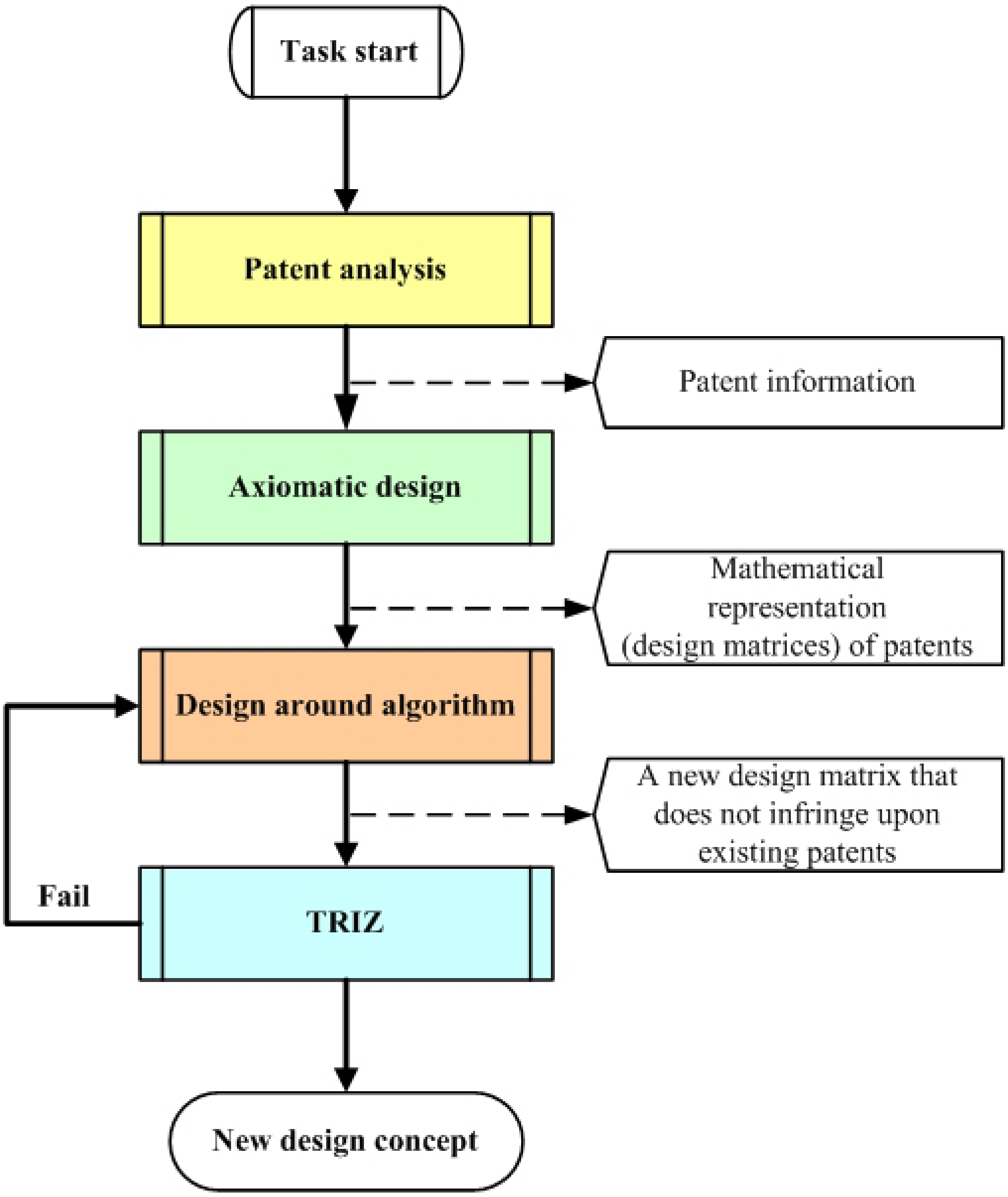

Figure 1. Conceptual flowchart of the patent-based design process

In this research, TRIZ is used to solve the engineering design problems generated by the algorithm. TRIZ is a systematic approach to finding innovative solutions to technical problems which was put forward by a former Soviet Union scientist Altshuller. TRIZ is an available tool for design engineers to handle conflict conditions during the innovation design problem solving process. There are several methods in the TRIZ toolset [Altshuller, 1998]:

- Ideality
- Contradiction Matrix
- Physical Contradiction Resolution Principles

- Substance Field (Su-Field) Analysis

In this research, the Contradiction Matrix is mainly used to convert the new design matrix into an engineering design solution. However, this transformation may fail because there may not be a feasible design corresponding to the new design matrix generated by the algorithm. Referring to Figure 1, if TRIZ fails to generate a feasible design, the algorithm is triggered again to generate the next design matrix which satisfies the patient infringement constraints and is the smallest variation of one of the design matrices of the existing patents. Finally, one or more new design concepts are generated.

The rest of the paper is organized as follows. In Section 2, the design of a golf club head with weight adjustment, which is taken as an example to illustrate the patent-based design methodology throughout this paper, is described first. Section 3 discusses how the related patents obtained from patent analysis are symbolized using the concept derived from Axiomatic Design. Section 4, 5, and 6 discuss the development of the design-around algorithm and the integration with TRIZ to generate the real engineering design concept. In particular, a computerized design-around tool is described in Section 5. The golf club head with weight adjustment design example is taken again to illustrate the detailed steps of implementation. Finally Section 7 concludes the paper.

2. Design of a golf club head with weight adjustment

The performance of a golfer is greatly affected by the selection of golf clubs. The “swing weight”, the weight distribution and the center of gravity of the golf club head, is one of the major concerns when selecting golf clubs because the swing weight significantly affects the driving characteristics.

Weight adjustment mechanism is often incorporated into the design of the golf club head, so that the golfers can customize the swing weight in different situations. Many related patents on weight adjustment of a golf club head can be found in a standard patent analysis. Figure 2 shows a golf putter head with weight adjustable arrangement which is disclosed in U.S. Patent 6,348,014[2002]. According to the claims of this patent, there are 5 components, receiving holes, weight adjustable arrangement, annular locating groove, rubber retaining ring, and golf putter head. The weight adjustable arrangement made by aluminum alloy or magnesium alloy, is fasten to the receiving holes. The golfer can use different weight adjustable arrangements to change the center of gravity of the golf putter heads. After a patent analysis, this patent is identified by the golf club manufacturer as the patent to be designed around.

In patent analysis, the technology/function matrix is used to investigate which techniques can produce the specific functions. The column of the matrix represents the functions while the row lists the disclosed techniques. The technologies and functions are obtained from the patent abstract lists of each concerned patent. Table 1 is the technology/function matrix of U.S. Patent 6,348,014.

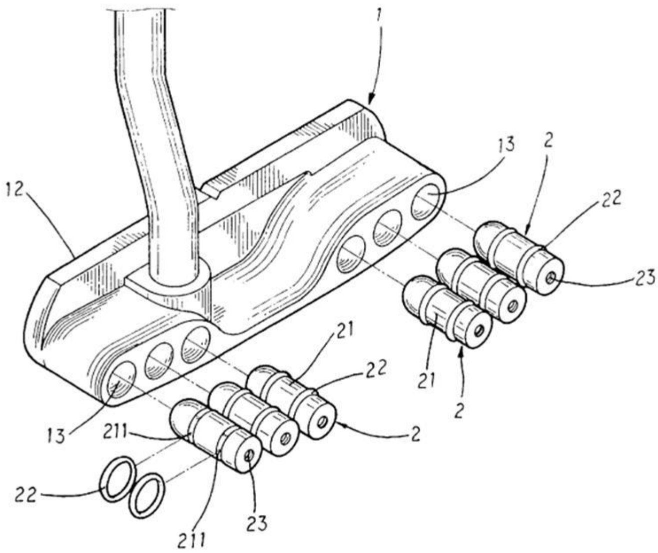

Figure 2. U.S. Patent 6,348,014

Table 1. Technology/function matrix of U.S. Patent 6,348,014

Functions / Technologies	Comprise the body	Fix the weight adjustable arrangement	Change the center of gravity
receiving holes	●	●	
weight adjustable arrangement		●	●
annular locating groove		●	
rubber retaining ring		●	
golf putter head	●	●	

3. Design matrix representation

In this research, each concerned patent in the technology/function matrix is symbolized by a design matrix, which is inspired by the Axiomatic Design methodology proposed by Suh [2001].

Axiomatic design is a system design methodology using matrix method to analyze the transformation of customer needs into functional requirements, design parameters, and process variables. The axiomatic design approach consists of two axioms. Axiom 1, which is called the independence axiom, deals with the relationship between functional requirements (FRs) and design parameters (DPs). Axiom 2, which is called the information axiom, deals with the complexity of the design. In this research, Axiom 1 is used for representing each patent to be designed around. A brief introduction to Axiom 1 is given below.

Let there be *m* components represented by a set of independent FRs where FR is the vector of functional requirements. DPs in the physical domain are characterized by vector DP with *n* components. The design matrix representing the relationship between FRs and DPs vectors is expressed as

$$\{FRs\}_{m\times 1} = [A]_{m\times n}\{DPs\}_{n\times 1} \tag{1}$$

$$[A] = \begin{bmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \cdots & \vdots \\ A_{m1} & \cdots & A_{mn} \end{bmatrix} \tag{2}$$

Equation (1) is a design equation for the design of a product, where $[A]$ is a “design matrix” that characterizes the product design. The components in the design matrix are either “0” or “1”. A cell takes a “0” if varying the design parameter has no effect on the corresponding functional requirement and a “1” if it does.

In general, Equation (1) may be written in terms of its elements as,

$$\sum_{i=1}^{m} FR_i = \sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij})DP_j \tag{3}$$

where *n* is the number of DPs.

In the “technology/function” matrix in Table 1, the “technologies” resembles the design parameters (DPs), and the “function” resembles the functional requirements (FRs) in Equation (3). For example, in Table 1,

FR_1 = Comprise the body

FR_2 = Fix the weight adjustable arrangement

FR_3 = Change the center of gravity

The corresponding DPs are as follows:

DP_1 = Receiving holes

DP_2 = Weight adjustable arrangement

DP_3 = Annular locating groove

DP_4 = Rubber retaining ring

DP_5 = Golf putter head

The technology/function matrix in Table 1 can be expressed as

$$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} T_1 & 0 & 0 \\ 0 & T_2 & 0 \\ 0 & 0 & T_3 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \end{bmatrix} \tag{4}$$

where $\mathbf{T} = \begin{bmatrix} T_1 & 0 & 0 \\ 0 & T_2 & 0 \\ 0 & 0 & T_3 \end{bmatrix}$ is the transformation matrix which transfers the DPs into FRs. For example, in Equation (5)

$$\begin{cases} FR_1 = T_1\left(DP_1 + DP_5\right) \\ FR_2 = T_2\left(DP_1 + DP_2 + DP_3 + DP_4 + DP_5\right) \\ FR_3 = T_3\left(DP_2\right) \end{cases} \tag{5}$$

The first equation above means that “Transforming components receiving holes and golf putter head achieves function of comprise the body.” Similarly, the second equation above means that “Transforming components receiving holes, weight adjustable arrangement, annular locating groove, rubber retaining ring, and golf putter head achieves the function of fix the weight adjustable arrangement”; the third equation above means that “Transforming components weight adjustable arrangement achieves the function of change the center of gravity.”

4. The design-around algorithm

This section discusses the development of the design-around algorithm. U.S. Patent 6,348,014 is also used to illustrate the detailed steps of implementation of the patent-based design process.

Consider a series of design matrices of existing patents $\mathbf{A}_i$, i = 1, …, n, to be designed around. The purpose of the design-around algorithm developed in this study is to generate a new design matrix $\overline{\mathbf{A}}$ that is similar to one of the existing matrices $\mathbf{A}_i$, but does not infringe with any of the existing design matrices. That is, to generate $\overline{\mathbf{A}}$ such that

$$\overline{\mathbf{A}} \approx \mathbf{A}_i \quad \text{and} \quad \overline{\mathbf{A}} \neq \mathbf{A}_i \tag{6}$$

where "$\approx$" means "is similar to", and "$\neq$" means "does not infringe with".

Figure 3 shows the flowchart of the design-around algorithm. To start with, the designer must identify the related patents to be designed around and to collect functions of each related patent, as in standard patent analysis. Each patent is then symbolized by a "design matrix" converted from the DPs and FRs of the patent.

After transferring the related patents into design matrices, the designer has to assign the priority of DPs to be designed around. The priority of DPs to be designed around is given to those having the least influence in the design matrix, which are the DPs having the least contribution to the FRs, and the DPs having minimal interaction with other DPs. The influences of the DPs are represented by the number of non-zero elements in the design matrix. To assign the priority of DPs to be designed around, the columns and rows of the design matrix are sorted according to the number of non-zero elements.

In our example, Equation (7) is the design matrix after sorting. DP_3 and DP_4 only contribute to the function FR_2 and have less interaction with other DPs. DP_2 contributes to the function FR_2 and FR_3. DP_1 and DP_5 contribute to the function FR_1 and FR_2. Comparing with DP_2, DP_1 and DP_5 have more interaction with other DPs. Therefore DP_3 and DP_4 have the highest priority to be designed around, and DP_2 has the second highest priority to be designed around. DP_1 and DP_5 are considered lastly.

$$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} T_1 & 0 & 0 \\ 0 & T_2 & 0 \\ 0 & 0 & T_3 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} DP_1 \\ DP_5 \\ DP_2 \\ DP_3 \\ DP_4 \end{bmatrix} \tag{7}$$

After the priorities of DPs are decided, the "design-around operation matrices" are applied to the DPs which have the highest priority to be designed around. In this research, four design-around operation matrices are proposed. They are applied in the order of "elimination" (to eliminate redundant component), "replacement" or "integration" (to make at least one constitutive DP substantially different), and "decomposition" (to replace a multi-functional technological characteristic with a few separate technological characteristics). New design matrices which do not infringe with the existing patents and the corresponding design problems are generated. The manipulation of the design matrix will be illustrated using the golf head design example in the next section.

In the next stage, TRIZ is used to solve the new design problems and transform the new design matrix back into a real engineering design concept.

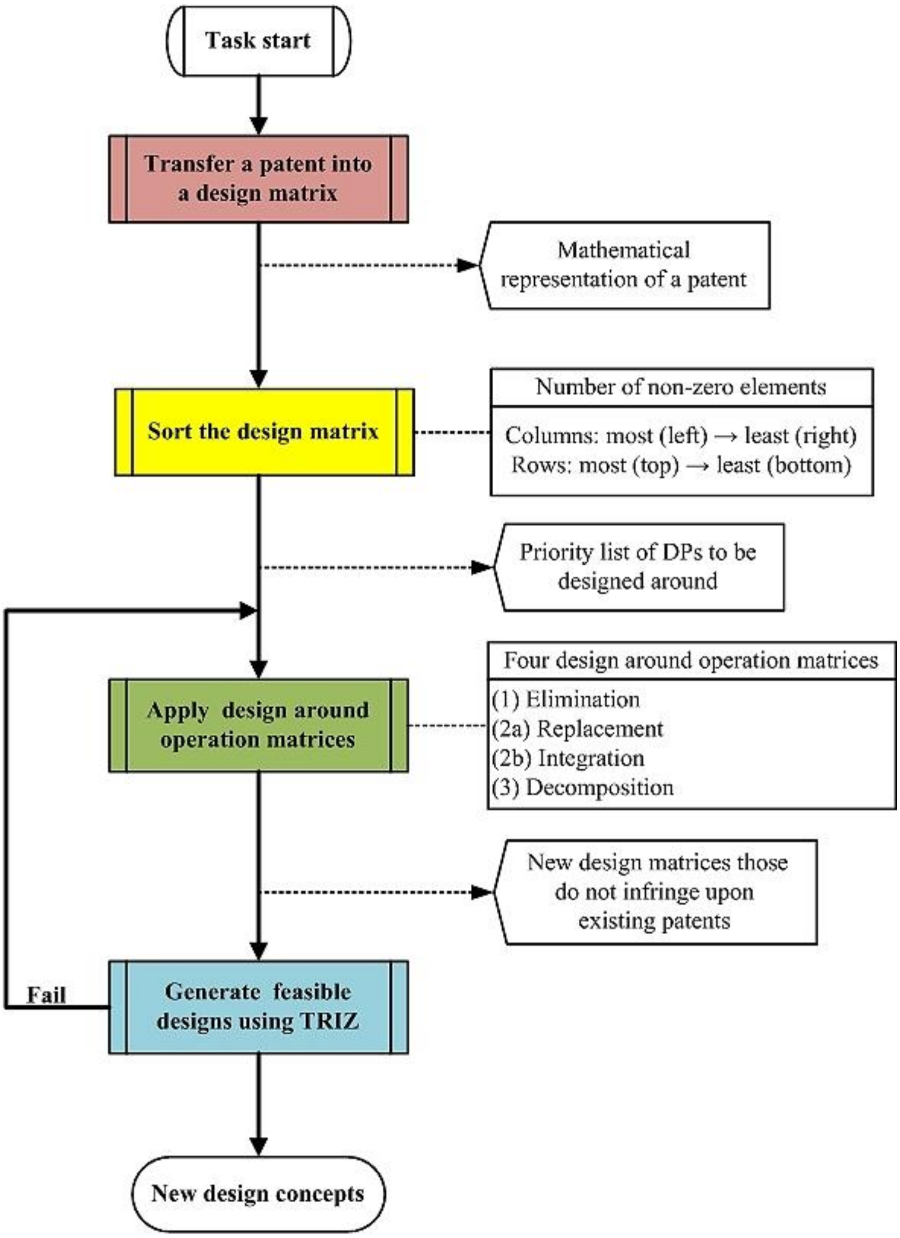

Figure 3. Flowchart of the design around algorithm

5. The computerized design around tool

The whole process is integrated into a computerized "Design-Around Tool (DAT)". As shown in Figure 4, by defining the DPs, FRs, and the design matrix of the patent to be designed-around, the designer can conveniently obtain a series of design problems to be solved, sorted by the extent of variation to the existing patent.

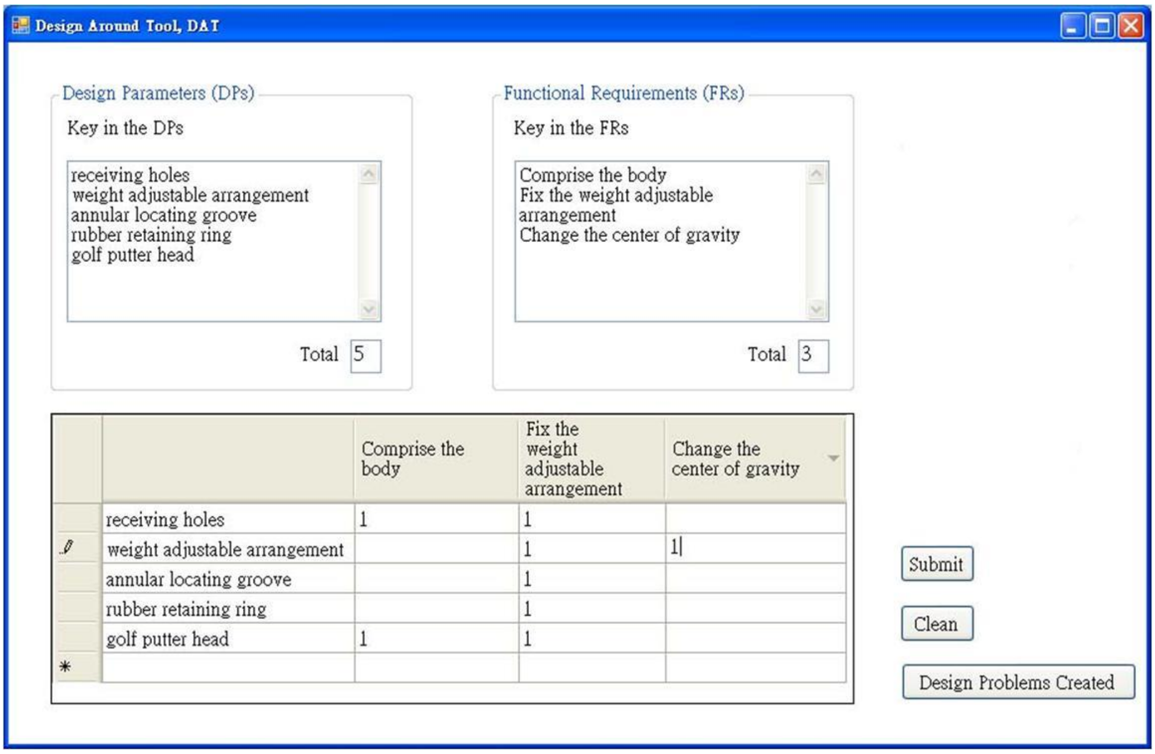

Figure 4. User interface of DAT

After the designer imports the technology/function matrix, DAT will start the design around algorithm and compute the design matrix **A** first. The "design around operation matrix" **D** is then applied on the design matrix to generate a new design matrix $\overline{\mathbf{A}}$:

$$\overline{\mathbf{A}} = \mathbf{A}_{n+c}^{E} + \mathbf{D} \tag{8}$$

where $\mathbf{A}_{n+c}^{E}$ is called the "expansion matrix" of A, defined as

$$\mathbf{A}_{n+c}^{E} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} & 0 & 0 & \cdots \\ a_{21} & a_{22} & \cdots & a_{2n} & 0 & 0 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} & 0 & 0 & \cdots \end{bmatrix}_{m\times(n+c)} \tag{9}$$

and c is the number of expanded columns. Note that the patent represented by design matrix **A** is equivalent to that represented by design matrix $\mathbf{A}_{n+c}^{E}$, that is, $\mathbf{A} = \mathbf{A}_{n+c}^{E}$. For example,

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ \vdots \\ FR_m \end{Bmatrix} = \begin{bmatrix} T_1 & 0 & \cdots & 0 \\ 0 & T_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & T_m \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}_{m\times n} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_n \end{Bmatrix}$$

$$= \begin{bmatrix} T_1 & 0 & \cdots & 0 \\ 0 & T_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & T_m \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} & 0 \\ a_{21} & a_{22} & \cdots & a_{2n} & 0 \\ \vdots & \vdots & \ddots & \vdots & 0 \\ a_{m1} & a_{m2} & \cdots & a_{mn} & 0 \end{bmatrix}_{m\times(n+1)} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_{n+1} \end{Bmatrix} \quad (10)$$

The expansion matrix will be needed when new DPs are introduced in the design around process. For example, in order to avoid patent infringement by the all elements rule, the new product can be obtained through integration of the two technological characteristics of DP_3 and DP_4. A new component will be introduced in the integration operation, therefore the expansion matrix of **A** is used:

$$\mathbf{A}_6^E = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (10)$$

To integrate DP_3 and DP_4 into DP_6, let

$$\mathbf{D} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (11)$$

$$\overline{\mathbf{A}} = \mathbf{A}_6^E + \mathbf{D} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (12)$$

Clearly $\overline{\mathbf{A}} \neq \mathbf{A}_6^E$, because DP_3 and DP_4 have been integrated into DP_6, and the design-around technique is successful according to the all element rule. The new design can be expressed as

$$\begin{cases} FR_1 = T_1(DP_1 + DP_5) \\ FR_2 = T_2^{*}(DP_1 + DP_2 + DP_5 + DP_6) \\ FR_3 = T_3(DP_2) \end{cases} \quad (13)$$

As shown in Equation (13), there is a new design problem to be solved ($FR_2 = T_2^*(DP_1 + DP_2 + DP_5 + DP_6)$), which can be can be translated into engineering language by DAT:

Design problem: "How to design a transformation T_2^* to achieve the function FR_2 (fix the weight adjustable arrangement) using a new component DP_6, while the technological characteristics of DP_6 are different from those of DP_6, DP_3 and DP_4."

Figure 5 shows the output of DAT. The engineering problems to be solved are listed according to their design-around priorities.

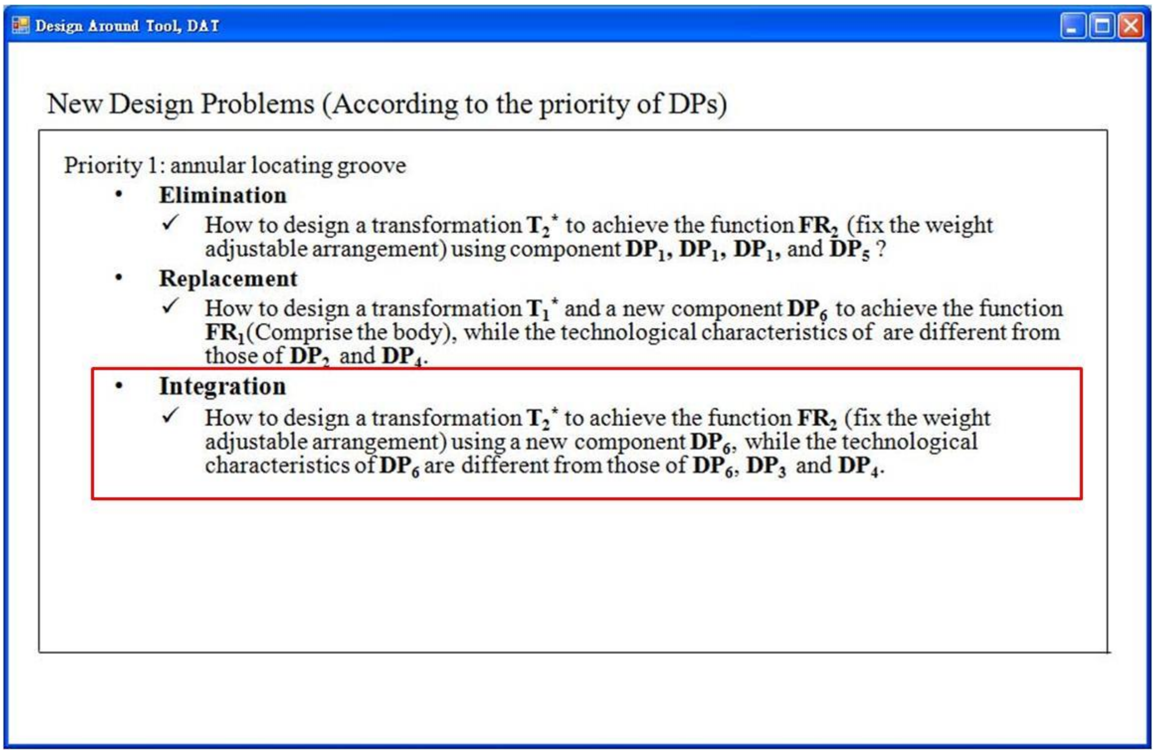

Figure 5. Design problems produced by DAT

6. Generate engineering design concepts using TRIZ

After applying the 4 design around operation matrices to the components with the highest priority to be designed around new design problems are generated. In this section, the Contradiction Matrix and the inventive principles of TRIZ are used to solve these new design problems.

The Contradiction Matrix in the TRIZ theory contains 39 design parameters and 40 inventive principles for solving related engineering design problems. As shown in Table 4, the designer searches in 39 design parameters to find the ones matching with the functions in the design problem, and the "inventive principles" appearing in the corresponding bracket are the possible guidelines to generate the "transformation" in the design problems described above.

For example, for design problem

"How to design a transformation T_2^* to achieve the function FR_2 (fix the weight adjustable arrangement) using a new component DP_6, while the technological characteristics of DP_6 are different from those of DP_6, DP_3 and DP_4."

Parameter 13 (stability of object) is selected as the feature for achieving the function of "fixing the weight adjustable arrangement" by DP_6. In addition, it is expected that DP_6 will be able to fix the weight adjustable arrangement. Therefore Parameter 33 (convenient of use) is selected as the feature to not being deteriorated in Table 2, in which the three inventive principles can be obtained. They are Principle 32 (optical changes), Principle 35 (physical or chemical properties), and Principle 30 (flexible films or membranes).

Table 2. The contradiction matrix

Undesired result / Feature to change		1	…	33	…	39
		Weight of moving object	…	Convenient of use	…	Productivity
1	Weight of moving object					
…	…					
13	Stability of object			32, 35, 30		
…	…					
39	Productivity					

After reviewing the three principles, Principle 30 was utilized to generate the new concept in the golf club head with weight adjustment. In TRIZ, Principle 30 has two explanations:

a. To use flexible shells and thin films instead of three dimensional structures;
b. To isolate the object from the external environment by using flexible shells and thin films.

In particular, “Use flexible shells and thin films instead of three dimensional structures” was used to solve the design problem presented above. In the new design concept generated, the new component DP_6 consists of spiral power spring. As shown in Figure 6, a tank in the golf club head contains the weight adjustment device comprised of an axle and the spiral power spring. The center of gravity of the golf club head can be changed by using a tool to rotate the axle. The spiral power spring inside becomes smaller and can be fit into the tank or taken off the tank.

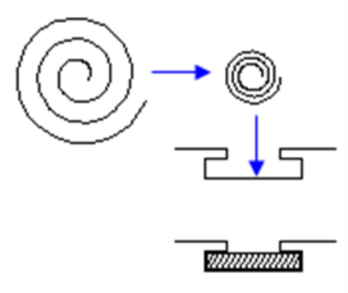

Figure 6. New design concept of new component DP_6

The innovative design concept in Figure 6 is then developed in to a prototype as shown in Figure 7. The designer can try to find solutions for other design problems utilizing the Contradiction Matrix in TRIZ. However, a good engineering design concept cannot be generated “automatically”. It still depends on the domain knowledge and experience of the designer. Moreover, transformation from a design matrix to an engineering design concept may fail for there may not be a feasible design corresponding to the new design matrix generated by the algorithm.

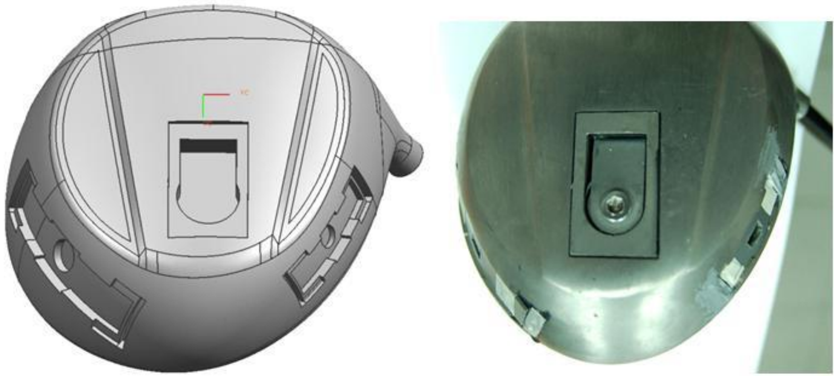

Figure 7. The prototype of golf club head

7. Conclusions

The design problem constantly faced by engineering designers across industries is how to design around existing patents, instead of generating a completely innovative design. Although patent analysis has almost been a standard process in the early stage of product development in industry, information obtained from patent analysis is often not fully utilized.

This paper proposes a patent-based design process by systematically integrating patent information, the rules of patent infringement judgment, strategies of designing around patents, and innovation design methodologies. The basic idea is to consider patent infringement before engineering design concepts are actually generated. Design matrices are used as the mathematical representations of patents and design around operations, such that a new design matrix that does not infringe with design matrices of existing patents can be generated by mathematical manipulations. New design problems are formed. Finally the Contradiction Matrix in TRIZ, which is a perfect match to this design process, is then used to generate a real engineering solution.

The whole process is integrated into a computerized “Design-Around Tool (DAT)”. By inputting the DPs and FRs of thee patent to be designed-around, the designer can obtain a series of design problems to be solved, sorted by the extent of variation to the existing patent. This design process aims to assist enterprises to enhance the efficiency of product development, lower the possibility of patent infringements, and increase the potential to patent results of innovation. From another point of view, the enterprises can also use this process to check whether it is easy to design around their own patents, and how to establish a complete patent portfolio without any possible loopholes.

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Paper ID: 137

Systemic Innovation of Logistics Finance Operation Model Based on TRIZ Theory

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Abstract

In recent years, with the globalization and Webification of modern logistics, the demand of synthesis services for the Logistics Finance like the settlement and payment that beyond the space constraints has become stronger constantly. The academia has made large amount of researches on the Logistics Finance theory and its operation models. Different kinds of methods for classifying its operation models have been brought forward. Most of them are raised from the aspects of financial organization like the banks and so on which provide the capital, so these methods should have some defects. Towards these defects, this paper made deeper research and creatively applied TRIZ to the classification of the operation models. The paper also firstly brought forward the new methods for classifying the operation models from the aspects of market demands and financing companies. The new method strengthened the universality and the practicality of Logistics Finance, which makes the systemic innovation to the operation model of Logistics Finance.

Keywords: TRIZ theory, logistics finance, systemic innovation, risk assessment

1. Introduction

In recent years, Logistics Finance has been developed to some degree. In 1987 Wei Chen made the assumption of material bank and in 2002 Daoli Zhu raised the concept of financing warehouse. In 2004, Xiaofan Zou and Yuanqi Tang raised the concept of Logistics Finance. From then on, Logistics Finance has become the new research field of Chinese logistics experts.

Logistics Finance is the combination of logistics service and finance service. It puts the industry capital in the dominant position. Its connotation can be described from the following two aspects: broadly, it means series operational activities which could solve the currency capital problems in logistics field, including the whole process of logistics operation, development and application of finance products, integration of logistics, cash flow and information flow, and coordinating the capital flow in the operation of supply chain. Strictly, Logistics Finance is the service provided by the bank and the third party logistics in the operation of supply chain so as to improve the whole efficiency of the supply chain and the capital operation, including logistics service, distribution processing, financing, assessment, supervising, assets handling, and financial consultant. Logistics Finance could also be considered as the company financing services developed with the help of logistics companies, which is Inventory and Receivables financing.

2. Present operation models of logistics finance and their defects

A lot of experts and scholars in china have made abundant researches on the Logistics Finance in practice. From the proposal of “material bank” being raised in 1987, to the practice of “logistics bank” in 2000, and also with the implementation of the” supply chain finance” strategy, the content of Logistics Finance has been greatly enriched and also the classification of its operation models has been diversified. In the paper 《logistics finance———roll booster of the development of SMEs》 (2005), it was divided into three kinds according to the basic operation procedures of Logistics Finance: Operation model on credit advance payment, Warehouse Receipts pledge model and confirmed warehouse model. Wu Gang and Yao Yina divided the operation models into two kinds from the aspect of combining Logistics Finance and future delivery: buying customer credits and selling customer credits. Han Qiang, in his paper 《logistics finance: realize the Trigonal win logistics value-added services》 (2008) divides the operation models into three kinds according the participating degree of logistics companies: pledge model, assurance model and the credit advancement model.

These researches integrated the material flow, capital flow and multi-party information flow, achieved the high efficiency and low cost of whole process supply chain, and becomes the profit increasing point of supplier, purchaser, the third party logistics companies and the banks. Meanwhile, there are also defects and risks. For the diversity of its operation models and the inconsistency of the classification by the experts, its practicability is not strong and it has certain limitations. All that made this kind of operation is only limited to the large logistics companies and banks. So far most of the logistics company in Tianjin still did not carry out this operation. So it is very urgent to identify one united method for classifying the operation methods.

3. Systemic Innovation Research of the Logistics Finance Operation Model based on the TRIZ theory

3.1 New operation models of logistics finance based on the TRIZ theory

TRIZ is a very important innovation design method. Its ideal target is the principle of simplification. The ideal formula could be used to analyze the defects of the above original Logistics Finance operation models and the ideal formula is as followed:

$$\frac{\sum A}{\sum B + \sum C} \qquad ①$$

In the formula “A” represents efficiency; “B” represents cost; “C” represents damage.

According to the Logistics Finance, “A” represents the profits of each party brought in by the Logistics Finance; “B” represents the cost in the operation process and “C” represents the damage to other enterprises caused in the Logistics Finance realizing process.

Through the analysis of the above formula, it can be seen that compared with further increasing profit “A” and controlling operation cost “B”, reducing damage “C” through the systemic improvement of operation model and strengthening the universality of Logistics Finance would be much easier.

a. Problem Analysis

(a) Problem Description

The first is the credit problems of the financing corporation. The financing targets are mostly SMEs in logistics financial businesses, so that audit services are often not carried out and even the current China's corporate credit and risk assessment systems are not perfect. All these factors may lead the enterprises obtained the loans by distortion inventory and receivable accounts from the financial institutions.

Secondly, in terms of financial institutions, the risk and the benefit does not match among the risk participants, at the same time, the evaluation system for the current assets is not perfect, banks do not have enough experience about logistics financial credit service, and financial management measure do not go up with requirement, as a result, current system of risk prevention and regulations are often inconsistent with the highly efficient and timely operational requirements of enterprise supply chain.

As a result, the risk protection system and the regulations in being do not comply with the corporate requirement in efficiency and timely response.

(b) Abstract Description

The thresholds for financial institutions to provide credit are neither too high nor too low, and so as to low the risk of finance organizations, the requirement for the credit customers is sure to be raised. By the question analysis and abstract results, we can see the conflicts of system as follows: with the Logistics Finance universality be improved, which means by the time small and middle companies made good use of Logistics Finance to obtain capital, the credit risk of financial institutions increases (parameters of deterioration); with the increase in risk control of financial institutions, the harm to SMEs increases (parameters of deterioration).

b. Problem solving

After the conflict is confirmed, the universality of Logistics Finance is strengthened, and the credit risks of financial organizations are getting higher. Therefore, the factor needs to be improved—adjustability No.35the factor that is getting worse—intension No.14

Apply the above conflicts parameter No.35 and No.14 into Conflict Matrix (that is 39 matrix tables), the following 4 invention principles could be obtained: No.35---changing the parameter of objects, No.3---locality, No.32---color changing and No.6---universalization. Then make the comparison with the 40 invention principles table of TRIZ theory and make deep study into the invention principle No.35 and No.3. After determining a conflict, redraw the mode of operation by using the methods of general and part separation in TRIZ separation principle, thoroughly break the fetters of conducting division of model from the perspective of financial institutions before and in terms of market demand and financial business, and identify a more valuable category.

Contact the market demand and financing companies, determine the different combinations and determine the different forms for financial institutions providing loans by the different combinations. Then it produces the new operation modes of Logistics Finance, and it is more focused and more practical compared to the existing pattern classification methods. (Specific expression can be combined with chart). As follows:

Table 1.　New Model Chart

market / financial business	popular	personalized
large-scale enterprises	Financing side Grant credit Advance model	financing side grant credit assurance model
SMEs	Financial Institutions grant Credit pledged Model	financial institutions grant credit guarantee model

The above classified new operation models needs both the industry environment and the business supervising be well improved.

In the aspect of industry environment: (1)relevant gage documents form the industry standard and there should be a socialized warehouse receipt system; (2)the third party logistics stocking business being well developed; (3)operation system form an industry regulation; (4) the relevant facilities are well improved.

In the aspect of business supervising: the surprising model should be according to different gages and partners, a high risk control level is required.

3.2 Practice meanings of new logistics finance operation models

The improving new operation model, Well-targeted, well-oriented, convenient and reliable application, it can effectively improve the efficiency of financing in SMEs and control the credit risk of financial institutions. It can also solve the shortcomings of the existing pattern classification and increase the efficiency of funds utilization dramatically. Its practice meaning is even greater. Take some SMEs in Binhai New Area of Tianjin for example, they can not meet the standards for the credit of financial institutions in the old operation model, so they can not finance needed funds very well. However, from the long term, Binhai New Area of Tianjin is the key developing area in the Fifty-one Period, so a lot of SMEs could become the largest profits increase points. And just because they can not take the good advantage of the present operation model, they may miss the chance. But in the innovated operation model, they can be correspond with certain criteria and will finance the needed funds without increase the credit risk of financial institutions.

4. Conclusion

Based on the analysis of current Logistics Finance defects, this paper transferred the conflicts between the finance organizations and small or middle companies to standard problems. By defining the technique inconsistency and referring to the 40 innovation principles and 39 engineer parameter methods of TRIZ theory, this paper found the relevant problem solving scheme 35 and 3. By deep studying into the scheme, this paper achieved the tractable practicable operation model of Logistics Finance. However, the practice of the new model raised a high demand for the work staff of logistics companies and financial organizations and the detail operation process need to be refined, so it still needs to be further improved in practice.

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Paper ID: 139

Systematic Innovation of Engineering Maintenance and Service Through Axiomatic Design Mapping

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Abstract

A systematic innovation framework based on Axiomatic design mapping extended to include Control Factors (CFs) is proposed for the maintenance and service. The systematic innovation framework is starting from establishing knowledge representation of existing product to maintenance analysis, and then to innovative action. The activities of maintenance analysis consist of Customer Attributes (CAs) in Value Analysis, Functional Requirements (FRs) in Failure Mode and Effects Analysis, Design Parameters (DPs) in Troubleshooting, Process Variables (PVs) in Process Variables Validation and CFs in Optimal Setting. Different innovative action in CAs, FRs, DPs, PVs, and CFs are classified. The priority of maintenance and service value is analyzed. Innovative action is screened by customers, products, and patents. A case study on wire bonder is used for the illustration of the framework of maintenance and service innovation. The maintenance value and cost of DPs on a first-bond failure are analyzed. The first priority of DPs in innovation is selected for the further illustration of innovative action.

Keywords: Axiomatic design, Maintenance and service, Systematic innovation, Value engineering, Wire bonder.

1. Introduction

Engineering maintenance and service is to afford maintenance with service for the acceptance or worth by customers (Keith, et al., 2008). Systematic innovation in engineering maintenance and service provides a systematic approach to generate, nurture and disseminate successful new ideas, methods, techniques, or products in the maintenance and services. Systematic innovation methods, mainly, can be classified into TRIZ-based and non-TRIZ approaches, although there are some approaches proposed to combine, and integrate these two different approaches in different scopes and levels (Mann, 2002, Zhang and Liang, 2007).

TRIZ method is developed for inventive problem solving. In non-TRIZ approaches, Axiomatic Design employing information measure is one of the most important methods for analysis and synthesis of a general system. In the past years, both TRIZ-based and Axiomatic Design methods have been producing a considerable impact on innovative engineering products design. Recently, the applications of these methods have been extended to service engineering (Zhang, et al, 2003, Chang, et al., 2009).

Axiomatic Design (Suh, 2001) helps designers to structure and understand design problems through a mapping between “what we want to achieve” and “how we want to achieve it.” In addition, two design axioms are employed to facilitate the decision of optimal synthesis of products in the process from mappings Customer Attributes (CAs), to Functional Requirements (FRs), to Design Parameters (DPs), and to Process Variables (PVs). The design mapping is very general and can be applied to various complex systems. Two design axioms are applied most successfully for precision system design. However, they may not be applied to the innovation in general engineering activities.

In a semiconductor business, the importance of maintenance and service and their management has rapidly grown in a wire-bonder industry since the first development of ball bonding technique by the Bell Laboratories (Harman, 1997). With the increasing numbers and workload of wire bonders in a semiconductor business, customers are relying on suppliers to provide efficient and effective maintenance and service of wire bonder equipment. Maintenance is an engineering decision and associated actions for the optimization of specified capabilities. A service is to perform an action for customer to keep a product in good operating condition. The benefits of maintenances procedures in manufacturing environment will optimize machine reliability to reduce production costs while improving product quality. The service operation enhances the technical oversight of specialized engineering operations at a fraction of the required cost to maintain the performance in-house. A systematic innovation method for efficient and effective maintenance and service of semiconductor equipments should provide new returns in productivity for a semiconductor manufacturing business (Boit, et al., 2001, Rooney et al., 2005).

In this paper, firstly, a systematic framework of maintenance and service innovation starting from establishing knowledge representation of existing product by Axiomatic design mapping will be proposed. Next, a case study on the maintenance and service innovation of wire bonder is used for the illustration of the proposed framework. Specifically, the cost and value in the maintenance of the first bond failure are analyzed. Then, the paper is to carry on innovative action of the first priority DPs. Finally, the contribution by the present approach on the maintenance and service innovation of a wire bonder is concluded.

2. Framework of Maintenance and Service Innovation

Maintenance and service innovation on engineering systems will reduce maintenance cost, increase equipment utilization, and improve productivity for the attributes of customers. There are several activities including Failure Mode and Effects Analysis (FMEA), troubleshooting, process variables validation, and process optimization involved in the maintenance and service of machine (Chang, et al., 2009). In this section, a framework is developed for providing an efficient and effective maintenance and service innovation. A framework of maintenance and service innovation is constructed and proposed as shown in Figure 1. The procedure in the framework for realizing a systematic innovation of equipment maintenance and service will be introduced.

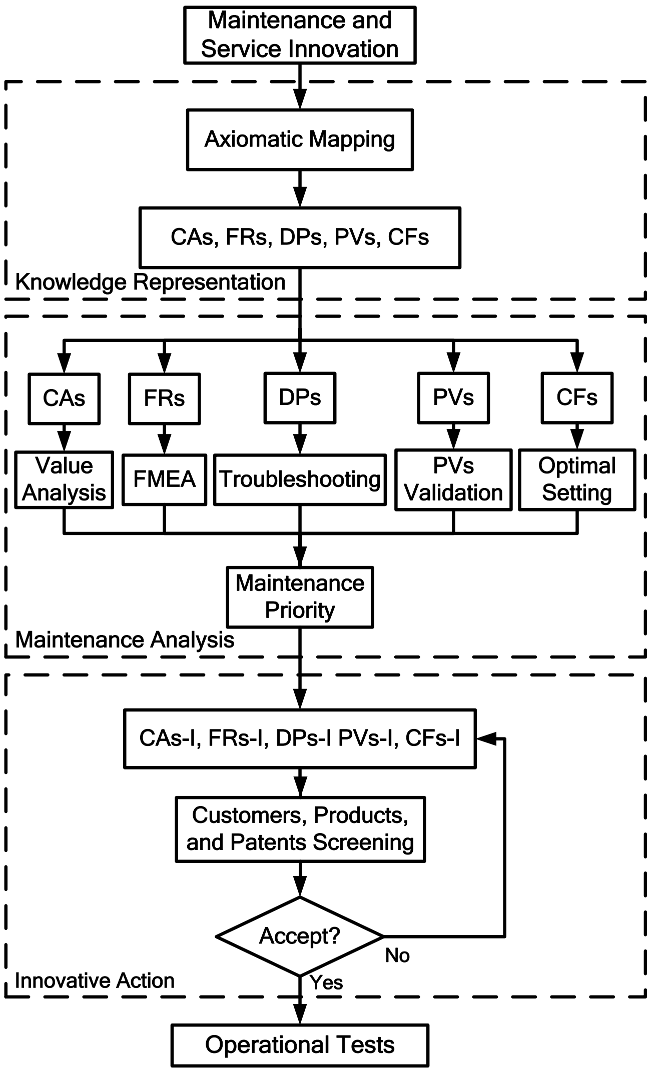

Figure 1. Framework in innovative maintenance and service.

2.1 Knowledge representation

An equipment as a system can be decomposed into many sub-systems for engineering operation, testing, and maintenance. In the decomposition of equipment, it is essential to understand the equipment's principle and mechanism in operation. With the knowledge of equipment, failure analysis and maintenance can be undertaken by engineers in service.

For an engineering system, a generic method based on Axiomatic design is employed for the knowledge representation. From Axiomatic design, the design mappings are from CAs to FRs, then from FRs to DPs and finally from DPs to PVs. The construction of mapping is through a zigzag procedure between "what we want to achieve" and "how we want to achieve it."

2.2 Maintenance analysis

Under the framework constructed in Figure 1, there are five activities associated with the mapping domains, respectively in the maintenance analysis. The five activities including CAs in Value Analysis, FRs in FMEA, DPs in Troubleshooting, PVs in Process Variables Validation, and CFs in Optimal Setting are described as follows.

1. CAs in Value Analysis

Value is the most important concern by customers in maintenance and service. From the voice of customers to derive CAs, the value of maintenance service is analyzed based on the operational function and maintenance cost.

2. FRs in FMEA

FRs are essential operational requirements by equipment. By reviewing FRs, FMEA can be inferred by identifying the failure problem and the corresponding DPs.

3. DPs in Troubleshooting

DPs are related to the hardware and software to generate FRs. For the failure due to DPs, the troubleshooting is undertaken by iterating test and check in order to resolve any issues of DPs in the subsystems or components.

4. PVs in Process Variables Validation

PVs are the variable in the operation of equipment in maintenance. The operation of equipment will be validated by reviewing and revising PVs to make sure that PVs are correct and no failures occur in the fabrication process software.

5. CFs in Optimal Setting

The maintenance is completed after setting the optimal CFs. The implementation of CFs in optimal setting will indicate that the failure has been resolved and the machine performance is robust in operation.

In the maintenance of FRs, DPs, PVs, and CFs, the cost and value in CAs will be evaluated eventually. With the analysis of function, cost, and value in the maintenance and service, a maintenance priority will be listed for the decision of taking innovative action in the maintenance and service.

2.3 Innovative action

With a priority of maintenance and service obtained by employing maintenance analysis, the next procedure is to take innovation action. In the innovative action, five different types of innovations (I) in CAs, FRs, DPs, PVs, and CFs are classified and appended with -I as CAs-I, FRs-I, DPs-I, PVs-I, and CFs-I, respectively. For the FRs-I in maintenance, the original FRs will be reviewed and revised through the analysis of failure modes and their causes and effects. For the DPs-I in maintenance, the troubleshooting for failure due to original DPs in mechanism and/or software will be reviewed and revised. For the PVs-I in maintenance, the validation of original PVs in fabrication process software will be reviewed and revised. For the CFs-I in maintenance, the original optimal setting of CFs will be reviewed and revised.

From the lists of maintenance and service priority, the priority of taking innovative action in the CAs-I, FRs-I, DPs-I, PVs-I, and CFs-I can be identified. Next, the detail innovative action will be screened by the customers, existing products, and patents through data base and the detail innovative action is to proceed with an iterative loop to decide an acceptable innovative action. With an acceptable specific innovative action, operational tests for the specific innovative action can be undertaken.

3. Knowledge Representation of Wire Bonder

The design and operation principle of a wire bonder encompasses engineering mechanics, automatic control, signals, communication and network, electrical hardware, and computer software. Thus, the function and structure of components in a wire bonder can be analyzed by utilizing Mechatronics Engineering (Bradley, 1993). By analyzing the system structure of a wire bonder, the design mapping can be obtained and documented as machine knowledge for maintenance and service.

3.1 Knowledge structure

A wire bonder with five modules of subsystem is required to satisfy functional requirements in operation (Chang, et al., 2009). The mapping between FRs and DPs which satisfies a decoupled module design is given by Equation (1) with weighting a_{ij} as

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \\ FR5 \end{Bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & 0 & a_{44} & 0 \\ a_{51} & a_{52} & 0 & 0 & a_{55} \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \\ DP5 \end{Bmatrix} \tag{1}$$

The FRs in Equation (1) are listed as

FR1: Provides command control and electronic control of equipment

FR2: Affords bonding motion for each recipe selected

FR3: Recognizes the image of materials by operator and machine

FR4: Provides material transportation capabilities

FR5: Maintains bonding table movement over the working area

The DPs for the subsystems in Equation (1) are listed as

DP1: Signal, motion, and power control in Console System

DP2: Wire bonding is accomplished by mechanisms and controls of Bond Head Assembly

DP3: Targeting of devices is accomplished by Vision System

DP4: Move the materials for bonding demands as Material Handling System

DP5: X-Y Table Assembly moves bonding mechanisms over the working space

3.2 Knowledge representation

The knowledge representation constructed by axiomatic mapping can be derived from decomposition and zigzag mapping (Suh, 2001). Only two levels in the representation of equipment knowledge are given in the following list.

3.2.1 Console system

FR1-1: All subsystems to be under control

DP1-1: Monitor and control system

FR1-2: Supply energy resources

DP1-2: Power system

FR1-3: Control the operation of machine

DP1-3: Human/machine interface

FR1-4: Software operations and data storage

DP1-4: Storage system

FR1-5: Air supply and control

DP1-5: Pneumatic system

FR1-6: Feed wire for automatic bonding

DP1-6: Wire feed system

3.2.2 Bond head assembly

3.2.2.1 Electronic Flame Off (EFO)

FR2-1: Discharge for wire ball formation

DP2-1: EFO assembly

3.2.2.2 Wire Clamp

FR2-2: Feed and hold wire

DP2-2: Wire clamp assembly

3.2.2.3 Ultrasonic Generator (USG)

FR2-3: Generate and transmit ultrasonic energy

DP2-3: USG system

3.2.2.4 Z-axis Servo System

FR2-4: Bond head positioning and force control

DP2-4: Z-axis servo system

3.2.2.5 Bond Integrity Test System (BITS)

FR2-5: Detection of bonding outcome

DP2-5: Bond integrity test system

3.2.2.6 Flexure Bearing Assembly

FR2-6: Provide rotational movement

DP2-6: Flexure bearing

3.2.3 Vision system

FR3-1: Clear image

FR3-2: Image acquisition with high speed

FR3-3: Focus range and field of view extension

DP3-1: Illumination and image acquisition system

DP3-2: Image processing system

DP3-3: Optomechanical extension mechanisms

3.2.4 Material handling system

FR4-1: Carry the materials in the bonding cycle

FR4-2: Fix the materials on the bond site

FR4-3: Provide the working temperature

FR4-4: Prevent materials damaged during transportation

FR4-5: Handle magazines during the bonding operation

DP4-1: Transporting mechanism

DP4-2: Clamping assembly

DP4-3: Heater assembly

DP4-4: Detection sensor

DP4-5: Elevator mechanism

3.2.5 X-Y table assembly

FR5-1: I/O density of IC chip become higher

FR5-2: Chip dimension and the bond pad pitch become smaller

DP5-1: High speed and steady X-Y servo system

DP5-2: X-Y table mechanism

4. Wire Bonding Failure and Maintenance Analysis

The maintenance analysis of wire bonder will follow the flowchart as shown in Figure 1. For a wire bonder to be maintained and serviced in field operation, the operational behavior is to be monitored and recorded in terms of FRs. In proceeding with maintenance and service, it is first tested whether the issue is due to optimal setting in CFs. Then, the PVs will be verified to assure the maintenance issue can be resolved. If the issue cannot be resolved, then the maintenance will be undertaken by checking the DPs which are mapped by the PVs.

In a bonding process, five failure modes as First Bond, Second Bond, Looping, Ball Formation, and BITS can be identified. For the analysis of potential failure modes by the approach of FMEA, the principle factors regarding equipment can be divided into mechanism, software, and bonding process. An approach to detect and analyze failures in the mechanism, software, and/or bonding process can be carried out through DPs and PVs as shown in Figure 2. For a failure mode which has been identified, the potential causes in the failures are further analyzed. The failure troubleshooting of a wire bonder for the failure mode can be analyzed and obtained by referring to DPs in the documented equipment knowledge. By employing failure troubleshooting, the results of failure modes corresponding to DPs are obtained as shown in Figure 3.

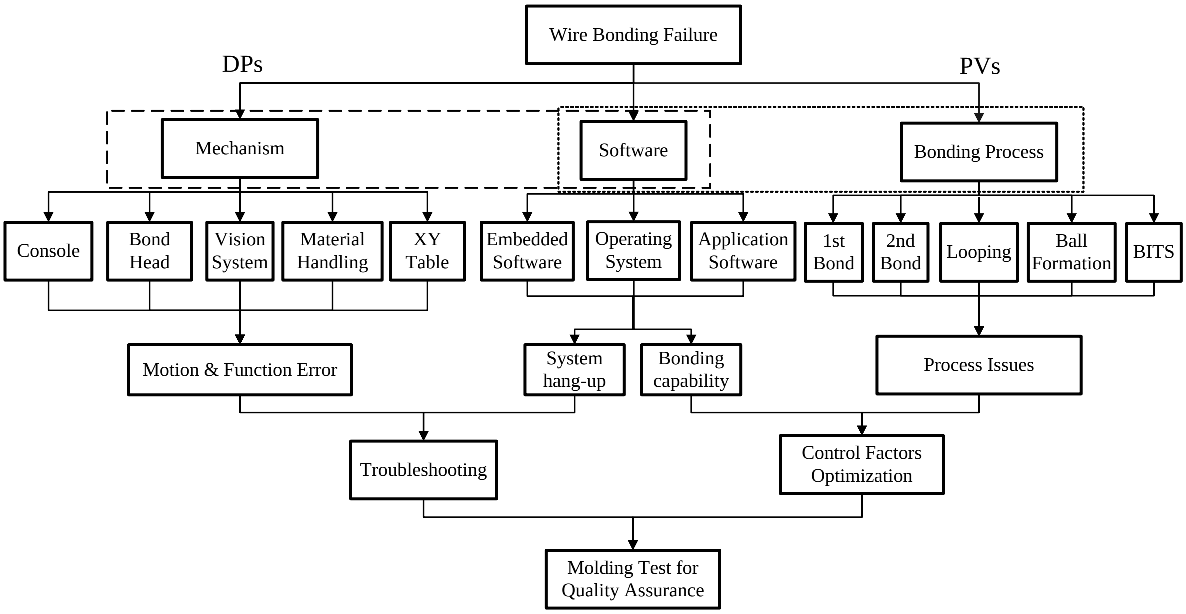

Figure 2. Wire bonding failure analysis through DPs and PVs.

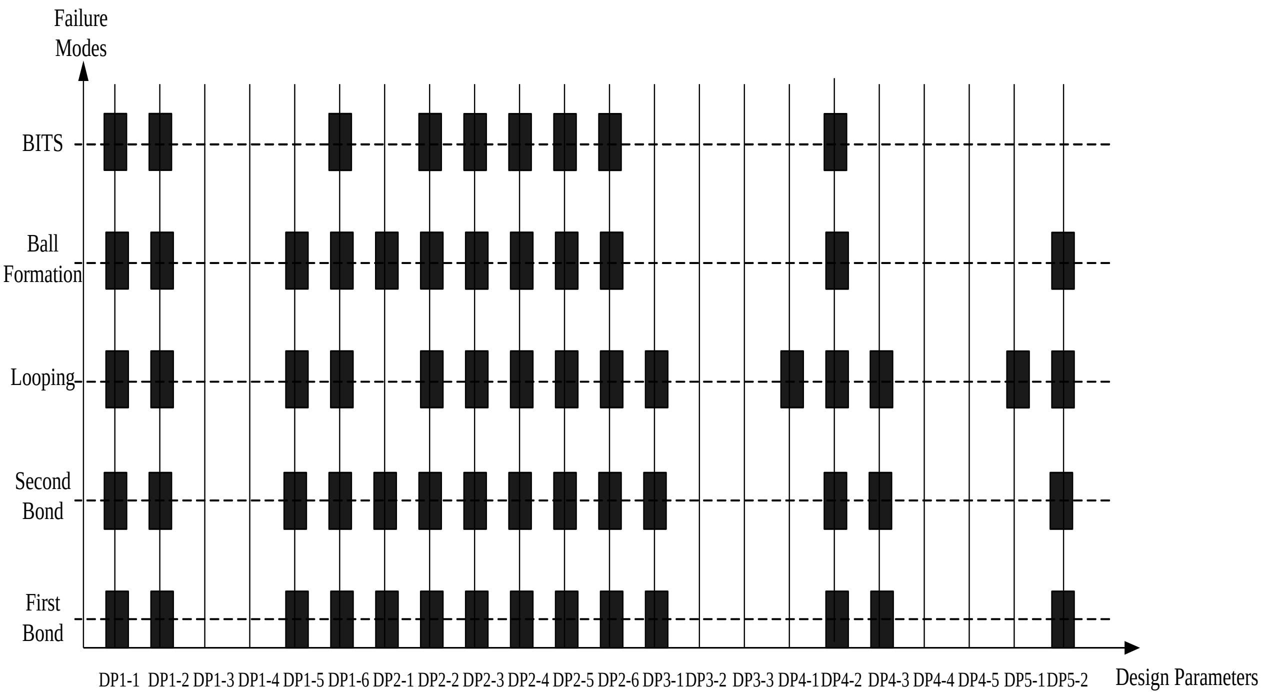

Figure 3. Wire bonder failure modes corresponding to DPs.

For a specific type of industrial wire bonder, a wire bonding failure of the first bond process is selected for illustrating the maintenance analysis in the maintenance and service innovation of a wire bonder. For the first bond failure as shown in Figure 3, four common failure modes in sequence as Non-stick on Pad (Ⅰ), Bond Placement (Ⅱ), Deformed Ball (Ⅲ), and Metal Peeling (Ⅳ) are identified in a bonding process. The performance of the first bond can be qualified by employing the tests of ball size, ball shear, intermetallic compound, and etching. The cost and value for the maintenance of the first bond failure will be evaluated in the following sections.

4.1 RPN analysis

The effects of the first bond failure in FMEA are measured by employing RPN. The RPN is evaluated for the four failure modes in the first bond. The RPN is calculated as a mathematical product of the numerical severity, probability, and detection ratings given by

$$A_{i-j,k} = s_k \times r_{i-j,k} \times m_k \times e_{i-j,k} \times n_k \times f_{i-j,k} \tag{2}$$

In Equation (2), *i*, *j*, *k* is the sub-system, the component of sub-system, and the failure mode, respectively. The $A_{i\text{-}j,k}$ is RPN for each DPs of the failure mode *k*. The s_k is a severity rating for failure mode *k* and the $r_{i\text{-}j,k}$ is a severity rating for each DPs of the failure mode *k*. The m_k is a probability rating for failure mode *k* and the $e_{i\text{-}j,k}$ is a probability rating for each DPs of the failure mode *k*. The n_k is a detection rating for failure mode *k* and the $f_{i\text{-}j,k}$ is a detection rating for each DPs of the failure mode *k*. In practice, the RPN is calculated by assigning potential failure modes a rank from 1 to 10 with respect to the severity of the failure mode effect, its probability of occurrence, and the likelihood of its being detected (Whitcomb and Rioux, 1994, Bowles, 2003). In applications, these ranking factors are highly dependent on the attributes of the system in operation.

4.2 Cost and value analysis

The total relative cost of maintenance can be evaluated by the following equation

$$P_{i-j,k} = \sum_{i,j} (B_{i-j,k})(C_{i-j}) \tag{3a}$$

with the $B_{i-j,k}$ as

$$B_{i-j,k} = A_{i-j,k} / \sum_{i,j} A_{i-j,k} \tag{3b}$$

where $P_{i\text{-}j,k}$ is the relative cost of maintenance for failure mode k, $B_{i\text{-}j,k}$ is the RPN ratio for each DP among failure mode k. The RPN ratio is a quantity that denotes the percentage of RPN of one quantity relative to all RPN. $C_{i\text{-}j}$ is the relative cost of maintenance and service in life cycle for the component or sub-system of semiconductor equipment. The $C_{i\text{-}j}$ is assumed with ranking from 1 to 10. The assignment of relative cost for each design parameter is based on the supplier and service in the industrial environment.

The objective of the maintenance and service for semiconductor equipment is to acquire an appropriate measure of the function, quality and cost for decision making. It is noted that for each component, the higher RPN ratio means the lower function in operation. By considering value as functional performance per unit cost, relative value of DPs in the maintenance and service will be identified and expressed as

$$V_{i-j,k} = \frac{(1 - B_{i-j,k})}{C_{i-j}} \tag{4}$$

4.3 Maintenance and service priority

Traditionally, the priority of maintenance and service for each failure mode can be analyzed through the calculated RPN. The higher number means that the related DPs or the components of wire bonder are proposed to be maintained with greater weight. However, higher number of RPN may not always reflect the true concerns in maintenance and service. The concern of loss in expense due to failure is important in maintenance management. Therefore, the information of relative value and relative cost integrated with RPN analysis will be effective in the management of maintenance and service of components and system. The results of RPN ratio, relative cost, and relative value for the four kinds of failure modes of the first bond process are to be computed by utilizing Equations (2) to (4) with data from Table 1 and $C_{i\text{-}j}$. In order to simplify calculation for illustration, the $e_{i\text{-}j,k}$ and $f_{i\text{-}j,k}$, respectively, for different failure mode k are assumed to be the same. The $C_{i\text{-}j}$ for each component of the wire bonder in maintenance and service is assigned as 1 for DP4-3, 3 for DP1-5, DP1-6, DP2-5, DP2-6, DP4-2, 4 for DP2-2, DP3-1, 5 for DP1-1, DP2-3, 6 for DP2-1, DP2-4,8 for DP1-2, and 9 for DP5-2. The calculated results of RPN ratio, relative cost, and relative value with respect to DPs are obtained and plotted in Figures 4, 5, 6, respectively. From Figures 4 to 6, the highest and lowest interest of RPN ratio, relative cost, and relative value are compiled as given in Table 2.

Table 1. Rating factors for evaluation of RPN in the first bond failure modes.

Failure Modes and Rating Factors / DPs		Failure Modes ($k=1,4$)											
		Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅰ	Ⅱ	Ⅲ	Ⅳ
		Individual Severity Rating s_k, $k=1,4$				**Individual Probability Rating** m_k, $k=1,4$				**Individual Detection Rating** n_k, $k=1,4$			
		10	10	9	10	7	9	8	3	4	3	5	7
		$r_{i\text{-}j,1}$	$r_{i\text{-}j,2}$	$r_{i\text{-}j,3}$	$r_{i\text{-}j,4}$	$e_{i\text{-}j,k}$				$f_{i,\text{-}j,k}$			
Console System	**DP1-1**	7	7	7	7	5				3			
	DP1-2	2	2	2	1	4				3			
	DP1-5	3	7	10	1	3				2			
	DP1-6	1	3	10	1	3				3			
Bond Head Assembly	**DP2-1**	7	1	10	4	6				7			
	DP2-2	3	1	1	1	7				5			
	DP2-3	10	2	10	10	6				6			
	DP2-4	10	10	10	10	4				8			
	DP2-5	1	1	1	1	3				7			
	DP2-6	8	8	8	8	6				8			
Vision System	**DP3-1**	1	10	1	1	2				4			
Material Handling System	**DP4-2**	7	9	10	1	4				4			
	DP4-3	10	8	3	1	2				3			
XY-Table Assembly	**DP5-2**	4	10	7	1	3				7			

Table 2. Comparison of RPN ratio, relative cost, and relative value of the first bond failure modes in maintenance and service.

Evaluation / Failure Mode	RPN Ratio		Relative Cost		Relative Value	
	Highest	Lowest	Highest	Lowest	Highest	Lowest
Failure Ⅰ	Flexure Bearing (DP2-6)	Lighting System (DP3-1)	Z-Axis Servo System (DP2-4)	Wire Feed System (DP1-6)	Heater Assembly (DP4-3)	X-Y Table Mechanism (DP5-2)
Failure Ⅱ	Flexure Bearing (DP2-6)	BITS (DP2-5)	Z-Axis Servo System (DP2-4)	Heater Assembly (DP4-3)	Heater Assembly (DP4-3)	X-Y Table Mechanism (DP5-2)
Failure Ⅲ	EFO Assembly (DP2-1)	Lighting System (DP3-1)	EFO Assembly (DP2-1)	Heater Assembly (DP4-3)	Heater Assembly (DP4-3)	X-Y Table Mechanism (DP5-2)
Failure IV	Flexure Bearing (DP2-6)	Heater Assembly (DP4-3)	Z-Axis Servo System (DP2-4)	Heater Assembly (DP4-3)	Heater Assembly (DP4-3)	X-Y Table Mechanism (DP5-2)

In the maintenance and service, the priority can be inferred from observing Figures 4 to 6 and Table 2. In Figure 4, DPs with higher PRN for each failure mode are assumed to be more important and given higher priority than those having lower RPN. From Table 2, it is observed that the highest priority for failure mode Ⅰ, Ⅱ, and Ⅳ is DP2-6. The DP2-6 is a flexure bearing assembly. For failure mode Ⅲ, the highest priority is DP2-1. The DP2-1 is an EFO assembly. The priority distribution of RPN ratio for the components of wire bonder in Figure 4 provides enough information for engineer to analyze the failure modes by the scientific approaches. In Figure 5, higher relative cost of DPs in maintenance may cause the pressure of budget control for the productive management. From Table 2, it is realized that the highest cost for failure mode Ⅰ, Ⅱ, and Ⅳ is DP2-4. The DP2-4 is a Z-axis servo assembly. For failure mode Ⅲ, the highest cost is DP2-1. The DP2-1 is an EFO assembly. In Figure 6, the relative value of maintenance indicates a cost effective way, which satisfies the customer needs, to reliably accomplish a function. From Table 2, it is apparently that the DP4-3 can be realized to achieve the maximum value for the cost-effective maintenance in a whole system. The DP4-3 is a heater assembly. The lowest relative value of maintenance in the whole system is DP5-2, i.e., X-Y table. With the lowest relative value of DP5-2, the maintenance and service of X-Y table will be considered as the first priority for the innovative maintenance and service. The lowest relative value of X-Y table is because of the higher cost in maintenance and service. In order to get higher value and lower relative cost in the maintenance of X-Y table, it is expected to reduce the RPN and maintenance cost. By reviewing the DPs of the specific type of wire bonder, the X-Y table is with ball-screw drive. Therefore, an innovative action in maintenance and service is decided for the FRs-I, DPs-I, and cost of innovative X-Y table.

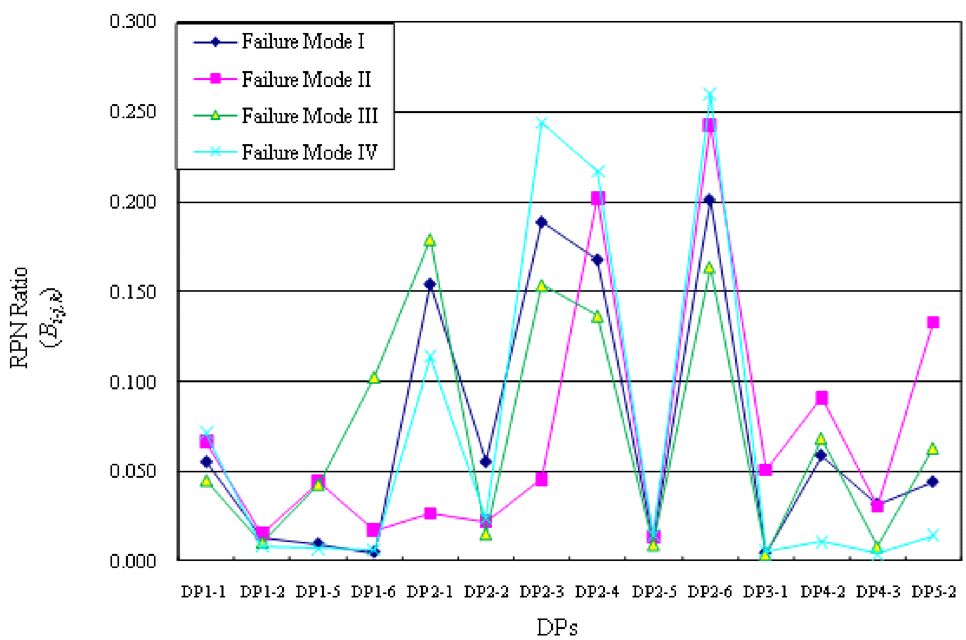

Figure 4. RPN ratio of maintenance for first bond process.

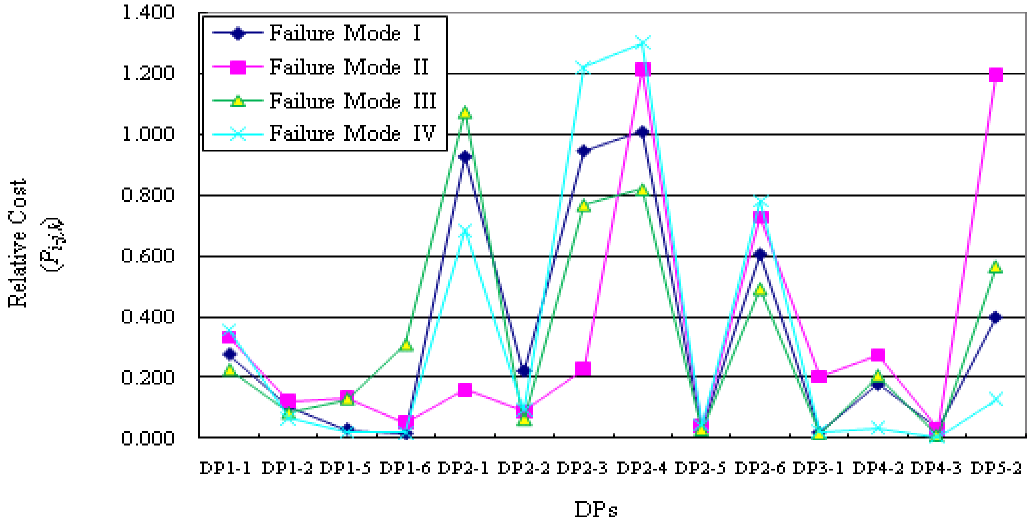

Figure 5. Relative cost of maintenance for first bond process.

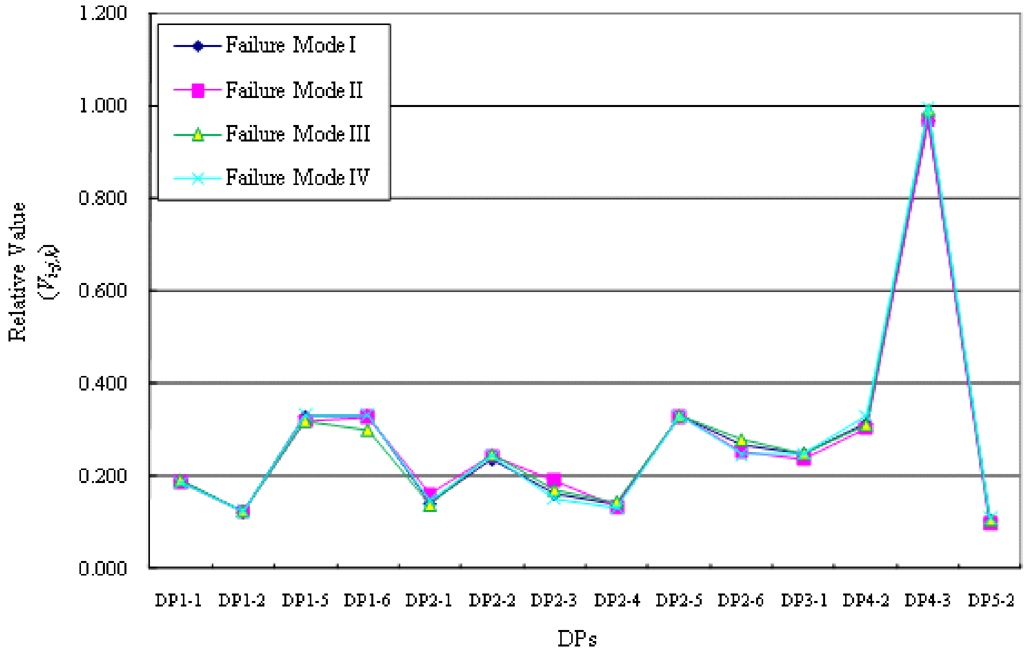

Figure 6. Relative value of maintenance for first bond process.

5. Innovative action

5.1 Customers, products and patents screening

There are several types of wire bonder in a global market. In the recent market share, four types of competitive wire bonder including K&S Maxum Plus, by American K&S Industries Inc., SKW UTC-1000 Super, by SHINKAWA Ltd. of Japan, ASM Eagle 60, by ASM pacific technology Ltd. of Hong Kong, and ESEC 3100, by ESEC Inc. of Switzerland, are collected for screening analysis in innovative action. For a wire bonder, the bonding capability in FRs affected by X-Y table assembly mainly includes bond placement accuracy, productivity, and bonding area. The performance of four wire bonders related to X-Y table is listed for comparison. An ultra high speed ball bonder of Maxum plus has a total bond placement accuracy ±2.5μm at 3 sigma and productivity 15 wires/sec, and bonding area 56mm×66mm. A wire bonder of Eagle60 has a total bond placement accuracy ±3μm at 3 sigma, productivity 15 wires/sec, and bonding area 56mm×66mm. A wire bonder of WB3100 has a total bond placement accuracy ±2.5μm at 3 sigma, productivity 17 wires/sec, and bonding area 52mm×70mm. A wire bonder of UTC1000 has a total bond placement accuracy ±2.5μm at 3 sigma, productivity 13 wires/sec, and bonding area 55mm×65mm.

X-Y table assembly is composed of linear drive components, X-Y table mechanism, sensor, and controller. The actuating and positioning of X-Y table for high speed and high precision requires linear drive components. Four types of industrial linear drive component are surveyed and the performance of drive components is given in the Table 3 (Li, et al., 2005). According to the table, the precision of large stroke drive such as the precision ball screw transmission and the linear motor generally is limited to micron level. The positioning accuracy of the piezoelectric type can reach submicron level, while with small stroke and low speed. The stage by voice-coil motor possesses high speed, high acceleration, and high precision, while with small stroke. For an X-Y stage with direct-drive positioning mechanism such as linear motor, it doesn’t require transmission mechanism such as gear or screws which can greatly reduce the effects of contact-type nonlinearities and disturbance such as backlash and frictional force, and consequently, maintenance cost.

Table 3. Performance comparisons of drive components.

Drive components		Stroke (mm)	Accuracy (μm)	Resolution (μm)	Max. Speed (m/s)	Max. Accel. (m/s^2)
Ball screw with motor	Common	25 ~ 2000	+/-2 ~ +/-10	Above 0.5	1.5	30
	LM150D-200 (USA BAYSIDE Inc.)	200	+/-5	2.5	1.3	29
Piezo motor	Common	20 ~ 200	Below +/-0.25	Below 0.05	0.3	5
	MAK-HR4-CL (Isarel Nanomotion Inc.)	60	+/-0.1	0.01	0.25	5
Linear motor	Common	50 ~ 3000	+/-1 ~ +/-5	Above 0.1	5	60
	400 LXR (USA Parker Inc.)	250	+/-1	0.5	1.5	50
Voice-coil motor	Common	1 ~ 100	+/-0.02 ~ +/-1	Below 0.05	3	150
	SVC module (Taiwan Astway Tech. Co.)	50	+/-1	0.5	2.2	100

In comparing with the specific type of wire bonder with ball screw drive in section four, the X-Y table assembly in the recent four industrial wire bonders has been innovated to use linear motor for lower RPN and maintenance cost.

5-2 Further innovation of X-Y table assembly

The innovative action on X-Y table will be further investigated by surveying the performance requirement of X-Y table assembly employed in the future semiconductor industry. With further increasing of maintenance and service value in the X-Y table through excellent reliability and low maintenance cost, newer generation of wire bonders demands productivity of 20-40 wires/sec and bond placement accuracy to be less than 1μm.

In order to satisfy the requirement of newer generation of wire bonder, further improvement of bonding capability by the X-Y table relies on the innovative action on FRs-I and DPs-I of X-Y table assembly through Equation (5) as

$$\begin{bmatrix} \text{Bond placement accuracy} \\ \text{Productivity} \\ \text{Bonding area} \\ \text{Failure probability rating} \\ \text{Maintenance and service cost} \end{bmatrix} = \begin{bmatrix} A_{ij} \end{bmatrix} \begin{bmatrix} \text{Stage} \\ \text{Actuator} \\ \text{Sensor} \\ \text{Controller} \end{bmatrix} \tag{5}$$

The innovative action on Equation (5) can be further analyzed and implemented by the following considerations,

– New servo motor design

– Stiffer X-Y bearings and X-Y slides

• Faster motions- increase G force

• X-Y encoder interpolation calibration

– Improves positional accuracy of X-Y table

• Higher X-Y resolution

– Good stress and thermal stability

• Enhanced cooling for X-Y motors and X-Y table

– Advanced motion controller

• Provides good dynamic performance for all travel distances

– Excellent reliability

– Simple and easy maintenance

6. Conclusions

A systematic innovation framework based on Axiomatic design mapping which is extended to include CFs is proposed for the maintenance and service innovation. The proposed framework includes knowledge representation, maintenance analysis, and innovative action in sequence. The systematic innovation of CAs, FRs, DPs, PVs, CFs, are classified as CAs-I, FRs-I, DPs-I, PVs-I, CFs-I, respectively. By employing the proposed approach, it is systematic in proceed with maintenance and service innovation through CAs-I, FRs-I, DPs-I, PVs-I, and CFs-I. A case study on the maintenance and service innovation of wire bonder is used for the illustration of the proposed framework. In the maintenance and service innovation of the first bond failure in bonding process, the first priority of innovative action on X-Y table is decided through a systematic evaluation of RPN ratio, relative cost, and value of DPs. The innovative action on X-Y table is screened by four types of competitive industrial wire bonders. In order to satisfy the requirement of newer generation of wire bonder, further considerations in the implementing of FRs-I and DPs-I of X-Y table assembly are addressed.

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Paper ID: 141

A Suggestion on Engineering Education Reform based on TRIZ

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Abstract

The engineering education needs innovation to match the rapid changing world. Many schemes of new methods have been proposed, but none were successful to transform our engineering education system. A new paradigm of engineering education is suggested based on so-called “Need based engineering education” to replace the traditional “Discipline based engineering education”. Even though this model is specific on design courses, the author believes it can be extended and applied to other disciplines. The whole contents of this approach came from the author’s experiences in practicing of implementing TRIZ into practical training.

Keywords: Effects Module, Engineering Education, Reform, TRIZ.

1. Introduction

Modern curricula of mechanical engineering are being challenged in many senses. And it is said to be same for all other engineering disciplines. At first the curricula are the offspring of so-called engineering sciences. As it was pointed out during the ASEE conference in 2004, engineering science is near dead and it should be moved to real engineering. Here real engineering means design activities and synthesis rather than analysis. It is well known that there are tension between science and engineering (technology). The fundamental differences are epitomized in the words of famous T. von Karman, ' Scientists study the world as it is, engineers create the world that never has been'. For long time, engineers put endeavors to find solutions from knowledge of why. Sciences are pursuing why something happen. Mechanics are fundamental to understand why and how failures happen. Fracture mechanics has been fully grown and many numerical methods are developed and matured. After the Sputnik shock, the engineering sciences were main subjects in engineering curricula. TAM (Theoretical and Applied

Mechanics) were very active and many TAM departments were built as independent departments besides mechanical engineering department. But the trend has been reversed as the role of mechanics as one of major discipline of engineering science is diminished. Many TAM departments are disappeared. As the TAM departments of University of Illinois and Cornell University have been merged into mechanical engineering department, no TAM department is maintained in top-ranked universities in USA. (http://www.cornell.edu/president/statements/2008/20081222-tam.cfm) The subjects and spirit of mechanics are not gone but it is one news of showing the fact the requirements to engineering school should be more practical. One of the backgrounds of this movement is questioning what is left to understand the whole world. It is controversial to declare most necessary knowledge at continuum level is known and yet the role of engineering education should be changed. So nowadays, most researches are in sub-continuum level and nanotechnology is being the central area of R&D funding. The second fact is that the requirement of graduation of engineering school is diminishing. Currently, 120 credits are required in Korea while 160 credits were required in 1980's. As the credits become smaller, many courses should be squeezed in and the mechanics courses should be merged. At the same time, design courses become bigger to encompass the whole synthesis activities. And also the design courses develop into more specific one to broaden and deepen the knowledge of specific fields of mechanical engineering. The third trend in this direction is automation of many engineering activities. Many good engineering tools such as CAD, CAE, and mathematics are changing role of engineers. It was job of experts to analyze what is going on inside of the product for long time, but nowadays it is a matter of daily common work to use many analysis softwares. This trend requires the engineer's work more creative. Robots took away the blue collar's work and the smart softwares are taking away the normal engineers job. It is natural that the increasing of the industry size doesn't necessarily means the increase of jobs because of process automation. So the necessity of reform in engineering education is more crucial than ever before. Engineering design courses became major curricula in modern mechanical engineering. In Korea, the name of courses changed from Design Theory, Introduction to Engineering Design to current Creative Engineering Design. As ABEEK(Accreditation Board of Engineering Education of Korea) requires more than 18 credits inside the curriculum of mechanical engineering department strictly, engineering design become more important. As the author was involved in lecturing the design course from early 1990's, he can witness the changes of structures of the courses. Current courses related with design are shown in Fig. 1. Various contents with design are provided and it will be culminated as the course of capstone design and NPD (New Product Design) in senior class. When the experiences on students of undergraduates and graduates are compared with, followings are observed. Many undergraduate students have difficulties to find the project subjects. Usually the first part of the course devotes time to make teams and find subjects to tackle during the semester. As a due procedure of design experience, time for 'need finding' is allocated. The purpose of this process is to simulate to hear the VOC (voice of customers) and also feel the spirit of QFD (Quality Function Deployment). Students start from the daily life and some may proceed to find a subject from more professional area. Only for the process of this finding and selection of the subject, the students of Graduate School of Industry are best in the speed and quality of the topic. Many topics are very much practical and have certain design point inside. It is natural that the students of graduate school of industry are currently employed students who exercise design in their jobs. We can see easily where the differences come from when we account for this fact. Faculties always spend times to encourage and guide students to identify adequate subjects. One of ways to escape from these difficulties is to post a project and all teams attack the same problem as a contest. This kind of approach is adopted in the entry design course and students get much insight from their own design and various different designs. But more divergent thinking should be developed to bring out creative engineers. So finding process of needs and project is essential part in this context. To author's point of view, current curricula of design are not ready for fostering creativity of student's design capability. Several points make the deficiency more serious as follows. The first one is related with the history of curricula of mechanical engineering.

2. New Engineering Education Model

A new engineering design education model is suggested using following 3 new concepts. This model was developed during the process of applying TRIZ concepts into design course. Following 3 concepts were found useful for the usual first phase of need finding in the design project.

2.1 Bank of Korea Annual Report

I wanted the students to be able to view the whole world. Their experiences are short and can't cover all the industry activities. I found one of the good path is to check the database of the Bank of Korea (which is the national authoritative bank and every country has same one.). As the central bank in Korea, they publish many reports summarizing the facts, statistics, and policies. Especially the annual report of financial statement analysis of industries is a good one for this purpose. Even though this report is about financial status, it has dual benefits for the design students. At first it is a good source to have economic mind and perspective of national status of companies. Although it does not provide individual company's status, it provides the whole trend and status of the specific industry's overall performance. As the potential employee of the companies, it is good to know the current status and trend of the industry. Secondly the detailed subgroups are good representation of product and services appear on real world. It is important to see what the possible products are real and have values. Students confess they didn't realized how many and what kind of products and industries are going around. The team of students then is able to start to discuss what their interests are and have clues to start their discussion. Also the statistical trend can imply very important meaning from the cumulative annual reports. It is critical to estimate the size and soundness of the industry as the student's activity blossom after several years after their career in the specific industry.

2.2 F-TERM

One of the good resources to look into the specific product is to check the classification of Intellectual properties. The IP offices of each country keep their own IP databases and also the WIPO (World Intellectual Organization) has own system. We have used and checked many different systems. We found that Japanese system is most exhaustive and best for our purpose. Japanese system consists of 2 databases. One is FI and the other is F-TERM. Japanese F-Terms, the Japanese F-Index, and F-I Facets are all specific classifications devised by the Japanese Patent Office for their in-house use, to make searching quicker by sub-dividing and indexing technological subject matter. While F-Index was created to further subdivide classes from the slow-moving pre-reform IPC system, the F-Term system was designed to be an independent Japanese classification mechanism. The limitations of the roughly 70,000 divisions of the IPC classification prompted European patent examiners to create the ECLA system as an in-house extension to the IPC, increasing the number of sub-divisions to around 130,000. These same limitations in turn prompted the Japanese patent office to create their own in-house extension to the IPC, called the F-Index system, which extended the system to over 170,000 unique sub-groups. F-Index subgroups are added on to the original IPC classification to create further sub-divisions within these existing categories. F-Index terms make use of “subdivision symbols," which are 3-digit numbers, and then are further divided using “discrimination symbols,” which consist of a single letter. submitted manuscripts must use SI (Metric) Units in text, figures, or tables. File forming term (F-term) is the technical term for computerized searches of patent documents, developed from multiple viewpoints in the JPO. While the IPC is organized from single technical viewpoint, F-term is expanded or reorganized the IPC, in some technological fields, from multiple technical viewpoints (purpose, use, structure, materials, manufacturing method, method of processing and operation, means of control, and so on). F-term has been created to improve search efficiency in some specific technological fields, F-term does not cover all technologies. F-term consists of a 5-digits theme code, a 2-digits viewpoint, and a 2-digits figure. After the students checked and decide the field of industry they want concentrated on, they search and investigate the F-Term groups and a specific product. Extremely find specification helps the student to feel and search the exact items to design.

2.3 Effects module

The 3rd useful tool for engineering design education is effects module of TRIZ software. Here I am talking about the effects module of Goldfire. The main purpose of this paper is to describe the process of introducing creative design to engineering students. The first 2 tools are for identifying the subject of design purpose. Next step is to bring out creative solutions of the subject. Effects module has potential of helping improving the engineering design process. It can be considered as changing discipline based engineering education into need based engineering education. As I wrote before, engineering sciences has dominated the engineering education for long time and courses are developed according to the separated disciplines. So statics, dynamics, solid mechanics, fluid mechanics and thermodynamics are the core courses representing each discipline. Additionally material science, control, manufacturing courses are added as the major courses for providing core skills as a mechanical engineer. The outcome of this approach has fundamental deficiencies such that each student has own taste and find difficulty to have broad balanced view on practice. One of the examples can be found on the cantilever beam of solid mechanics. The cantilever is a very popular engineering solution for many practical problems. But the students who just finished solid mechanics course do not know what is the use of a cantilever. They learned the mechanics of bending problem of a beam and can derive the governing equation and find solutions of stresses and deflection under certain loading. But they just don't know where to use this. The cantilever beams are used in many sensors. For this problem, the whole question may start from the function of sensing acceleration instead of asking to find the deflection under dynamic loading. The SIT (Systematic Innovation) company is practicing 'Function follows Form' instead of 'Form follows Function' as a traditional design axiom.

3. Experiences

In recent years, our department has improved scheme of design courses. The senior design courses consist of a capstone design and the NPD (New Product Development) course. The capstone design course is mandatory for the seniors and considered as the summation of the whole learning of design. The NPD course is elective and designed to guide the students to be independent and creative designers. The students should find their own subjects of the projects using almost one third of the total semester time. They used above three steps to find the right subjects. Many students spent much time without any direction when we didn’t provide any clue. It may be a difficult task for the students with little experiences on open problems. This situation was recovered when we introduced the above three concepts and make them to think from the outside not from themselves. They become more familiar with specific industries and patents and finally with specific items they found. This process could shorten the time to find and make them to concentrate more on the solving phase. This helped the students to find useful improvements and ideas on the subjects and consequently file applications of patents.

4. Conclusion

In this paper, a new paradigm of design course in mechanical engineering is suggested. It may be modified and refined to fit the situation of each school. There is a potential to change radically current discipline based courses into new need based engineering. Three tools including financial report of central bank, f-term of Japanese IP system and effects module of TRIZ software are presented as the core module of the new paradigm. The experience with this new scheme is described. The authors believe this new paradigm can ignite serious discussions on the practically meaningful curricula of mechanical engineering. This model is suggested for the need finding phase of engineering design process. Our next report will cover the second creative problem solving phase. The first author thanks for the support from KICOS which is now NRF of Korean government.

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Paper ID: 142

Applying GQFD and TRIZ to construct evaluation patterns of the environmental protection non-washable tableware research and development

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Abstract

In recent years, environmental protection has become a global subject. In Taiwan, eating out became a dietary fashion for most people because of the present generation's dietary habits. The amount of non-washable tableware being used is astonishing and consequently produces massive amounts of trash as the Styrofoam and plastic non-washable tableware can not be decomposed. Meanwhile, tableware made by paper consumes the tree resources of the earth. This research considers the customer's demands and uses the company's most competitive and strongest technologies as back-up to produce new styles of, and materials for, non-washable tableware. Hopefully this can provide a substitute product with considerations for convenience, health and environmental protection.

This research will start with green design and green supply chain, and also will examine the customer's demands and product design technology by green quality function development (GQFD). We are going to take the benefits from the products made of paper and recyclable environmental protection tableware as references for design. We expect to transform the customer's demands into design of the related products by GQFD in the early research and development phase. This is able to help the enterprises to design the products to meet the customer's demands when they research and develop. At last, we will solve the conflict between the customer's demands and project's technology design in

GQFD by TRIZ. We discover win-win green plastic environmental protection tableware instead of ones made of PP plastic or paper.

Keywords: Environmental Protection Non-washable Tableware, Green Supply Chain (GSC), Green Quality Function Development (GQFD), Triz

1. Introduction

Most people usually eat meals out because they are very busy in their modern lives. This causes the amount of nonwashable tableware used to increase steadily, meanwhile, it brings about a corresponding increase in waste. For using tableware, we have to consider reducing waste and the amount of garbage first of all. Then we consider reusability, material regeneration, energy recycling, and proper processing. The Environmentally friendly Administration, Executive Yuan, R.O.C. has been not only giving an impetus to recycling, but also giving an impetus to reduce the amount of usage of products which are used one time only in recent years. These included two phases of “the policy of limited use of plastic bags when people shop and limited use of plastic nonwashable tableware” in 2002 and 2003, and also “forbidding the use of nonwashable tableware in the restaurants at government offices and schools” from July to September, 2006.

Most tableware is used only once, for convenience, so it has become more common day by day. Cutting trees for paper cups that are made of primary paper pulp wastes natural resources. People appeal for reducing the number of trees cut, so trees with a short growth cycle are planted manually instead. If we can recycle and reuse tableware fully, it may increase business opportunities and resource usage. Of course it needs long-term view to establish propaganda and educate people to use their own tableware when they eat out. Researching, developing and manufacturing products that are recyclable and fully utilized initially is the best way to do this in the short-term.

From the point of view of material use cycles and benefits, using nonwashable tableware is convenient, however, there is lack of resource sustainability as a long-term target. The use cycle of nonwashable tableware is only a meal, but the processing afterward needs massive amounts of resources and manpower which doesn’t conform to the principle of recourse sustainability. The government can only educate people to use their own tableware when they eat out or take out. If everyone uses nonwashable tableware less, it will reduce garbage and also damage the environment less. People’s habits are not easy to change in a short time so we could make improvements to environmentally friendly tableware. Requirements for environmentally friendly tableware are: (1) conforming to the principle of reducing the amount used: using less but not forbiddance, (2) encouraging people to use reusable tableware such as metal tableware. As metal tableware is only suitable as environmentally protective tableware, not as nonwashable tableware, the shape of metal tableware isn’t as easy to change as plastic materials. This research discusses possible situations such as tableware producing harmful materials when it is heated, discarding it will not cause environmental pollution, ease of carriage, reasonable price, and so on. The purposes of this research are; establishing that the most important item is customer’s perception, project technology with people doing research and development, analyzing future tendencies, and setting up an evaluation model of environmentally friendly for nonwashable tableware research and development. After the entire construction of the research is completed, researching and developing a new product will be compatible with environmentally friendly and convenience of its design material and coordinating TRIZ.

2. literary Reviews

2.1 TRIZ

TRIZ theory has the same meaning as the acronym TIPS (Theory of Inventive Problem Solving) in Russian. It was invented by a Russian inventor, G. Altshuller, in 1946, with his team. They developed a set of methods from patent document analysis (Altshuller, 1999). Altshuller and his TRIZ team proposed a lot of problem analysis tools and the problem solving tools of invention innovation. In general, it is called TRIZ technique. Today TRIZ is becoming respected by more countries in the world gradually and used by different industry leaders, such as Chrysler, Ford, GM, Xerox, and so on. It has also been quoted by academia to develop related software (Dourson, 2004; Hipple, 2005; Retseptor, 2003; Loh et al., 2006; Cong and Tong 2008).

TRIZ theory includes: 39 Contradiction Matrix, 40 principles Matrix(Z oyzen, 1997; Domb, 1998), Laws of Evolution (Petrov, 2002), Substance-Field (Terninko, 2000), Ideal Result (Domb, 1997), scientific effects (Frenklach, 1998), Algorithm of Inventive Problem Solving, ARIZ (Osborn, 1957; Hauser, 1988; Treffinger and Isaksen, 1992; Chakraborty and Dey, 2007), and so on. Here is a TRIZ diagram:

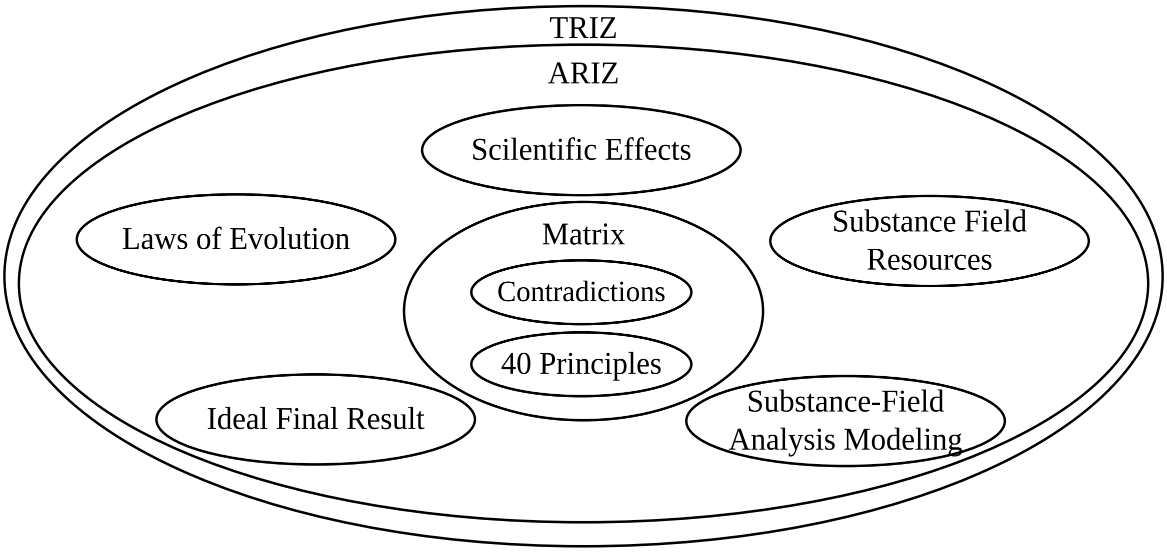

Figure 1: TRIZ system diagram

Resource：Chang and Chen, 2003

2.2 The green quality function deployment

Quality Function Deployment (QFD) was proposed by Japanese quality management masters, Yoji Akao and Shigeru Mizuno as an important quality management theory in 1991 (Akao, 2004). Dr. Shigeru Mizuno defined quality function deployment as: deploying it into the most detail by the stage of functions of forming quality and business with purpose and strategy.

Considering each kind of environment factor of the green quality function deployment will help the designing engineer to discover customer's green demands or the green quality characteristics of the product which need to be improved most to develop the valuable green product or manufacturing process. Jiang and some other people first proposed Green Quality Function Deployment (GQFD) in 1997. They analyzed and compared different compound materials for making a cruise ship to find out the compound materials manufacturing process that conforms to environmentally friendly the most, with good quality and low cost. Kuo (2003) proposed a set of green product design structures which are based on fuzzy analysis and designed green products by developing green quality function deployments (GQFD). GQFD integrated quality function deployment with the theory and idea of green designing, deployed customer's feedback by quality function. GQFD also turned each stage of the product life cycle, which includes the stages of material, manufacturing, assembling, taking apart, transit, distribution, and consuming. Discarding is the last stage into the project characteristics to satisfy consumer's demand,

and furthermore to conform to the environment design to promote the product’s competition in the market. (Chou et al., 2009).

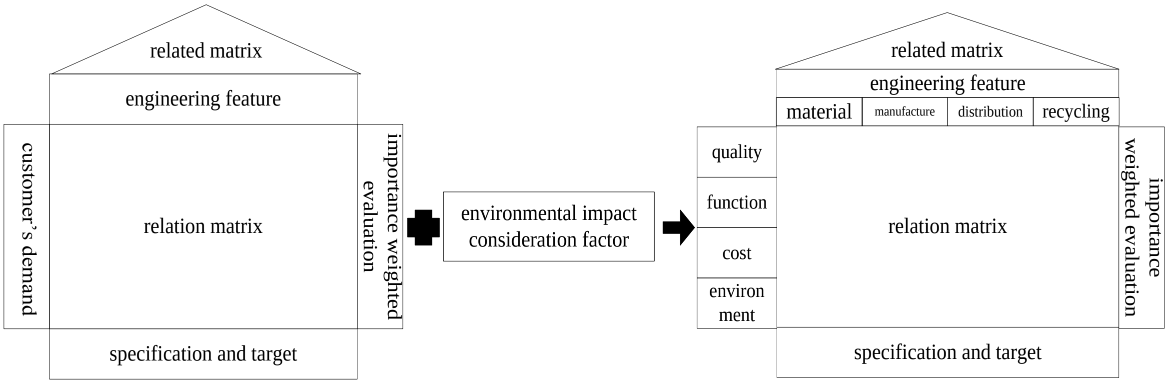

Figure 2: Green quality function deployment

Resource：Kuo, 2003

2.3 Green supply chain

Choosing appropriate partners is an important step of supply chain management. Suppliers providing the materials or services have a close relationship with the enterprise. If the enterprise could have the supplier conform to the industrial characteristics and satisfy supply chain demand, it will increase the competitiveness of the supply chain. From the point of view of the enterprise’s supply chain management, the links from product design to operation management combine with green value which is based on humanity’s environmentally friendly idea to become a chain structure with endless cycles, called Green Value Chain. This includes Green Design, Green Purchasing, Green Manufacturing/Processing, Green Product, Green Marketing, Green Consumer, Green Recycling Process, Green Materials and so on. Beamon (2005) proposed Environmentally Conscious Supply Chain Management (ECSCM). A professional engineer's moral responsibility is to consider how the product will affect the environment finally.

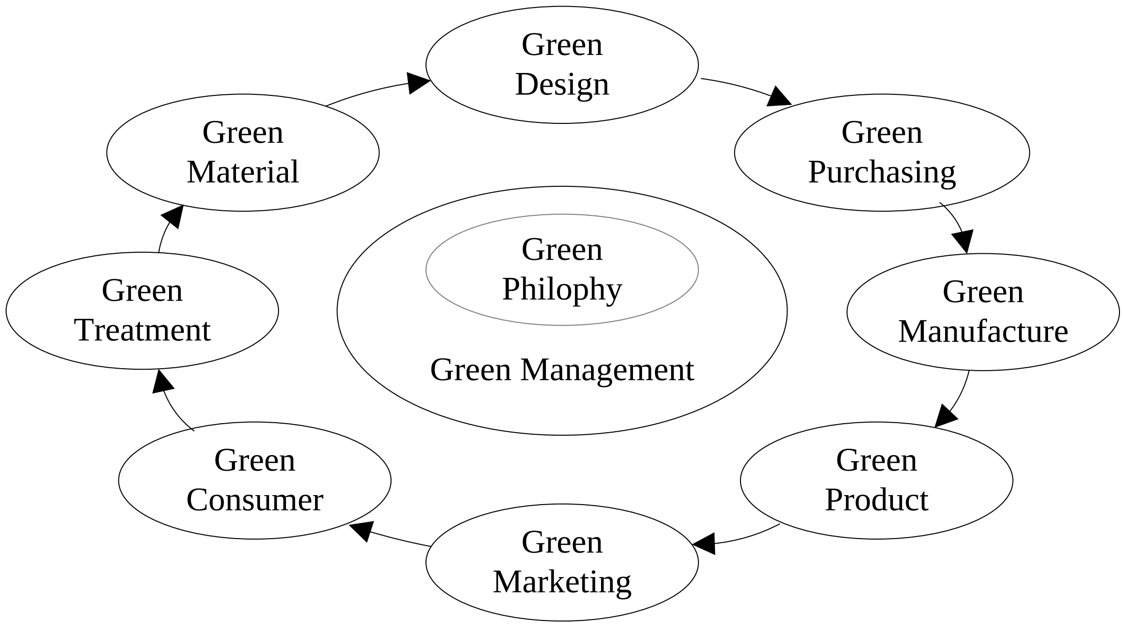

Figure 3: Green value chain

Recourse：Boks and Komoto, 2007

3. Case analysis

This research integrated TRIZ theory with green design ideas to develop a set of development processes and GQFD questions. We discussed customer's feedback and project technology analysis by GQFD to decide the product development direction. We sorted content of patent, used contradiction matrix and ideas of invention principle to get innovation concepts. Meanwhile, we drew a picture of the commodity and made a model. Then we did tort comparison as reference and a basis for designing existing patent evasion. Finally, we completed the development project. Its process is shown in figure 4:

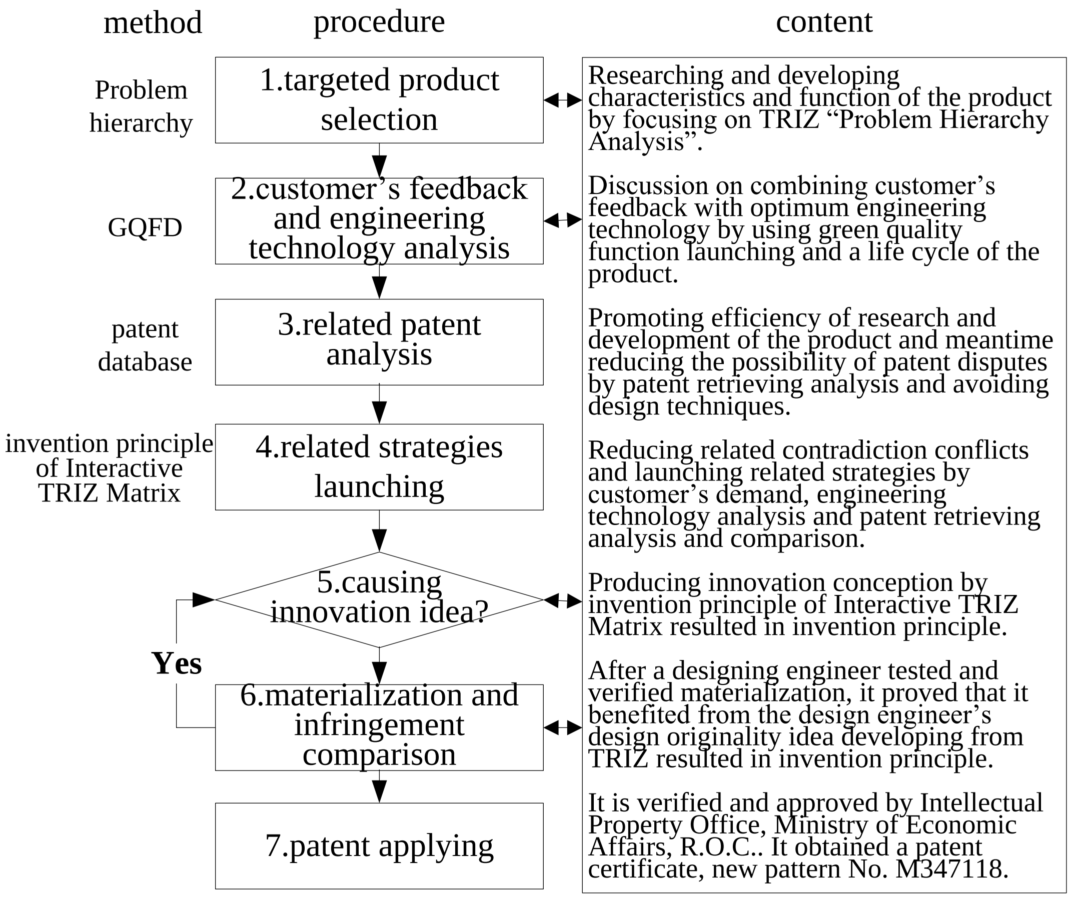

Figure 4: Executive procedures of new product and new process

3.1 Product chosen

In this stage, we discovered the problems and sorted out the possible solutions that may become the directions of development for new product design. There are usually some Problem Exploration Tools including Problem Hierarchy, Ideal Final Result (IFR), and Product Hierarchy. Problem hierarchy is for solving the problem of a large amount of garbage from using nonwashable tableware. As the amount of garbage increases it isn't easy to handle, the laws and regulations stipulated that plastic cups are replaced with paper ones and Styrofoam tableware is replaced with paper. These may reduce the amount of garbage but can't eradicate it. These also reduced the structure and function of paper and raised costs. We wanted to promote durability of paper tableware so we chose environmentally friendly paper tableware as the development target of this research. We also considered that in the future there will be a lot more people eating out, so there is demand for tableware in the market. Furthermore, there is a problem processing the garbage after tableware is used, so using tableware that conforms to environmentally friendly is the foundation of living on the earth forever. If we developed a series of green environmentally protective tableware for supplying and recycling, we will create more business opportunities. Therefore, the purpose of this research is to develop a kind of tableware that doesn’t cause garbage problems.

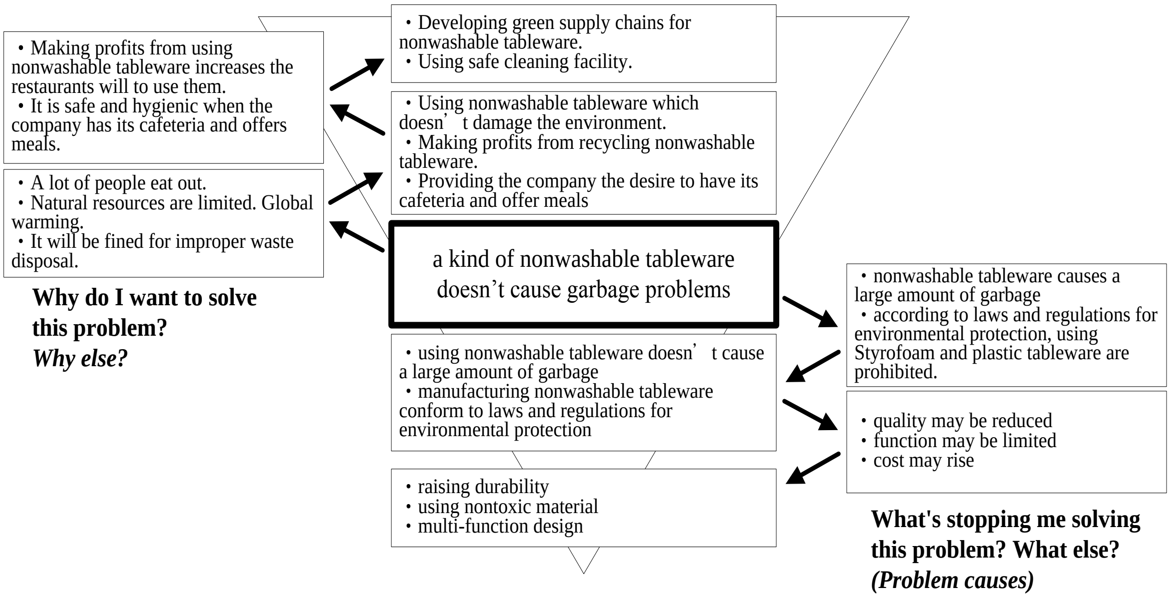

Figure 5: Product hierarchy analysis

3.2 Customer’s feedback and project technology analysis

In order to ensure our research contribution, we expected to make a correct classification and then to find the solutions for key factors at each level. Therefore, the questionnaires for this research were distributed to restaurant business owners and consumers. The questionnaires were provided from August 7, 2009 to August 10, 2009. There were 73 questionnaires provided and 68 questionnaires returned, for a return rate of 93.15%. There were 62 valid questionnaires and 6 invalid questionnaires, for a validity rate of 91.18%. The major purpose of this research is to learn and realize the restaurant business owners’ and consumers’ demands for nonwashable tableware by providing the questionnaires to different industries.

From the point of view of demand for nonwashable tableware, we analyzed different sides in depth. For example: what difference is there between the consumer’s demand and restaurant business owner’s demand. We would also like to help the business owners who want to develop environmentally friendly tableware to set up development directions and business models to increase service energy and profits. In general, there are two purposes of this research:

(1) Customer's demand analysis: analyzing what difference there is between different consumer's demands for environmentally friendly in depth by providing questionnaires.
(2) Project technology analysis: the advantages of technology that cooperates with the laws and regulations of environmentally friendly to help the business owner to set up business models.

3.2.1 Customer's demand analysis

According to the appendix, GQFD table, acceptance and demand of environmentally friendly tableware rose because customer's environmental consciousness rose and developed. If the restaurants provide good environmentally friendly tableware, it may increase customers' consumption. Results of analyzing the consumer's demands are as follows. The top 5 customer's feedback (above 6.5 points) are:

(1) Durability of environmentally friendly nonwashable tableware. When it hasn't been used, it doesn't damage easily. When it is being used, it must be firm. If it is for reuse, its durability has to be increased too. There is testing standard for either samples or production and also the basis of quality approval.
(2) Nontoxic materials in the environmentally friendly nonwashable tableware. Existing paper products need to be coated with some kind of paint for strengthening the structure and waterproofing. Chopsticks may be soaked in chemical water for prevention of mold. These may be carcinogenic. In addition, they must be nontoxic materials in consideration of decomposition and impact on the environment.
(3) Price of environmentally friendly nonwashable tableware. People need to pay for environmentally friendly plastic bags today, and they may need to pay for environmentally friendly tableware later. As the price of environmentally friendly nonwashable tableware may affect the price of meals, the cost of environmentally friendly nonwashable tableware will affect profits for restaurant owners. Both consumers and restaurant owners wish the price of environmentally friendly nonwashable tableware can be reduced.
(4) Reuse of environmentally friendly nonwashable tableware. There are more and more stores selling reusable tableware. On the one hand, it doesn't reduce garbage, and on the other hand consumers have the choice to use the reusable tableware when they eat or drink. Sometimes the stores may provide certain discounts for people who use reusable tableware. This tempts consumers to consume and reuse tableware and will gradually become a tendency.
(5) Environmentally friendly nonwashable tableware can be decomposed by organisms. Considering that resources on the earth are finite and injury the earth, the concept that

there are a lot of materials which can be decomposed by organisms is gaining acceptance slowly. Recently, the convenience store, 7-11, reported using cups and lids made of corn for “slurpee”. They will decompose by themselves after some time or be decomposed after they are buried in soil. Plastic bags which are used at the convenience store are made of materials that can be decomposed too. If the enterprise is supported by environmentally friendly consciousness plus government policy propaganda, every kind of plastic material can be replaced by decomposable materials.

3.2.2 Project technology analysis

From the point of view of project technology, we decided to use more environmentally friendly manufacturing processes at the beginning phase of product design. We took economizing on resources and reducing the discharge of CO_2 policy, energy recourse and resources, and environmentally friendly materials as considerations. We have to also consider the entire life cycle circulation and recycling to reduce garbage. The key points of development technology (above 7 points) are:

(1) Easy to recycle, reuse, and re-reuse. These characteristics can reduce environmental impact plus the government policy propaganda will be better. If recycling, like bottles, may earn money and can be remanufactured, it will be more competitive than other businesses in the same field. It is also an important meaning of environmentally friendly development today.

(2) Using proper product design to reduce or eliminate production waste. When we use environmentally friendly materials for production, we can return offcuts into material production and remanufacture them.

(3) Reducing or eliminating energy usage. According to government propagandas which aim to educate people to economize on resources and reduce discharging CO2, it consumes a lot of energy to melt metals during the manufacturing process and paper products consume forest resources. We looked for a kind of material that needs about 100 degrees centigrade during the manufacturing process and doesn’t come from natural resources. It will grow fast like bamboo, or it can be planted large numbers. When it mixes with other materials, it may conform the economical scale demand to reduce consuming resources and cost. Now new materials are being researched and developed continually. Mixing new materials with natural plants will be the tendency of development later.

(4) Reduced or the eliminated use of resources. Styrofoam is prohibited now. Most tableware is made of paper, so a large number of trees are consumed. We have to consider the planting of plants that grow fast in a short time manually. There are also a

lot of procedures for making tableware. When production processes are more complicated, it may consume more resources. Therefore, reducing the production processes is one of directions of the environmentally friendly claim.

(5) Tableware which is easy to recycle can be reused and decomposed easily. If we could find a material which can be recycled after usage, be decomposed into pieces or pellets easily, be remanufactured, be refined into diesel, or be turned into fertilizer, these can increase its' value.

3.3 Related patent analysis

This research studied the structure of patent retrieval analysis, application of patent tort and launching evasion design techniques to raise research and development efficiency, to accelerate technical knowledge innovation, and the application of an environmentally friendly nonwashable soup spoon. It will create competition advantages in the industry continually, reduce the possibility of patent disputes at the same time and increase the possibility of the product obtaining a patent. This research used the patent which is approved by the authority to do patent analysis. As for the patent, we studied more about the tendency of technology research and development and also analyzed the research and development level, patent the present and innovation ability of competitors in different countries.

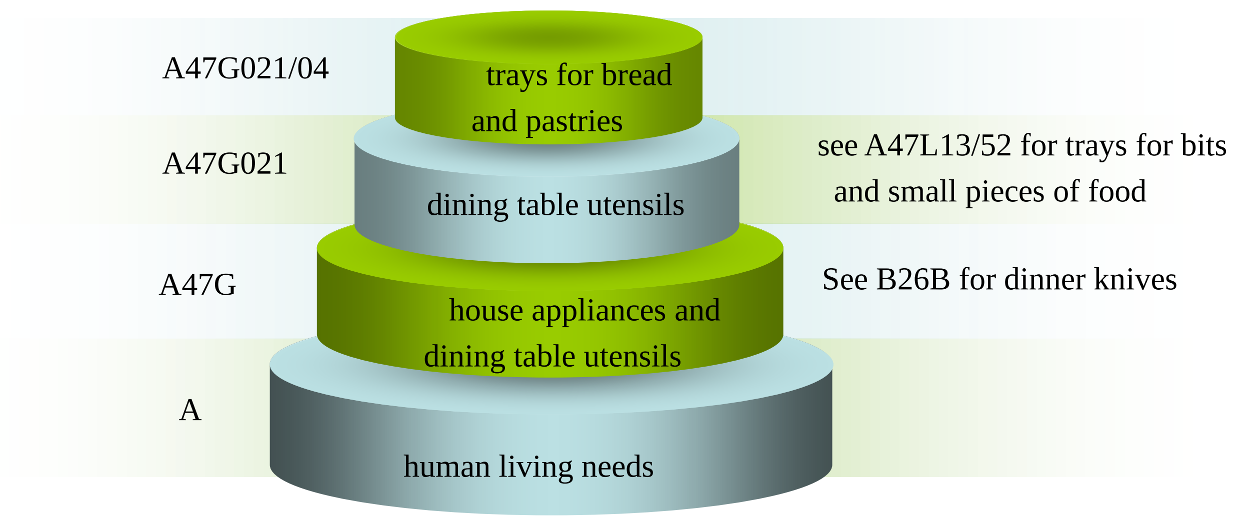

Figure 6: Patent Analysis

After we analyzed detection patents comprehensively, the result we obtained from the patent map can be a reference for enterprisers to plan medium and long-term development targets for the enterprise. Researchers can also learn about the tendency of products and market circumstances and integrate them with the skills of patent tort judgment and patent information collection and analysis to develop a completed patent evasion design process, launching procedures and policies. They can also discuss the relationship between patent evasion designing techniques and innovation methods.

Table 1. Patent number of articles

Key Word	Searching for pieces of writing of the patent in Taiwan
International Classification A47G21/04	94
Spoon	2063
Soup Spoon	172
Measure Spoon	12
Nonwashable Spoon	13
Ladle	27
Soup Ladle	5
Wooden Ladle	41
Wooden Soup Ladle	12
Tableware	429

Table 2. Patent number

Application No.	Announcement Date	Patent Category	Name of Patent
95140657	97/05/16	into the open	An universal measure spoon / ladle
95119802	97/01/01	into the open	A Spoon-knife(it's not only a spoon also a knife)
95221339	96/07/11	new pattern	a reformed spoon
95217259	96/04/11	new pattern	A nonwashable spoon
95210346	96/03/11	new pattern	A flexible spoon
94204235	94/09/11	new pattern	A spoon with a clip
94204954	94/09/01	new pattern	A cap with a spoon's structure improvement
93221261	94/07/21	new pattern	A spoon
93215232	94/05/11	new pattern	Tableware's structure improvement
93210925	94/05/01	new pattern	A spoon's structure

			improvement
92222323	93/11/21	new pattern	Structure of one-piece spoon
91219018	93/09/01	new pattern	A Straw spoon
92215002	93/08/11	new pattern	Structure of
91206041	93/04/21	new pattern	A cap with a spoon
89209006	90/02/11	new pattern	A spoon's structure improvement
87216217	88/04/21	new pattern	A paper spoon's structure improvement
83215325	84/08/21	new pattern	A simple and easy using spoon's structure improvement
79214103	80/07/11	new pattern	a sealed sanitary spoon
79213845	80/07/11	new pattern	a nonstitch paper spoon

This research is base on a "patent" for setting up the process with systematized innovation methods. It is conductive to developing researching technology and reducing or avoiding infringing on other people's patents, meanwhile, it is conducive to developing the competitiveness and marketability of the patent and product.

3.4 Strategy deployment and innovation

We compared differences between customer's demand and project technology by customer's demand and project technology overlapping analysis. The table of related strategies is as follows:

Table 3: Customer's demand, project technology and related strategy

Customer's demand	Project technology	Strategy
Nontoxic material of environmentally friendly nonwashable tableware	easy to recycle, reuse, and re-reuse	Toxic material may be cancer substance and impact the environment.
Reuse of environmentally friendly nonwashable tableware	reduced or eliminated energy resources using reduced or eliminated recourses using	Reusing reduces not only garbage but also manufacturing resources use.
Environmentally friendly nonwashable tableware can be decomposed by organisms	tableware which is easy to be recycled can be reuse and decomposed easily	It is made of natural material and will decompose by itself after some time. Or it will decompose after it is buried in soil.

Durability of environmentally friendly nonwashable tableware	Reduced or eliminated manufacturing waste by proper product design	Set up testing standards for quality check. This prevents the quality is over or not enough.

We reduced contradictory conflicts between customer's demand and project technology by customer's demand and project technology analysis and comparison, and deployed related strategy on the following table:

Table 4: Customer's demand, project technology ,contradiction conflict and strategy

Customer demand	Project technology	Strategy
Durability of environmentally friendly nonwashable tableware	easy to recycle, reuse, and re-reuse	We set different cycles of disposal tableware by bathtub hazard rate curve.
Price of environmentally friendly nonwashable tableware	easy to recycle, reuse, and re-reuse	If we can make profits from recycling and remanufacture it, we are more competitive than people who own the same business.

We set up an evaluation model of environmentally friendly nonwashable tableware by this analysis to evaluate customer's feedback and product design techology. We put related strategy and contradictory conflicts together to do strategy analysis. We invested massive resources for carrying on development for the same part of demand; brainstorming for looking for other substitute schemes to reduce contradiction and conflict for the part of contradiction conflict.

Table 5: CM & IP

Engineering parameter will be worsened / Engineering parameter will be promoted	12. Shape	13. Stability of an object	16. Time of duration of a fixture's activity	36. Complexity
8. Volume of a fixture	7,35,2	40,35,34,28	35,38,34	1,31
12. Shape	—	1,18,33,4	—	29,28,1,16
14. Strength	10,40,35,30	35,13,17	—	2,13,25,28
17. Temperature	14,19,32,22	1,35,32	18,19,36,40	2,16,17
33. Improving to use easily	28,29,15,34	30,32,35	1,16,25	12,32,17,26

(1) invention principle 15 "Dynamic": this invention principle changes the structure of a

nonwashable soup spoon from invariable to foldable and its shape and structure can be changed. This spoon can be folded to 1/3 of original size.

(2) invention principle 22 “Turn harmful into benefits ”: this invention principle suggests turning the harmful material quality into the material which has the positive effect on the environment.

(3) invention principle 27 “Disposable”: designing a disposable soup spoon with this invention principle.

(4) invention principle 34 “Discarding and restoration”: discharging by dissolving and evaporation.

(5) invention principle 40 “Compound materials”: combining with corn material. Using organism material suppresses plastic waste that pollutes the environment and mitigates lack of petroleum resources.

3.5 Materialization, Infringement Comparison and Patent Applied

The purposes of the product design concept are for easy storage and to be environmentally friendly. By Interactive TRIZ Matrix results in invention principle 15 “Dynamic”, invention principle 27 “Disposable”, invention principle 34 “Discarding and restoration” and invention principle 40 “Compound materials”. After design engineer materialization tested and verified, it proved that by using TRIZ it resulted in an invention principles advantage, and designing engineer’s design creativity conception development. The characteristics of nonwashable soup spoon are foldable and it is made of environmentally friendly material, PLA (anylum can be decomposed by organisms). The foldable soup spoon is highly acceptable in the market and we applied for a patent to avoid counterfeiting. It is verified and approved by Intellectual Property Office, Ministry of Economic Affairs, R.O.C.. It obtained a patent certificate, new pattern No. M347118.

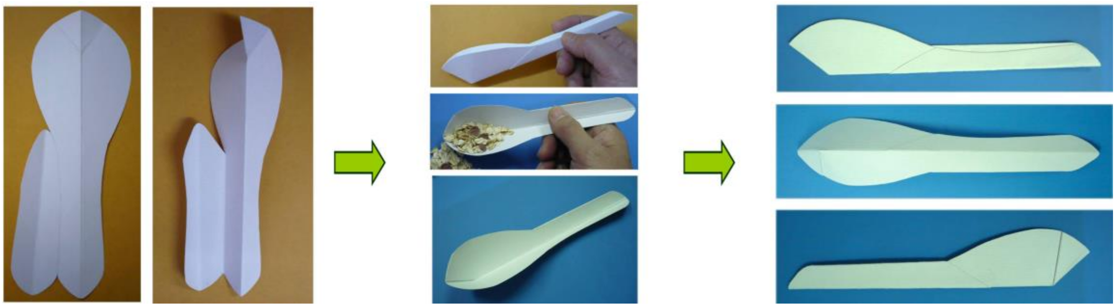

Figure 7: Patent analysis

4. Conclusion

As consumer's environmentally friendly consciousness rose and developed, we wished to develop the material that is more environmentally friendly. On the one hand we wanted to reduce the commodity's toxicity, and on the other hand we wanted to reduce resource consumption. This research proposed a set of design processes for the new product. We found the target that we wanted to research and develop by TRIZ "Problem Hierarchy Analysis." First of all for producing a brand new design commodity that is environmentally friendly and convenient. We also analyzed customer's feedback and project technology by GQFD. We integrated customers with technology. We combined patent analysis with customer's demands to analyze design directions of the commodity. We solved the conflicts we would possibly meet when we designed the commodity by TRIZ. And then we tested and verified the commodity to see if it meets customer's demands or not. After we reconfirmed infringement comparison, we finally applied for the related new patent.

The tendency of tableware development is based on customers' demands. The most important factor of environmentally friendly nonwashable tableware is using nontoxic materials. Reusability and the ability to be decomposed by organisms are secondary factors. Proper product design that reduces or eliminates manufacturing waste is the most important technical factor. The entire nonwashable tableware supply chain should be considered. Environmentally friendly nonwashable tableware needs to be easy to recycle, reuse, decompose, re-recycle, and re-reuse. Therefore this research considered the whole process from manufacturing, and usage to recycling for a commodity that will become available in the market, and then we developed a materialized commodity, a foldable soup spoon.

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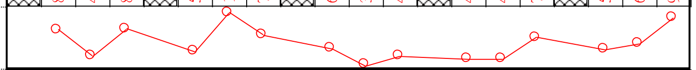
What vs Why Symbols		
Advertise	★	1.5
Mention	●	1.2
No Action	✖	1.0

Whats vs. Hows Symbols		
Strong	◎	9.0
Medium	○	3.0
Weak	△	1.0

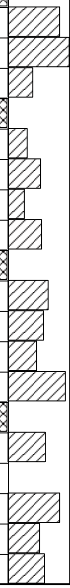
	#	1 importance of the percentage	1 material	2 natural material	3 avoiding using toxic material	4 easy to recycle and reuse	5 production	6 reduced or eliminated waste gas into air	7 reduced or eliminating production waste by proper product design	8 reduced or eliminated energy resources using	9 packing and transit	10 reduced or eliminated packing waste	11 avoiding using toxic material to pack	12 weight and volume of the minimum packing	13 using process	14 extending	15 discarding compatibly with the environment	16 reduced or eliminated resources using	17 discard and recycling	18 weight and volume of the minimum waste	19 module design provides the maximum upgrade	20 the tableware which can be recycled easily can be reused and decomposed
quality	1																					
durability of nonwashable tableware	2	7.79		○		○			○	◎		△				○					○	◎
nontoxic material of nonwashable tableware	3	8.66		◎	◎	○		◎	△	○			◎			△	◎			○		○
blemish ratio of nonwashable tableware	4	5.34				○			○	○		△				△				○	○	○
function	5																					
placement of nonwashable tableware	6	4.80							○			○		◎				△			○	
storage and carriage of nonwashable tableware	7	6.09							○			○		○		○					○	
multi-functionality of nonwashable tableware	8	4.56				△			◎	○		△				○		△			◎	○
simplified packing of nonwashable tableware	9	6.12						○	◎	○		◎		○				△		○	○	
cost	10																					
price of nonwashable tableware	11	6.77		○	△	○			○	○		○	△	○		○	△	△		○	○	○
additional profits from nonwashable tableware recycling	12	6.27		◎		◎				○			○			△	△	△		○		◎
preferential discount for using the tableware by oneself	13	5.69																△				
reusing nonwashable tableware recycling	14	8.30		◎	○	◎		◎	○	○		△				○		△			○	◎
environment	15																					
nonwashable tableware made of environmentally friendly material	16	6.44		◎	◎	◎		◎	◎	○			○			○	◎	△		◎		◎
nonwashable tableware is made of recycled material	17	3.00		○	○	○		○	○	○			○				○	△		○		△
nonwashable tableware can be decomposed by organisms	18	7.81		◎	◎	◎		○	◎	○			○			△	◎	△		◎		◎
nonwashable tableware conforms to environmental protection standard	19	5.94		◎	◎	◎		◎	◎	◎		◎	◎	○		○	◎	○		◎		◎
willing to respond and appealing to other people to give an impetus to environmental protection work together	20	6.41		◎	◎	◎		◎	◎	◎		◎	◎	○		○	◎	○		◎	○	◎
importance of design parameter	1			8.445	4.972	8.517		5.619	10.648	7.727		6.012	3.880	4.968		4.682	4.663	7.421		5.843	6.613	9.990

Max = 10.6
○ importance of design parameter
Min = 3.9



	#	1 importance of customers	2 consumer (0.60)	3 restaurant business owners (0.40)	4 importance of equalized the customer (1.00)	5 competition pressure	6 the product	7 competitor A (paper)	8 competitor B (environmental protection)	9 the products of 2009	10 improvement factor	11 equalized factor of the market	12 importance of integration	#
quality	1													1
durability of nonwashable tableware	2		3.8	3.4	3.64		3.1	2.2	4.1	4.1	1.32	●	5.8	2
nontoxic material of nonwashable tableware	3		4.2	4.4	4.28		4.2	2.3	3.5	4.2	1.00	★	6.4	3
blemish ratio of nonwashable tableware	4		3.6	4.5	3.96		4.3	4.1	3.5	4.3	1.00	✖	4.0	4
function	5													5
placement of nonwashable tableware	6		3.2	4.1	3.56		4.1	3.8	3.1	4.1	1.00	✖	3.6	6
storage and carriage of nonwashable tableware	7		3.6	4.0	3.76		4.2	3.6	2.7	4.2	1.00	●	4.5	7
multi-functionality of nonwashable tableware	8		3.5	3.2	3.38		3.7	3.5	3.1	3.7	1.00	✖	3.4	8
simplified packing of nonwashable tableware	9		4.1	3.3	3.78		4.1	4.0	3.1	4.1	1.00	●	4.5	9
cost	10													10
price of nonwashable tableware	11		2.2	4.5	3.12		2.8	4.2	4.5	4.5	1.61	✖	5.0	11
additional profits from nonwashable tableware recycling	12		2.1	4.6	3.10		4.2	2.0	1.8	4.2	1.00	★	4.7	12
preferential discount for using the tableware by oneself	13		4.3	4.1	4.22		3.6	3.5	1.9	3.6	1.00	✖	4.2	13
reusing nonwashable tableware recycling	14		3.1	3.8	3.38		3.1	1.9	4.7	4.7	1.52	●	6.1	14
environment	15													15
nonwashable tableware made of environmentally friendly material	16		4.1	3.8	3.98		4.8	3.1	3.7	4.8	1.00	●	4.8	16
nonwashable tableware is made of recycled material	17		2.3	2.1	2.22		2.3	2.3	2.1	2.3	1.00	✖	2.2	17
nonwashable tableware can be decomposed by organisms	18		4.3	3.2	3.86		4.9	1.8	1.6	4.9	1.00	★	5.8	18
nonwashable tableware conforms to environmental protection standard	19		4.4	4.4	4.40		4.8	2.6	1.7	4.8	1.00	✖	4.4	19
willing to respond and appealing to other people to give an impetus to environmental protection work together	20		4.2	3.6	3.96		4.7	2.4	3.8	4.7	1.00	●	4.8	20

Min = 3.0
importance of the percentage
Max = 8.7



Paper ID: 144

Mass Innovation Approaches for Systematic Innovation: Automatic Function Interpretation applied to Sustainable Design

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Abstract

With advances in computing power and the processes of globalization, the analytical and engineering science skills that contribute to innovation are becoming a commodity, and the activities of research and development—and innovation—are being outsourced. These trends leave the creative and systems integrative skills of engineering design as the value-added part of innovation. This paper presents a framework to address this challenge, termed *mass innovation*, which can be defined as expanding and diffusing innovation activities to the general population through *connecting* inventors and entrepreneurs with the engineering tools and services needed to *assess and realize their novel design concepts*. As part of mass innovation, this paper presents the development of an approach for automatic function interpretation, and an example is given, in the context of sustainable design, of the application of automatic function interpretation and automatic classification of level of invention to a means for producing compressed earth blocks. The method for automatic function interpretation is based on text extraction, natural language processing using a parser, and semantic definition of functional requirements and design parameters. The classification of level of invention is based on a machine-learning model using inputs based on patent citation measures.

Keywords: mass innovation, functional representation, natural language processing, TRIZ level of invention

1. Introduction

With advances in computing power and the processes of globalization, the analytical and engineering science skills that contribute to innovation are becoming a commodity, and the activities of research and development—and innovation—are being outsourced. (Engardio and Einhorn, 2005) These trends leave the creative and systems integrative skills of engineering design as the value-added part of innovation. (Uchitelle, 2006) This paper presents a new framework to address this challenge by integrating engineering design and social science innovation research, termed *mass innovation*, which can be defined as expanding and diffusing innovation activities to the general population through *connecting* individual inventors and entrepreneurs with the engineering tools and services needed to *assess and realize their novel design concepts*. (Adams and Tate, 2009; Tate et al., 2009) The approach presented in this paper in the context of sustainable design applications. (Tate et al., 2008a; Tate et al., 2010; Tate et al., 2008b)

The goal of mass innovation may be considered as *making innovators into better engineers*. That is, in coming up with a design idea, potential innovators should incorporate the engineering knowledge embodied in it and its connections to prior designs in the assessment of its innovative potential. The mass innovation approach combines fast and quantifiable assessment of engineering design innovation in terms of the *potential transformative impact of a design idea* with means for communicating the design idea with others for engineering analysis, prototyping, manufacture, and intellectual property protection. Both assessment and communication of the design idea make use of functional descriptions of the design idea, and this paper presents initial work for the automatic generation of functional description of design ideas and application of automatic classification of the design according to the theory of inventive problem solving (TRIZ) level of invention (LOI).

The assessment of engineering design innovation in terms of the *potential transformative impact of a design idea* is achieved by integrating several activities as shown in Figure 1: use of design methods for functional representation and creativity enhancement; use of natural language processing (NLP) and latent semantic analysis (LSA) for the extraction and interpretation of functional and physical data from patent databases; predicting the transformative impact of a design idea through using machine learning to identify and predict design outcomes, such as TRIZ level of invention or forward patent citation measures; and finally communication of the design idea to others for product realization through engineering analysis, prototyping, manufacture, etc. This paper focuses on the development of an approach for automatic function interpretation that is used throughout the mass innovation framework. The method for automatic function interpretation presented here is based on text extraction, natural language processing using a parser, and semantic definition of functional requirements and design parameters.

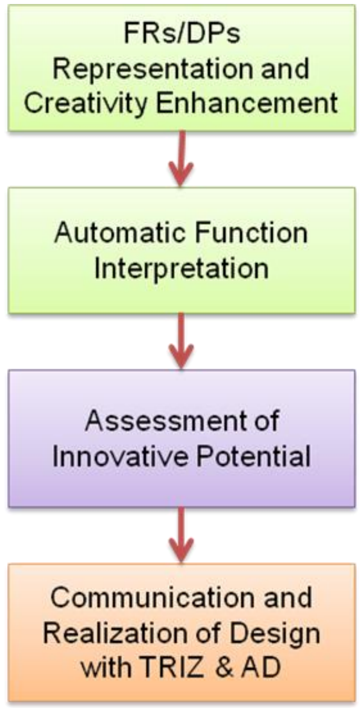

Figure 1. Framework for Mass Innovation

The paper is structured as follows: After the introduction, section 2 presents an overview of methods used in the framework. Section 3 presents a simple example of sustainable design centered on compressed earth block (CEB) technology, and section 4 discusses the results. Finally, conclusions and future work are given at the end of the paper.

1.1 Mass Innovation

Globalization and cyberinfrastructure provide new mechanisms to create opportunities for *mass innovation*, which is defined here as expanding and diffusing innovation activities to the general population through *connecting* individual inventors and entrepreneurs with the engineering tools and services needed to *assess and realize their novel design concepts*. The first piece of this vision is to provide fast and quantifiable assessment of engineering design innovation in terms of the *potential transformative impact of a design idea*. Quantifying the expected rate and breadth of adoption of new products and services remains a key uncertainty in design and development.

For sustained economic development and industrial competitiveness, participation in innovation activities needs to be broadened. The future of the innovation process should provide opportunities for individuals—especially expanding opportunities for additional individuals with or without engineering and scientific backgrounds—to participate in the genesis and realization of novel products and services. Ideas for novel products can arise from disparate sources: surgical tools and medical devices from a pathologist, sustainable building equipment from a rancher/contractor (Williamson, 2007), automotive power train components from a machinist (Dubose, 1996), a back brace from a physical therapist (McKinney, 2007), and so on. In these cases, as with all invention, an individual or small number of users have perceived unmet needs or shortcomings with existing products (Petroski, 1992), and they stand to benefit from resolving the shortcomings of the existing design or system (von Hippel, 1998; von Hippel, 2005).

The mass innovation approach seeks to provide a scientific foundation for the future of collaborative engineering designs. It is motivated by the needs of entrepreneurs and inventors and the desire to leverage cyberinfrastructure and globalization to expand and diffuse innovative activity. Once a person forms an idea, a set of computer tools should be available to state their idea formally, to assess the originality of the idea, and to quantify its prospects to have an innovative impact. Many of the pieces needed for mass innovation already exist, and others are in development. The piece that needs the most work is the first—the cyber-tools for modeling, communicating, testing, and refining of an idea to predict its innovative potential. This work is motivated by the search for the best means for non-technical individuals to formulate and develop their inventive or innovative ideas.

1.2 Sustainable Design

Sustainable design can be defined as incorporating larger environmental, resource, and social issues into decisions of the conceptualization, design, manufacture, operation, and end-of-life of products and systems. These larger issues include, for example, environmental concerns, energy independence, economic viability, and social impact. Sustainability as applied to engineering design is perhaps best understood in terms of energy resources, environmental issues, economic factors, and social impact. It is difficult for individual engineers to be conversant with the many technologies, social, and economic focuses bearing on new designs, and it is also difficult for engineers to define the right problems to be addressed (Tate et al., 2007). Radical, transdisciplinary approaches are needed for product conceptualization, development, and business models that incorporate environmental profiles, manufacturing processes, emissions, and resource consumption to achieve order-of-magnitude improvements (Ertas et al., 2000; Gumus et al., 2008; Tate et al., 2007). The example discussed in this paper is that of a means for producing compressed earth blocks (CEBs).

Earth can be formed into walls using dried mud bricks (adobe), dried poured earth, rammed earth, and compressed earth blocks. With rammed earth, forms are first built similar to cast-in-place concrete forms, and earth is then added in shallow layers and rammed. *Compressed earth blocks* are defined as earthen blocks created by means of compression in hand-operated or hydraulic machines. (Eko et al., 2006) Currently commercially available CEB machines make blocks up to about 25 x 35 x 10 cm which are stacked to form a wall. (Advanced Earthen Construction Technologies, 2009) Stabilizers such as Portland cement, lime, gypsum, and others can be used along with the soil in the blocks; however, in some cases, stabilization can also be achieved physically without chemical additives by using compaction and granular stabilization. (Burroughs, 2001; Minke, 2006) The Texas Tech University Whitacre College of Engineering and TTU College of Architecture have been working with EarthCo Building Systems to develop a comprehensive building system for efficient and low-cost manufacture and placement of earthen building envelopes using large-scale compressed earth blocks (CEBs). By scaling up the production and placement of CEBs, manual labor and production time can be minimized, and CEB technology can be made cost competitive with traditional building technologies. (Tate et al., 2008a; Williamson, 2007)

1.3 Functional Description of Design Intent

Formal methods used for representing functions during problem formulation describe a system's functions and how they interact. (Antonsson and Cagan, 2001; Chakrabarti, 2002) They are intended to facilitate communication among designers and stakeholders, build group consensus, and support the development of innovative and collaborative designs. (Hirtz et al., 2002) Problem formulation has been observed to be the most difficult task in design (Suh, 1990), and it is critical because design programs and designed artifacts will fail if problem formulation never stabilizes or is based upon incorrect premises. Recent research in engineering design has started with a "functional basis" for representing engineering designs, yet this is only one of many approaches to modeling function that have been proposed. (Antonsson and Cagan, 2001; Chakrabarti, 2002) The approaches to representing function can be divided into two categories—(1)

“functional basis” or “black box” approaches that trace various flows through a system (typical examples include functional basis (Altshuller, 1984; Pahl and Beitz, 1996; Stone et al., 2002; Stone and Wood, 2000), black box, and structured analysis and design technique (SADT) (Marca and McGowan, 1993; Ross, 1977; Ross, 1985)) and (2) those that alternate between functions and physical means, progressing from systems to components to create a hierarchy of functions (for example, function means tree (FMT) (Andreasen et al., 1995; Andreasen and Hein, 1987; Hubka and Eder, 1992) (compare with (Marples, 1961) and (Suh, 1990; Suh, 2001)), enhanced FMT (Johannesson, 2004), Gero’s function—behavior—structure (FBS) ontology (Dorst and Vermaas, 2005; Galle, 2009; Qian and Gero, 1996), and SysML (Hause et al., 2005)). Recent publications by Erdena et al. and van Eck et al. have compared and contrasted prominent approaches to functional modeling. (Erdena et al., 2008; van Eck et al., 2007) In this paper, the second type of approach will be followed that alternate between functions and physical means in a hierarchical manner.

Data mining should be useful for mining repositories of design intent (patents, electronic design notebooks, etc.) as noted at several NSF-sponsored workshops. (Kusiak, 2007; Schunn et al., 2006; Shah et al., 2005) Engineering design researchers have proposed or developed databases for searching for physical means to provide functionality, and several approaches to engineering design innovation incorporate the use of databases for stimulating or documenting conceptual engineering design. Early efforts to systematize engineering design information in repositories include design catalogs by German researchers (see examples in (Pahl and Beitz, 1996)), morphological analysis (Norris, 1962; Pahl et al., 2007; Zwicky, 1969), and a database of physical effects included as part of TRIZ. (Altshuller, 1984; Fey and Rivin, 2005; Savransky, 2000) More recently the biomimetic approach of Tinsley et al. uses a repository for storing biological functions that can serve as stimuli for engineering designers. (Tinsley et al., 2007) Work by Wood and colleagues proposes a design by analogy method to create transformative designs (defined as changing state or configuration to provide new functionality) (Skiles et al., 2006). Yang has investigated data mining of electronic design logbooks and the development of thesauri for retrieving design information. (Yang et al., 2005) A challenge of repository-based approaches is the effort required to populate the repository as well as efforts to ensure consistency, usefulness, and uniqueness of the information stored within the repository. This work addresses data mining of design intent using natural language processing from a large repository of U.S. patent documents. One of the outputs of this work are expected to be sets of functional and physical design data, organized by discipline, that can be used in populating design repositories.

1.4 Automatic Function Interpretation

The goal of engineering design is to create a product that can carry out certain tasks in order to satisfy the needs of customers (Hirtz et al., 2002; Suh, 1990). Modern marketing has been rephrased as (1) discovering needs and wants of its target customers, and (2) satisfying these needs in a better way than competitors (Wagner and Hansen, 2004). Typically, customer needs can be obtained by gathering market data and by analyzing these data with techniques such as customer analysis, product research, competitor analysis, trend forecasting, risk analysis, etc. However, this approach is both time-consuming and costly. To reduce potential cost, researchers may take the advantage of computational approached to interpret design intention by means of natural language processing (NLP) techniques and axiomatic design theories. The former is widely used for text understanding and text generation while the later provides a framework for representing solutions in terms of explicitly stated functional requirements (FRs) and design parameters (DPs) (Suh, 1990).

Given a description of an engineering design, such as given in a patent document, functional requirements (FRs) and design parameters (DPs) can be extracted by taking advantage of a computational linguistic model. Extracted FRs and DPs not only serve as source of inspiration for designers but also help designers focus on fulfilling customer needs (CNs). In order to rank FRs and DPs extracted from design descriptions, assessment of innovative potential is carried out to classify the level of invention.

1.5 Assessment of Innovative Potential and TRIZ

Goel and Singh (1998) suggest that product design is a goal-directed problem-solving activity that relies heavily on creative thinking, drawing analogies with related knowledge, and experience. Also, they indicated that this work should be done by integrating creativity and innovation tools with engineering design methods. However, there is still a remaining question: How can the innovative potential of a design be measured? The answer to the question above is TRIZ metrics such as degree of ideality and level of invention (Fey and Rivin, 2005). TRIZ provides a systematic process to define and solve given problems which helps increase creativity. In TRIZ, there are five level of invention. The relative percentages of the five level of invention are given in Table 1 (Clausing and Fey, 2004; Fey and Rivin, 2005; Savransky, 2000).

Table 1. TRIZ Level of Invention (Fey and Rivin, 2005; Savransky, 2000)

Level	Description	% of Patents (Fey and Rivin, 2005)
Level 1	Apparent solution: A component intended for a task is used.	32%
Level 2	Small improvement: An existing system is slightly modified.	45%
Level 3	Invention inside paradigm: At least one system component is radically changed or eliminated; the problem and solution are within one discipline.	19%
Level 4	Invention outside paradigm: A new system is developed using a solution that is interdisciplinary.	<4%
Level 5	Discovery: A pioneering invention is created, often based on recently discovered phenomenon.	<0.3%

These levels of invention are based on a combination of the resolution of engineering contradictions and interdisciplinarity—borrowing of a solution from another discipline. These levels of invention are based on the resolution of system conflicts (or functional coupling) through transdisciplinary approaches (Altshuller, 1984; Fey and Rivin, 2005). In a previous paper, Adams and Tate demonstrated the use of natural language processing for patent data and the use of a neural network model to estimate the TRIZ level of invention and TRIZ level of ideality for patents. (Adams and Tate, 2009) Adams (2009) also predicted innovative potential by constructing transdisciplinary metrics and training an artificial neural network. He concluded that such metrics helped not only integrate new technologies but also measure the success of a design based on the levels of integration across diverse fields and different parts of a company.

Two related works for evaluating level of invention include (Regazzoni and Nani, 2008) and (Verbitsky, 2004). Regazzoni and Nani use intellectual property density, given by the ratio of number of patents over the number of IPC 4 digit classes per year, to define a break event year that separates patents according to TRIZ level of invention (“breaking” between levels 2 and 3). They identify the LOI of a series of patents having the term “x-rays” in title, abstract, or claims. (Regazzoni and Nani, 2008) Verbitsky presents a measure of level of invention based on the actual number of citations a patent receives versus an expected number of citations, calculated based on the patent’s position in a series of patents. (Verbitsky, 2004)

1.6 Communication and Realization of the Design with TRIZ and Axiomatic Design

After the originality and feasibility of a design idea are validated, the next step in the mass innovation process involves the inventor communicating the idea to others. Engineering analysis can be accomplished through a variety of means, depending on the nature and complexity of the project: doing the analysis oneself, automated analysis with software, using virtual reality and other computer-aided engineering tools, outsourcing the analysis to domestic or overseas engineers, or collaboration with academic or industrial partners. Once the design and engineering analysis have been conducted, a prototype can be created. Again this can be accomplished through several possible methods: rapid prototyping, outsourcing, etc. Within a short time—a few weeks or days—an idea should go from germination to physical implementation. The inventor can then use the physical device for experimental validation, robust design, etc.

Additional steps in the entrepreneurial process to be considered include the development of business plans and strategy, quantifying the financial prospects of the design, raising capital, etc. as well as the need for protecting intellectual property and intellectual capital. These steps can be tied to existing architectural frameworks for modeling operational, functional, node connectivity, and other business and strategic aspects of a new design.

2. Methods for Automatic Function Interpretation

In this section, the methods adopted in this paper are discussed. The importance of analyzing patents is described in the first sub-section, and the formation of FRs/DPs from a given patent follows. The last part of this section describes the evaluation approach for innovative potential.

2.1 Patent Analysis

Tseng et al. (2007) state that patent documents contain valuable information for industry, business, law, and policy-making communities. Innovative solutions, business trends, technological details, and their relationships can be revealed if careful patent analysis is made. On the other hand, a patent has highly structured content which enables researchers to carry out multiple kinds of analysis. A typical U.S. Patent includes several sections: abstract, related U.S. patent documents, references cited, claims, and description.

By manually reviewing patents, functional requirements and design parameters can be obtained from both claims and descriptions. However, the sentences in claims are usually too long for the parser which results in low efficiency, and parsing performance is also less satisfactory. Therefore, the authors chose to implement the NLP techniques on the description section, especially the summary of invention section which is high-quality abstraction of the invention that has been summarized by a human.

2.2 Text Extraction, Function Generation, and Interpretation of Design Intention

The structure of functional requirement interpretation can be divided into the three steps shown in Figure 2. They are text extraction, natural language processing, and FRs/DPs generation. Each of these three steps interact with a local database to save or load data.

Figure 2. Framework of Function Generation

In the first step, the program downloads patents from United States Patent and TradeMark Office (USPTO) website for future processing. Patent content extracted and stored locally makes future steps faster and easier than searching online repeatedly. Also, during the extraction, the content of a patent is automatically segmented into different sections by using regular expression. These sections include patent title, abstract, reference, citations received, claims, and description. For example, the string *"(<CENTER>|<B>|<I>|\\s)+Claims(</B>|</CENTER>|</I>|\\s)+(.*)<HR>\\s*(<CENTER><B><I>)"* can be used to capture text in the claims section.

The second step is to implement two NLP techniques for extracted and segmented patents stored in database. The two NLP techniques include part-of-speech (POS) tagging and probabilistic parsing. In this paper, the POS tagger and statistical parser developed by Stanford Natural Language Processing Group[1] is adopted. The former technique helps clarify the identification of a word in a sentence by using maximum entropy approach

[1] http://nlp.stanford.edu/index.shtml

(Toutanova and Manning, 2000). The tagging annotation adopted by Stanford POS tagger is from the Penn TreeBank which contains 40 different tags[2]. An example of a tagged sentence extracted from U.S. Patent 6736626 following the Penn TreeBank tags is shown in Table 2.

According to Klein and Manning (2003), the tagger provides 97.24% accuracy on Penn TreeBank Wall-Street Journal. However, to form readable functional requirements and design parameters, single tagged words are still too ambiguous even with a given tag. Consider the simple word *run* as an example. According to explanations in Merriam-Webster online dictionary, the word *run* has 15 different meanings as an intransitive verb[3]. Therefore, it's extremely vague for readers if the single word instead of a phrase is used. Fortunately, the later technique, parsing, enables one to determine the grammatical structure given in a sentence. In other words, phrases can be used instead of single words in the output parse tree to eliminate the ambiguity of single words. Also, by parsing a sentence, pairs of dependent subjects, actions, and objects (SAO) can be found. This facilitates the generation of functional requirements and design parameters in the next step. An example of the parser output is shown in Table 3. In this example, the main subject of the sentence is "*The Homeland Secuirty secretary*" and main action is "*said*". The sub-subject of the sentence is "*legislative efforts*" and sub-action is "*will begin*". As Klein and Manning (2003) indicated in their paper, the Stanford parser adopted un-lexicalized straightforward probabilistic context free grammars (PCFGs) approach that provided performance of 86.36% when the length of a sentence was less than 40 words.

The last step is to concatenate corresponding noun phrases and verbal phrases to form functional requirements and design parameters by finding keywords such as "*to*" or "*for*" in verbal phrases. The keyword "*to*" in verbal phrases serves as a part of an inifitive to express design intention, and the keyword "*for*" in verbal phrases also express the intention to carry out a certain task. Therefore, by combining the verbal phrases and corresponding objectives, functional requirement can be formed as shown in Table 4. The subject of the sentence is the design intention for implementing designated tasks. Thus, it will be the design parameter for fullfiling funtional requirements that have just been defined before.

[2] http://www.cis.upenn.edu/~treebank/
[3] http://m-w.com/dictionary/run

Table 2. Penn TreeBank POS Tag and Tagged Sentence from U.S. Patent 6736626

Penn TreeBank Tags

CC - Coordinating conjunction
CD - Cardinal number
DT - Determiner
EX - Existential there
FW - Foreign word
IN - Preposition or subordinating conjunction
JJ - Adjective
JJR - Adjective, comparative
JJS - Adjective, superlative
LS - List item marker
MD - Modal
NN - Noun, singular or mass
NNS - Noun, plural
NNP - Proper noun, singular
NNPS - Proper noun, plural
PDT - Predeterminer
POS - Possessive ending
PRP - Personal pronoun
PRP$ - Possessive pronoun (prolog version PRP-S)
RB - Adverb
RBR - Adverb, comparative
RBS - Adverb, superlative
RP - Particle
SYM - Symbol
TO - to
UH - Interjection
VB - Verb, base form
VBD - Verb, past tense
VBG - Verb, gerund or present participle
VBN - Verb, past participle
VBP - Verb, non-3rd person singular present
VBZ - Verb, 3rd person singular present
WDT - Wh-determiner
WP - Wh-pronoun
WP$ - Possessive wh-pronoun (prolog version WP-S)
WRB - Wh-adverb

Sentence before tagging: The press foot is then lowered to a second level in the breech to receive a volume of the loose earth from the feed drawer into the breech.

Sentence after Tagging: The/DT press/NN foot/NN is/VBZ then/RB lowered/VBN to/TO a/DT second/JJ level/NN in/IN the/DT breech/NN to/TO receive/VB a/DT volume/NN of/IN the/DT loose/JJ earth/NN from/IN the/DT feed/NN drawer/NN into/IN the/DT breech./NN

Table 3. Example of Parsing Output using Stanford Parser

Sentence to be parsed: The Homeland Security secretary said legislative efforts to streamline the immigration system will begin early next year.

Parsing Tree:

```
(ROOT
 (S [124.189]
  (NP [35.301] (DT [2.455] The) (NNP [11.645] Homeland) (NNP [7.238] Security) (NN [7.587]
secretary))
  (VP [87.746] (VBD [1.395] said)
   (SBAR [83.238]
    (S [83.208]
     (NP [50.777] (JJ [7.443] legislative) (NNS [6.041] efforts)
      (S [31.333]
       (VP [31.238] (TO [0.011] to)
        (VP [31.209] (VB [7.876] streamline)
         (NP [21.299] (DT [0.650] the) (NN [10.787] immigration) (NN [6.083] system))))))
     (VP [28.633] (MD [1.176] will)
      (VP [25.251] (VB [5.289] begin)
       (NP-TMP [13.959] (RB [3.633] early) (JJ [4.537] next) (NN [1.231] year)))))))
  (. [0.002] .)))
```

Table 4. Extraction of FR and DP from a Sentence

Example: The press foot is then lowered to a second level in the breech to receive a volume of the loose earth from the feed drawer into the breech.

SAOs:
Main subject: *The press foot*
Main action: *is then lowered to*
Main object: *a second level in the breech*
Sub subject: -
Sub action: *to receive*
Sub object: *a volume of the loose earth the feed drawer into the breech*

FRs: *receive a volume of the loose earth the feed drawer into the breech*
DPs: *The press foot is then lowered to a second level in the breech*

2.3 Application of Innovative Potential Assessment Metrics

The TRIZ level of invention of a patent can be estimated by using patent citation analysis. The measure of originality is calculated using the following equation (Jaffe and Trajtenberg, 2002):

$$O_i = 1 - \sum_{k=1}^{n} \left(\frac{b_k}{b}\right)^2 \tag{1}$$

where b is the number of patents cited in current patent, and k indicates the subclass of the cited patent. For example, if one patent cites 3 patents and 2 of the patents are from subclass X and 1 patent is from subclass Y, then the originality measure is $1-((2/3)^2 + (1/3)^2) = 0.44$.

A patent's generality is measured in a similar way, but considers the forward patent citations by patents from multiple subclasses (Jaffe and Trajtenberg, 2002).

$$G_i = 1 - \sum_{k=1}^{n} \left(\frac{f_k}{f}\right)^2 \tag{2}$$

where f is the number of patents that cite the current patent, and k indicates the subclass of the patents that cite the current patent.

By combining the number of citations made, citation received, originality, and generality measures, the input for classification can be constructed. Also, the level of invention of each patent serves as the class label in a supervised machine learning method such as an artificial neural network (ANN) or support vector machine (SVM). The training sample in the example includes 140 patents of mechanical devices with manually assigned levels of invention (Adams, 2009). Part of the training data is listed in Table 5.

Table 5. Example of Level of Invention Training Data (Adams, 2009; Adams and Tate, 2009)

Patent #	Cmade	Creceive	Generality	Originality	Level of Invention
4118531	11	190	0.86	0.82	2
4367924	2	401	0.85	0.50	4
4310440	7	213	0.84	0.48	5
4031519	24	47	0.84	0.84	4
4194041	12	163	0.83	0.66	3
3229759	1	20	0.83	0.00	4
5143854	34	162	0.82	0.88	2
4049997	5	20	0.81	0.38	1
3702886	1	382	0.81	0.00	3
3906324	10	19	0.80	0.48	1
4230463	24	223	0.80	0.73	2
4063271	5	20	0.79	0.32	1
4440871	14	273	0.77	0.74	3
4907340	27	19	0.77	0.70	3
5053074	9	8	0.75	0.59	3
4133814	4	219	0.74	0.50	5
4983886	8	19	0.73	0.53	1
4688900	51	171	0.71	0.77	3
4036012	5	9	0.70	0.63	3
4060023	5	7	0.69	0.44	1
4399209	15	231	0.68	0.27	2
3753145	1	20	0.67	0.00	4
4061724	1	202	0.62	0.00	5
4072541	8	20	0.62	0.24	1
4706216	1	194	0.61	0.00	5
5109824	6	7	0.57	0.48	2

3. Example Sustainable Design Application

As mentioned earlier, the case study of this paper centers on an application of sustainable design. Compressed earth block (CEB) is a promising construction material for manufacturing building envelopes by mechanically compressing into blocks a mix of dirt, non-expansive clay, and possibly stabilizers. Since the materials for building CEBs can be all natural, the manufacturing process has minimal impact on the environment.

U.S. Patent 6736626[4] is an example that introduces a method for manufacturing CEBs. The first step of the case study is manually analyzing functional requirements and design parameters in the patent using axiomatic design in this section. Then, the results of implementing NLP techniques and assessment of innovative potential are presented in the following two sub-sections respectively and compared with the manual analysis.

3.1 Manual Analysis

In the description of U.S. Patent 6736626, a total of six key components are introduced: breech, press foot, feed drawer, bucking foot, hopper, and hydraulic system. Except the hydraulic system, the other key components are marked as 10, 20, 30, 50, and 60 in Figure 3.

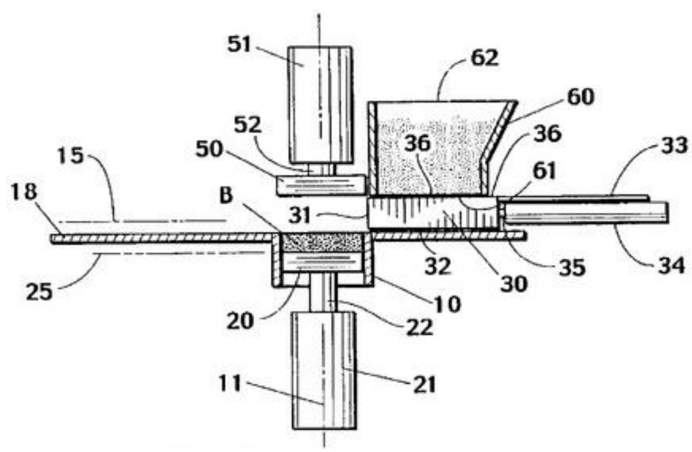

Figure 3. Proposed CEB Manufacturing Machine [from U.S. Patent 6736626[5]]

[4] http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6736626.PN.&OS=PN/6736626&RS=PN/6736626

[5] http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6736626.PN.&OS=PN/6736626&RS=PN/6736626

By carefully analyzing the summary of invention, 15 pairs of FRs and DPs can be obtained as follows:

- *FR_1: receive a volume of the loose earth*
- *DP_1: the press foot is then lowered to a second level in the breech*
- *FR_2: remove or screed the excess loose earth*
- *DP_2: feed drawer is withdrawn laterally across the planar surface*
- *FR_3: compress the loose earth in the breech*
- *DP_3: the press foot is raised to a third level in the closed breech*
- *FR_4: permit vertical ejection of the block*
- *DP_4: The bucking foot is then raised to a level higher than the top of the feed drawer*
- *FR_5: refill the feed drawer*
- *DP_5: feed drawer will be aligned under a hopper storing loose earth*
- *FR_6: push the previously-made block*
- *DP_6: abutment of a three dimensional face of the previously-made block with a leading face of the feed drawer*
- *FR_7: open and close the upper end of the breech*
- *DP_7: bucking foot is aligned above the breech for vertical reciprocal movement along the Z-axis*
- *FR_8: move the feed drawer across a surface coplanar*
- *DP_8: a hydraulic cylinder*
- *FR_9: move the bucking foot*
- *DP_9: the second hydraulic cylinder*
- *FR_{10}: move the press foot*
- *DP_{10}: the third hydraulic cylinder*
- *FR_{11}: provide the lateral tongue-and-groove of the block*
- *DP_{11}: the breech is substantially rectangular in the X-Y plane with two-dimensional surfaces in its Y-Z side walls and complementary three-dimensional surfaces*
- *FR_{12}: provide the vertical tongue-and-groove of the block*
- *DP_{12}: the press foot and the bucking foot have complementary three-dimensional surfaces in their upper and lower X-Y walls*
- *FR_{13}: close the hopper*
- *DP_{13}: trailing plate coplanar with its open upper end*
- *FR_{14}: pass over the three dimensional surface*
- *DP_{14}: feed drawer has a fixed wall with a lower edge notched*
- *FR_{15}: screed along the open upper end of the breech*
- *DP_{15}: hinged wall following the fixed wall with a level lower edge*

By further investigating these FRs and DPs, a hierarchical structure can be formed as some of FRs and DPs belong to a sub-level rather than the higher level of the design. For example, the block is formed by moving the press foot to a designated place to compress loose earth. Therefore, FR_3 and DP_3 belong to the higher level in the structure. On the other hand, the press foot is moved by a hydraulic system, thus FR_{10} and DP_{10} belong to a lower level. The detailed dependencies are described in Figure 4.

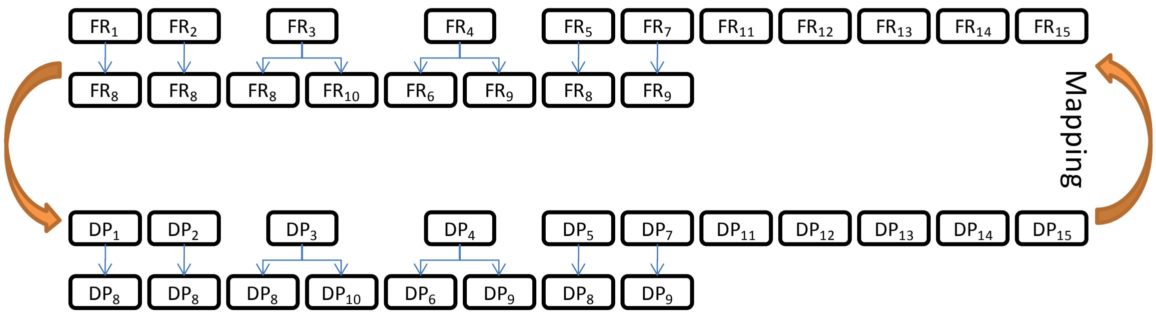

Figure 4. FRs and DPs in a Hierarchical Structure

3.2 Automatic FRs/DPs Interpretation for this Case Study

According to the description in section 2, the first step for interpreting FRs and DPs is to extract patents from the USPTO web patent databases (USPTO) and save the content of patents such as title, patent number, citations, abstract, claims, and description to a local database. An example from U.S. Patent 6736626 is shown in Figure 5.

Instead of implementing NLP on all the sections of patents, only the description section of a patent is analyzed with the parser and POS tagger. The reason is that the length of sentences in the claims are usually too long to be parsed and the parsing performance is not satisfactory. Therefore, this paper mainly focuses on using the two NLP techniques on the description section, especially the summary of invention. Figure 6 illustrates extracted subjects, objects, and actions from a patent that has been tagged and parsed.

In the last step, cause-effect relationships are searched throughout all the sentences by locating keywords such as "*to*" and "*for*". A verb is concatenated together with its object to form functional requirements, while the subject remains as the design parameter.

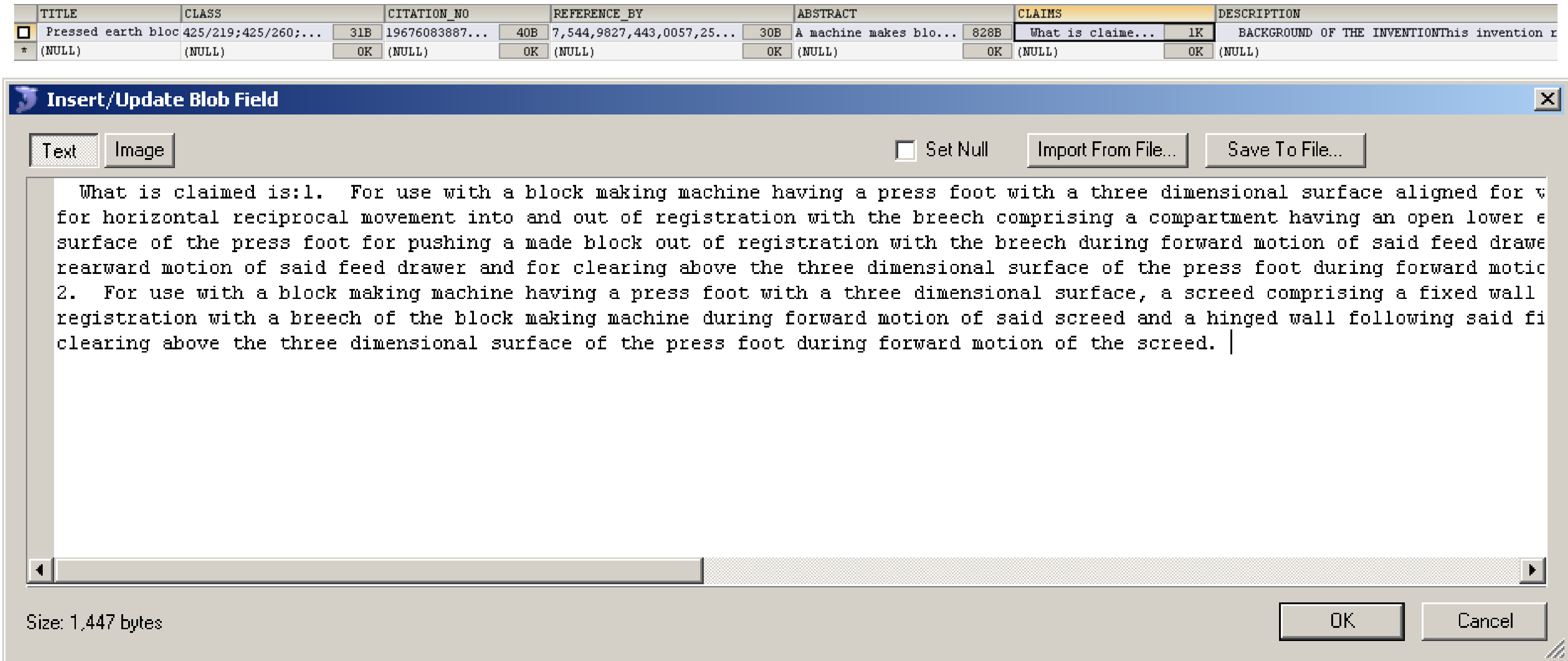

Figure 5. Extracted Patent Content

SECTION	SEQ	TAGGEDSENTENCE		SUBJECT		ACTION		OBJECT
Description	1	This/DT invention/NN relates/VBZ generally/RB to/TO machi...	261B	This invention machines for the...	61B	more particularly concerns	26B	a machine and a method for
Description	1	This/DT invention/NN relates/VBZ generally/RB to/TO machi...	261B		0B	making	6B	blocks of pressed earth
Description	2	In/IN my/PRP$ earlier/JJR US/NNP Patent/NNP No/NNP 5,629,...	209B	my earlier US Patent No 5,629,0...	116B	was disclosed	13B	
Description	3	However,/NNP the/DT invention/NN disclosed/VBD therein/RB...	250B	the invention	13B	disclosed therein	17B	three-dimensional surfaces in the o
Description	4	In/IN some/DT building/NN applications,/NN it/PRP is/VBZ ...	418B	some building applications it	29B	is desirable	12B	
Description	4	In/IN some/DT building/NN applications,/NN it/PRP is/VBZ ...	418B	the blocks	10B	have	4B	a tongue and groove configuration i
Description	5	A/DT three/CD dimensional/JJ configuration/NN in/IN ortho...	465B	A three dimensional configurati...	53B	presents	8B	new problems in the pressing of the
Description	5	A/DT three/CD dimensional/JJ configuration/NN in/IN ortho...	465B		0B	causing	7B	damage the block or its three dimen
Description	6	These/DT problems/NNS are/VBP in/IN addition/NN to/TO the...	306B	These problems	14B	are in	6B	the normal requirements in speed of
Description	7	It/PRP is,/FW therefore,/FW an/DT object/NN of/IN this/DT...	275B	It	2B	is , therefore ,	16B	
Description	7	It/PRP is,/FW therefore,/FW an/DT object/NN of/IN this/DT...	275B	an object of this invention	27B		0B	
Description	7	It/PRP is,/FW therefore,/FW an/DT object/NN of/IN this/DT...	275B	a machine and method for manufa...	38B	pressed	7B	earth blocks
Description	7	It/PRP is,/FW therefore,/FW an/DT object/NN of/IN this/DT...	275B		0B	make pressed	12B	earth blocks of constant density an
Description	8	Another/DT object/NN of/IN this/DT invention/NN is/VBZ to...	254B	Another object of this invention	32B	is	2B	
Description	8	Another/DT object/NN of/IN this/DT invention/NN is/VBZ to...	254B	a machine and method for manufa...	38B	pressed	7B	earth blocks
Description	8	Another/DT object/NN of/IN this/DT invention/NN is/VBZ to...	254B		0B	facilitate	10B	the rapid production of uniform ear
Description	9	Yet/RB another/DT object/NN of/IN this/DT invention/NN is...	326B	another object of this invention	32B	is	2B	
Description	9	Yet/RB another/DT object/NN of/IN this/DT invention/NN is...	326B	a machine and method for manufa...	38B	pressed	7B	earth blocks
Description	9	Yet/RB another/DT object/NN of/IN this/DT invention/NN is...	326B		0B	produce	7B	blocks
Description	9	Yet/RB another/DT object/NN of/IN this/DT invention/NN is...	326B		0B	are tongued-and-grooved in	26B	block surfaces
Description	9	Yet/RB another/DT object/NN of/IN this/DT invention/NN is...	326B		0B	are orthogonal to	17B	each other
Description	10	In/IN accordance/NN with/IN the/DT invention,/NN a/DT met...	146B	accordance with the invention a...	38B	is provided for	15B	
Description	10	In/IN accordance/NN with/IN the/DT invention,/NN a/DT met...	146B		0B	making	6B	a block pressed earth
Description	11	A/DT press/NN foot/NN is/VBZ raised/VBN in/IN a/DT breech...	160B	A press foot	12B	is raised in	12B	a breech to a first level an open u
Description	12	A/DT feed/NN drawer/NN having/VBG an/DT open/JJ lower/JJR...	255B	an open lower end A feed drawer	31B	filled with	11B	granular material or loose earth a
Description	13	The/DT press/NN foot/NN is/VBZ then/RB lowered/VBN to/TO ...	226B	The press foot	14B	is then lowered to	18B	a second level in the breech
Description	13	The/DT press/NN foot/NN is/VBZ then/RB lowered/VBN to/TO ...	226B		0B	to receive	10B	a volume of the loose earth the fee
Description	14	The/DT feed/NN drawer/NN is/VBZ withdrawn/VBN laterally/R...	290B	The feed drawer	15B	is withdrawn laterally across	29B	the planar surface out of registrat
Description	14	The/DT feed/NN drawer/NN is/VBZ withdrawn/VBN laterally/R...	290B		0B	to remove or screed	19B	the excess loose earth the open upp
Description	15	A/DT bucking/VBG foot/NN is/VBZ then/RB lowered/VBN to/TO...	114B	A bucking foot	14B	is then lowered	15B	
Description	15	A/DT bucking/VBG foot/NN is/VBZ then/RB lowered/VBN to/TO...	114B		0B	to close	8B	the upper end of the breech

Figure 6. Tagged and Parsed Patent in Database

The programming language used in this project is the Java[6] language, and the IDE is MyEclipse[7]. MySQL[8] is selected as the local database. SQLyog[9] serves as the GUI for manipulating the local database. The running result is shown in Table 6. In total, 11 functional requirements and design parameters are extracted from U.S. Patent 6736626. As can be seen, the first functional requirement is irrelevant, and some of phrases in sentences such as the 2nd FR and 3rd FR contain mistakes that may cause ambuiguity for readers. However, the result is encouraging as most of them match the manual work presented in section 3.1 very well.

Table 6. Generated FRs and DPs from U.S. Patent 6736626

1st FR is: making a block pressed earth
1st DP is: accordance with the invention a method is provided

2nd FR is: receive a volume of the loose earth the feed drawer the breech
2nd DP is: The press foot is then lowered to a second level in the breech

3rd FR is: remove or screed the excess loose earth the open upper end of the breech
3rd DP is: The feed drawer is withdrawn laterally across the planar surface out of registration

4th FR is: close the upper end of the breech
4th DP is: A bucking foot is then lowered

5th FR is: compress the loose earth in the breech a block
5th DP is: The press foot is raised to a third level in the closed breech

6th FR is: permit vertical ejection of the block the open upper end of the breech the lateral path of the feed drawer
6th DP is: The bucking foot is then raised to a level the top of the feed drawer

7th FR is: refill the feed drawer
7th DP is: additional loose earth will be dispensed from the hopper

8th FR is: open and close the upper end of the breech
8th DP is: The bucking foot is aligned above the breech for vertical reciprocal movement along the Z-axis

9th FR is: receive a volume of loose earth
9th DP is: the loose earth the breech against the bucking foot form a block of pressed earth

10th FR is: provide the lateral tongue-and-groove of the block
10th DP is: the breech is substantially rectangular in the X-Y plane with two-dimensional surfaces in its Y-Z side walls and complementary three-dimensional surfaces in its X-Z side walls

11th FR is: provide the vertical tongue-and-groove of the block
11th DP is: All preferably , the press foot and the bucking foot have complementary three-dimensional surfaces in their upper and lower X-Y walls , respectively

3.3 Estimation of Innovative Potential for this Case Study

According to U.S. Patent 6736626 (425/219), five citations are made in it, and they

[6] http://www.java.com/en/

[7] http://www.myeclipseide.com/

[8] http://www.mysql.com/

[9] http://www.webyog.com/en/

are U.S. Patent 1967608 (425/260), U.S. Patent 3887685 (425/260), U.S. Patent 5037287 (425/352), U.S. Patent 5885625 (425/260), and U.S. Patent 6302675 (425/219). Also, it is cited by U.S. Patent 7544982 (257/294), U.S. Patent 7443005 (257/432), and U.S. Patent 7252120 (141/71). By using two equations given in section 2.3, the originality and generality are calculated as 0.56 and 0.67 respectively.

The prediction is made by taking advantage of Matlab Neural Network Fitting Tool[10] (abbreviated as nftool). The network is a two-layer feed forward network with 20 hidden neurons in hidden layer, and the training algorithm is back-propagation. 147 training samples are divided into 3 parts: 70% of them are used for training purpose, 15% of them are used for validation, and the remaining 15% of them are used for testing. The training completes in 33 iterations with 0.067 mean square error on validation sample (shown in Figure 7 and 8).

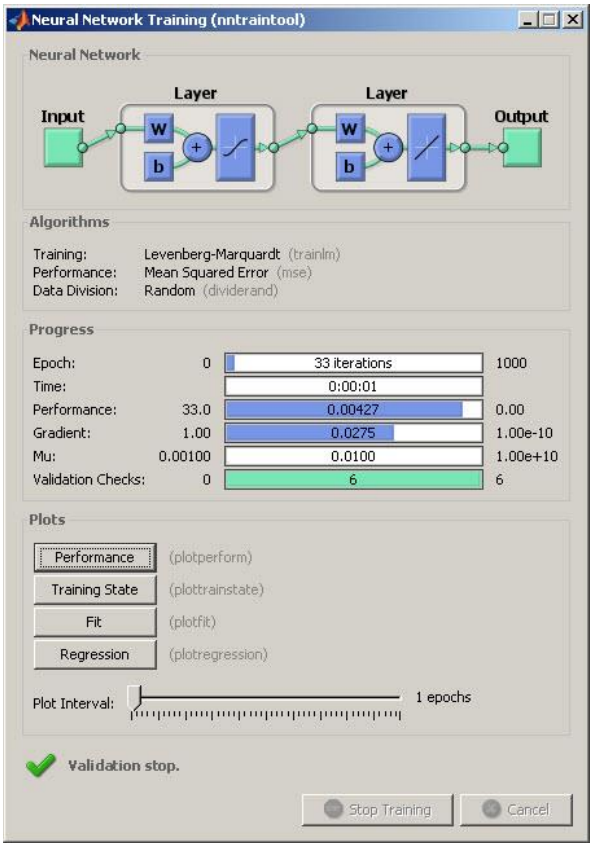

Figure 7. Neural Network Training Result

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[10] http://www.mathworks.com/access/helpdesk/help/toolbox/nnet/nnet_product_page.html

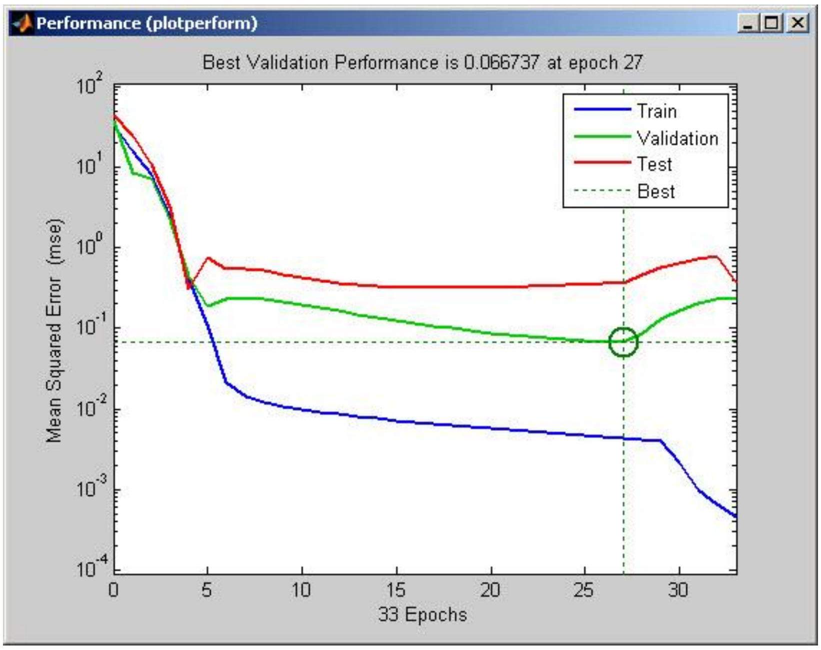

Figure 8. Neural Network Performance

4. Results and Discussion

The classification result and network performance may vary as the limited training sample is randomly divided into three parts for training, validation, and testing. However, this effect can be cancelled if a sufficient training sample is presented for training the network.

After the network is trained, the test sample of U.S. Patent 6736626 is applied. The result shows that the level of invention of U.S. Patent 6736626 is 1.36 which is a reasonable estimation considering the content of the patent.

By selecting FRs/DPs from patents ranked with level of invention, designers have sufficient knowledge regarding the scope of their designs. With the help of the framework of axiomatic design or TRIZ, more innovative solutions can be found cheaply and quickly.

Generating functional requirements and design parameter pairs from given patents has not been done previously because high quality text abstraction requires sophisticated natural language processing techniques that are still immature. Most of the work done in this area concentrates on extracting words instead of phrases or sentences to represent functions which can cause vagueness for readers. In this paper, the authors present the effort that has been done to show that this goal is feasible through using parsing and tagging techniques combined with axiomatic design theories.

Although the result indicates that the method adopted is still mechanical and inflexible, the result is still encouraging as most of statements of functional requirements and design parameters are highly readable and understandable compared with single words.

As this is a fresh attempt in this field, the method adopted is inevitably immature. For example, because both the parser and tagger used in this paper are statistically based, the training sample used will undoubtedly affect performance. Unfortunately, because there is no dedicated parser or tagger for patents, the accuracy may not be satisfactory in some cases. Also, the method proposed cannot be used so far for constructing functional requirements and design parameters in a hierarchical way, resulting in a loss of information.

The proposed evaluation of innovative potential is simple but effective. However, as the training sample used thus far is limited, the classification performance can be improved by preparing a larger sample in the future. Furthermore, the methodology for evaluating innovative potential in this paper depends on the number citations received which makes it less accurate for classifying patents that have received few citations. To reduce this dependency, the classification should be made based solely on the content of patent or design idea instead.

5. Conclusions and Future Work

In this paper, a framework for enhancing creativity by combining engineering design concepts, automatic function generation, and evaluation of innovativeness was proposed. By doing these steps, novel design concepts can be assessed and realized which facilitates innovation in engineering design activities. In this paper, the authors present the effort that has been done to generate functional requirements and design parameter pairs from given patents to show that this goal is feasible through using parsing and tagging techniques combined with engineering design theories. The result is still encouraging as most of statements of functional requirements and design parameters are highly readable and understandable compared with single words. The proposed evaluation of innovative potential is simple but effective for classifying patents that have already received citations.

Future Work

In the light of the preliminary result, the authors will extend the work in the future by taking several steps. WordNet[11] developed in Princeton University has been shown to be a useful tool in natural language processing. By combining this lexical database, phrases that have the same meaning can be grouped as one to make functional generation more accurate. Additionally, taking advantage of the axiomatic design framework to express functional requirements and design parameters in a hierarchy is another topic to be covered in future. In assessment of innovative potential, the authors will extend the application of NLP techniques to patents to create a training sample for a machine-learning model based on functions for classification instead of using the number of citations received or made. This step helps evaluate or predict the potential of an innovative work more independently. Also, this step will be helpful for entrepreneurs or inventors to evaluate their work even without citations. Finally, the authors intend to incorporate function generation and assessment of innovative potential into a standalone software suite.

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[11] http://wordnet.princeton.edu/

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Paper ID: 149

Concerning Parameterization of Artificial Systems

"Growth-Curves" (S-Curves)

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Abstract

The assumption of artificial systems development in accordance with Law of evolution along S-curve is one of the principal statements of TRIZ. This Law supplies researchers with a very powerful instrument of analytical prediction. Awareness of a system location on the S-curve makes it possible to increase research efficiency and to redistribute financial resources in the most promising directions. Indeed, if a system is on the second stage then: while improving system or its elements it should be made mean depth modifications; trimming and expansion are approximately equal; compromises and decisions aimed at struggle against undesirable effects without their cause elimination are permitted.

If a system is on the third stage then: for long-term outlook there should be considered system or its elements operating principle modification allowing inhibiting development of contradiction. It is very efficient to use different ways of transition to a super-system, they are deep coagulation, alternative systems unification and others. For short and middle-term outlook it is necessary to settle problems concerning reduction of costs and service functions development.

The report presents a detailed technique (more than ten statements) of "growth curves" parameters estimation of artificial systems and a lot of illustrated examples. Also it is given an example of a system with decreasing efficiency parameter – processing size of large integrated circuits production.

Keywords: Growth curves, Increasing efficiency, Parameters, Technique.

1. Introduction

The assumption of artificial systems development in accordance with logical regularity (S-shaped development law) is one of the principal propositions of TRIZ (Altshuller, 1984, Altshuller et al., 1999). This regularity supplies researchers with a very powerful instrument of analytical prediction. Awareness of a system location on an S-shaped curve makes it possible to increase research efficiency and redistribute financial resources in the most promising directions. Indeed, according to contemporary TRIZ theoreticians Simon Litvin and Alex Lyubomirskiy (2003), if a system is on the second stage then:

- While improving system or its elements it should be made mean depth modifications (with their operating principle not being changed);
- Folding and unfolding are approximately equal;
- It is worth to solve problems of adaptation of a system to new ranges of application;
- Orientation to use of specially adapted super-system resources is permitted;
- Compromises and decisions aimed at struggle against undesirable effects without their cause elimination are permitted.

If a system is on the third stage then:

- For long-term outlook there should be considered system or its elements operating principle modification allowing inhibiting development of contradiction;
- It is very efficient to use different ways of transition to a super-system, they are deep coagulation, alternative systems unification and others;
- For short and middle-term outlook it is necessary to settle problems concerning service functions development and reduction of costs.

According to the above mentioned recommendations in the first and the second cases developers are to settle absolutely different problems.

2. Growth curves approximating expressions

There exist various ways of mathematical notation for an S-shaped curve. The most simple and widespread of them is a logical function the classic form of which is as follows (Martino, 1972):

$$P(t) = \frac{1}{1+e^{-t}} \tag{1}$$

This formula is applied for a nonparametric logical curve. For approximation of real technical systems action it should be entered at least three parameters (Meyer et al., 1999): the largest extremum of the curve (K) and the parameters characterizing timing data of the logical curve. Historically, a logical curve described the action of the population that is why it included α and β parameters which characterized population size action.

$$P(t) = \frac{K}{1+e^{-\alpha(t-\beta)}} \tag{2}$$

Such parameters as the logical curve centre point (T_m) and center part width (ΔT), directly characterizing curve position on the time base, are more natural for defining artificial systems action. When moving to these parameters there also appears D factor which characterizes relative center part width. It means that the value of D factor depends on the center part limits selection criterion.

$$P(T) = \frac{K}{1+e^{-\frac{D}{\Delta T}(T-T_m)}} \tag{3}$$

If we take that the center part occupies 80% of the logical curve largest extremum then D=ln(81). If we take the center part limits for mathematical “extreme points”, then D=2π, later for D there will be used this very formula. The graph of the logical curve with the curve centre point and center part limits points marked according to the both criteria is presented on the Figure 1.

Some artificial systems “growth curves” (S-shaped curves) can be rather easily approximated with a logical curve. Figure 2 in particular presents a “growth curve” of organic light-emitting diodes (OLED) efficiency. As a complex parameter there is used luminous efficiency (a ratio of luminous flux to applied power), standard light-emitting devices complex parameter. Analyzing this ratio it can be assumed that OLED will move to the third level in 2011.

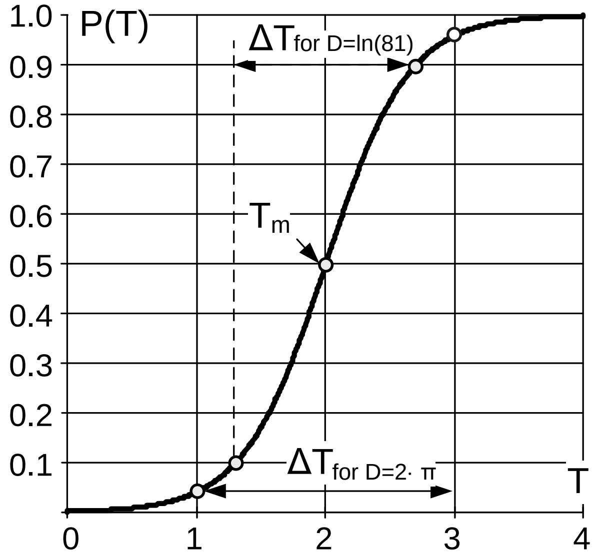

Figure 1. Logical curve graph, K=1, T_m=2, ΔT=2.

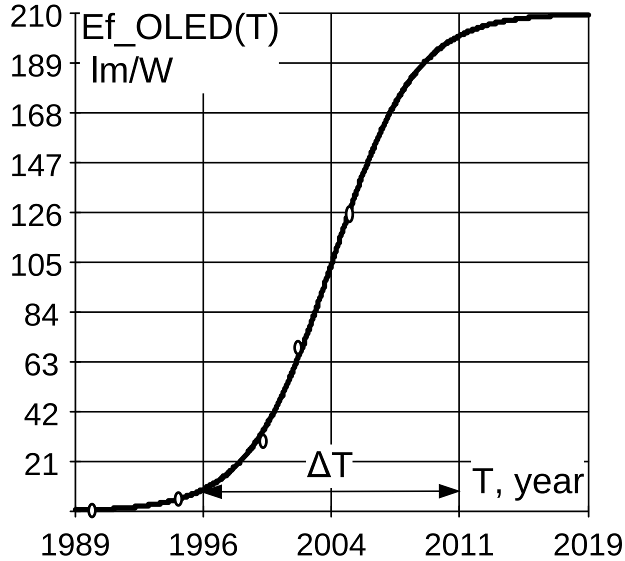

Figure 2. Dependence of OLED efficiency from time K=210 lm/W, T_m=2004 year, ΔT=15.37 year.

Nevertheless not all the artificial systems growth curves are approximated by a single logistic curve. For the more adequate approximation there can be used a sum of several logistic curves; then the general formula is as follows

$$P(T) = P_0 + \sum_{i=1}^{n} \frac{K_i}{1 + e^{-\frac{D}{\Delta T_i}(T - T^i{}_m)}} \tag{3}$$

Here P_0 is initial displacement of the S-shaped curve (the value of the main manufacturing parameter at the creation moment of the system), while K, T_m, ΔT marked with “i” indexes are the respective maximum values, the center and the center part width of constituent logistic curves. According to these logistic curves parameters ratio the shape of the resultant curve is considerably modified.

If the center parts of the constituent logistic curves do not overlap the resultant curve becomes multistage. The example of such curve with center parts limits circled is given at the Figure 3.

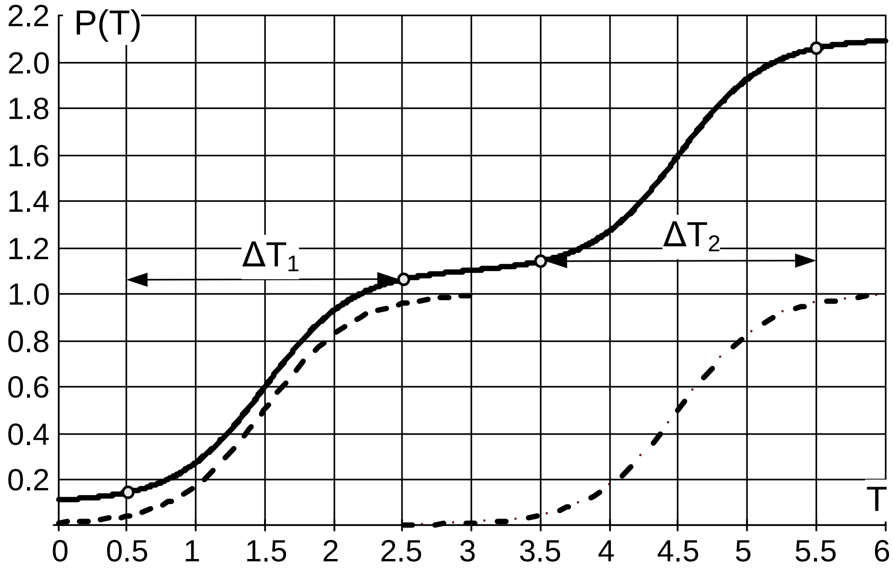

Figure 3. Two-component logistic curve graph (center parts do not overlap), P_0=0.1; K_1=1; T_m^1=1.5; ΔT_1=2; K_2=1; T_m^2=4.5; ΔT_2=2.

“Growth curves” of artificial systems the development of which was accompanied by multiple changes of operation principle are well approximated with polylogistic curves. The Figure 4 in particular presents efficiency growth curve of luminous devices from paraffin candles to organic light-emitting diodes. On the curve basing on parameters of the constituent logistic curves and the history of luminous devices development one can conventionally mark out three epochs: the incandescent lamp epoch, the luminous tube lamp epoch, and light-emitting diode (solid-state) light source epoch. The duration of these epochs is shortening as coming to the present.

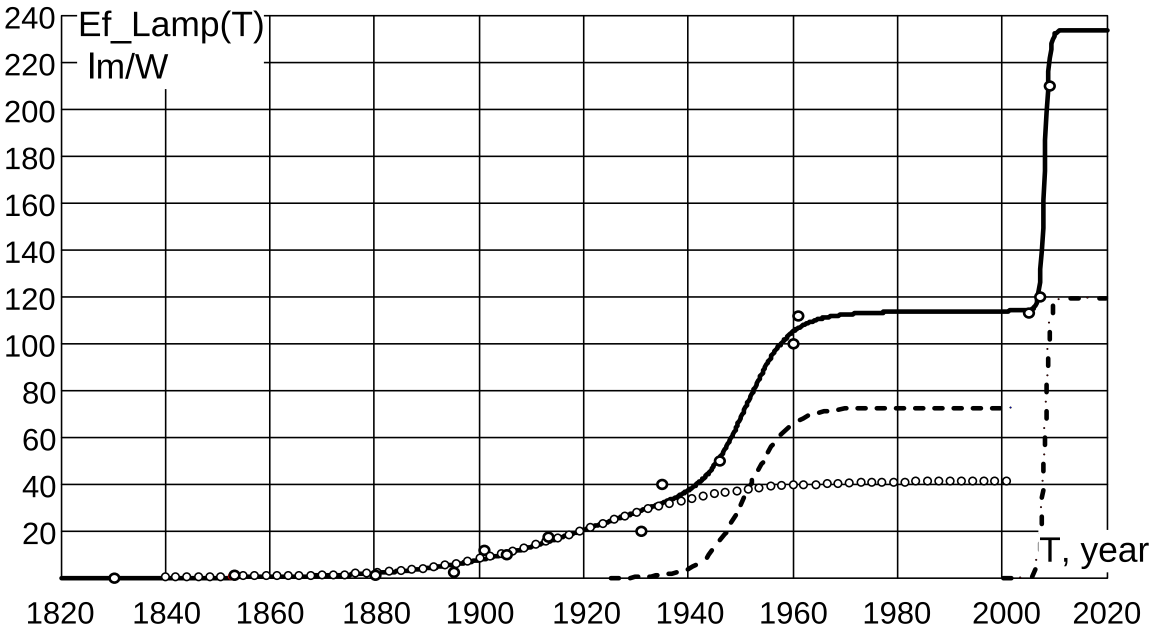

Figure 4. Dependence of luminous devices efficacy from time P_0=0.3 lm/W; K_1= 41.38 lm/W; T_m^1=1920; ΔT_1=86.72 year; K_2= 72.8 lm/W; T_m^2=1951; ΔT_2=24.7 year; K_3=119.66 lm/W; T_m^3=2008; ΔT_3= 2.9 year

If center parts of logistic curves overlap there are two options. In the first variant "the faster curve" is situated farther on the time base. The example of such curve with center parts limits circled is given on the Figure 5.

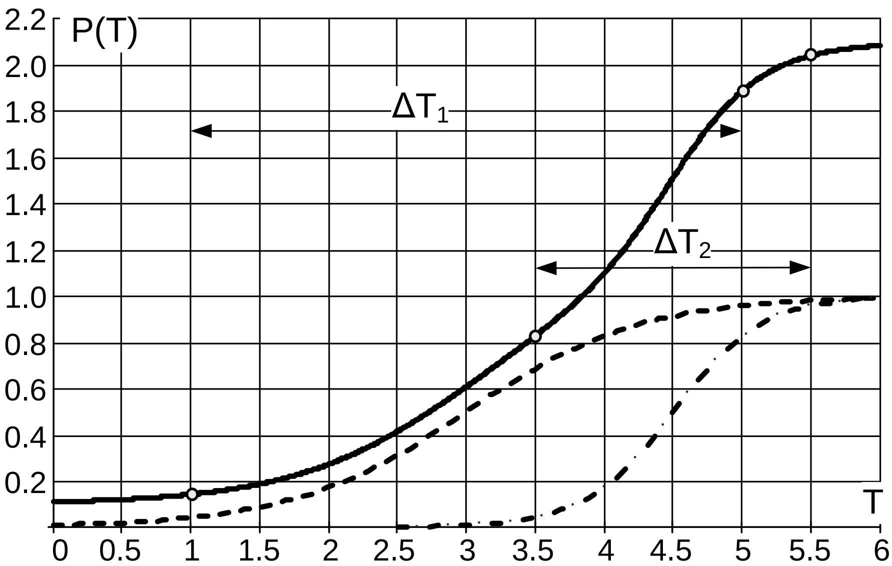

Figure 5. Two-component logistic curve graph (center parts overlap, "the fast curve" is later than "slow" one), P_0=0.1; K_1=1; T_m^1=3; ΔT_1=4; K_2=1; T_m^2=4.5; ΔT_2=2.

"Growth curves" of the artificial systems the development of which was accompanied by operation system modification are well approximated with bi-logistic curves center parts of which overlap. The Figure 6 in particular presents a "growth curve" of light-emitting diodes (LED) efficiency. On this "growth curve" it can be found out a zone of abrupt change of the parameter, which does not end at the passing to the third stage.

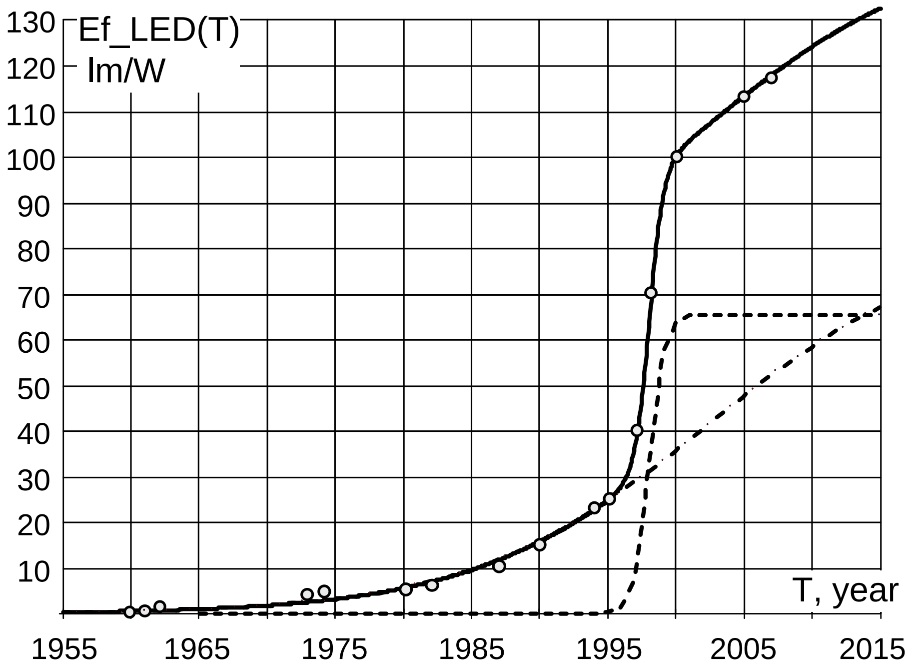

Figure 6. Dependence of LED efficacy from time P_0=0.3 lm/W; K_1= 81.17 lm/W; T_m^1=2002; ΔT_1=53.12 year; K_2= 72.8 lm/W; T_m^2=1998; ΔT_2= 3.23 year.

Thus, we can **conclude** that artificial systems "growth curves" are most adequately characterized with bi- and polylogistic curves, parameters of which are maximum values (K_i), and also center (T_m^i) and width (ΔT_i) of center parts.

3. "Growth curves" parameterization techniques.

All systems can be divided into two big classes in regards to "growth curves". Systems with "increasing" complex parameter relates to the first class. The examples of such systems were considered in the second chapter. This class is more significant, then the second one. Systems with "decreasing" complex parameter relates to the second class. An example of such systems is a system of fabrication of microelectronic components. Their complex parameter is a feature size. Parameterization techniques for both classes will be considered in the present report. The first technique is presented for systems with "increasing" complex parameter.

3.1 The systems with “increasing” complex parameter.

At the beginning it will be considered a technique of a single logistic curve approximation. For this simplest case it is required to define three parameters: K, T_m, ΔT. These parameters can be defined by using MathCAD intrinsic function «genfit(X,Y,N,F)» (Berdonosov et al., 2008), where X,Y are basic data vectors, for which approximation is introduced; N is a vector of initial approximations; F is a vector consisting approximating function and partial derivatives of the function according to the required parameters. While conducting approximation there occurs the following problem: K parameter is extremely susceptible to basic data set, especially when the system has not moved to the third stage. Figure 7 presents results of LED parameterization with different number of basic data.

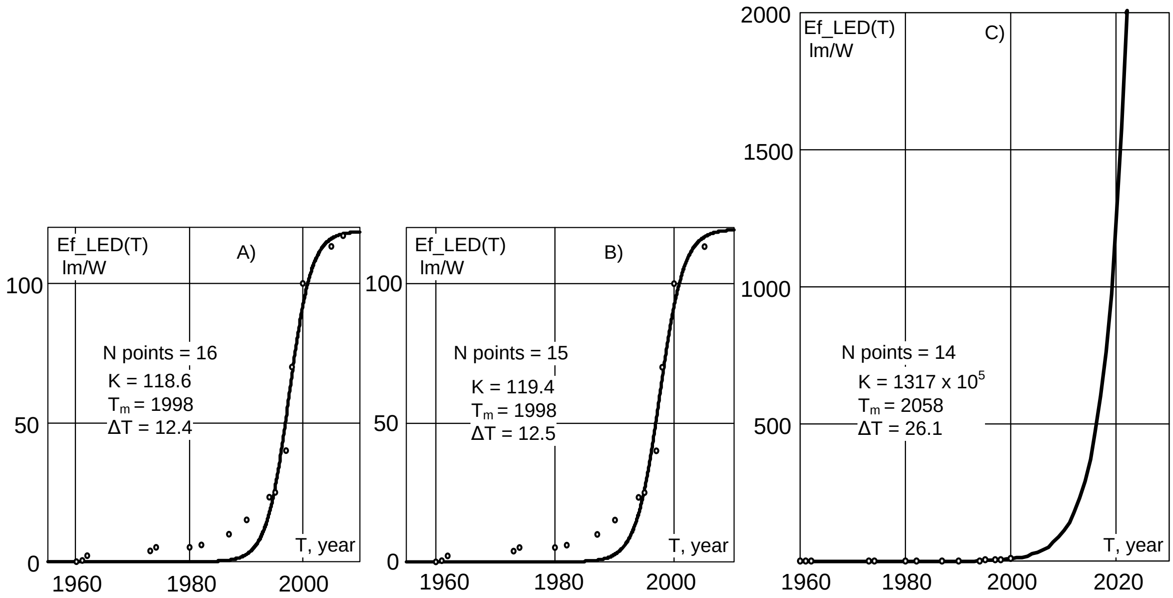

Figure 7. The results of parameterization of dependences of the LED effectiveness from the time, under a various number of the basic dots (values T_m, ΔT, K); A) – 16 dots, B) – 15 dots, C) – 14 dots.

As it can be found in diagrams, parameters for15 and 16 dots are already identical, which is surely determined by the LED effectiveness curve to the third stage. At the same time, in chart C the last thirteen dot remains equal of the second stage, that is why the approximation curve almost “ran to eternity”.

In order to eliminate this problem, most of the authors (Kynin et al., 2009, Kudryavtsev, 2009) suggest determining the K-parameter on the basis of physical, technical or social limitations of the researched system, while still calculate the T_m и ΔT parameters on computer.

It is possible to perform the same operation using the same example: the “growth curve” of LED effectiveness. There is a technical limit of LED (120 lm/W) determined in (Kynin et al., 2009). This value will be used in the following analysis. The maximum value of the non-decreasing (in effectiveness) data turned out to be equal of 16. During the experiment, the values of the data T_m и ΔT being estimated by the “genfit()”) function, had decreased in one point each time. The results of the research are shown in Figure 8. Analyzing the results it was found out that decreasing number of dots from 16 to 13 T_m values do not change, while ΔT values are in a tolerance range for practical use. Keeping decreasing the number of dots the values of T_m и ΔT significantly increase. Functional connection of T_m и ΔT data from the number of dots is shown in Figure 9. Based on this research, it can be assumed the following algorithm of the basic data integrity estimation: it is possible to build certain functional connection of T_m и ΔT from the amount of the basic data; to consider the values researched as being valid enough if while decreasing the amount of data the deviation of the estimated values do not exceed a preset value (for example, 10%)

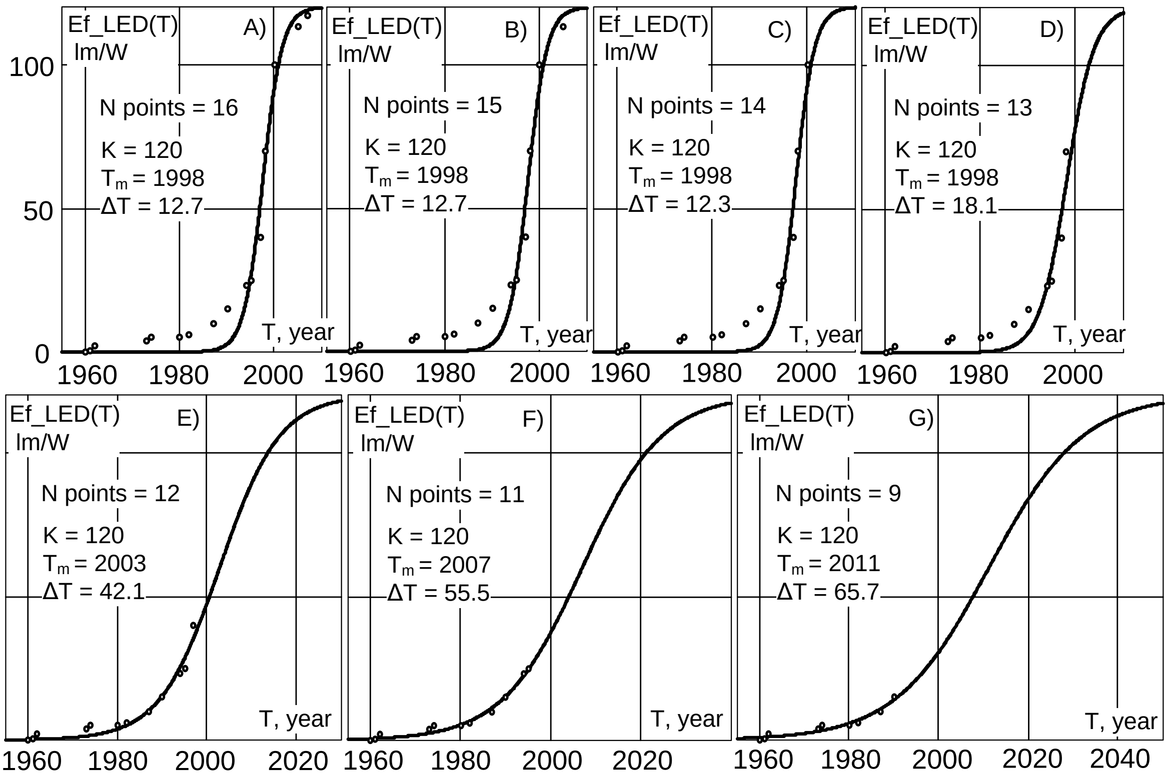

Figure 8. The results of parameterization of dependences of the LED effectiveness from the time, under a various number of the basic dots (values T_m и ΔT, K is equal 120 lm/W); A) – 16 dots, B) – 15 dots, C) – 14 dots, D) – 13 dots, E) – 12 dots, F) – 11 dots, G) – 9 dots.

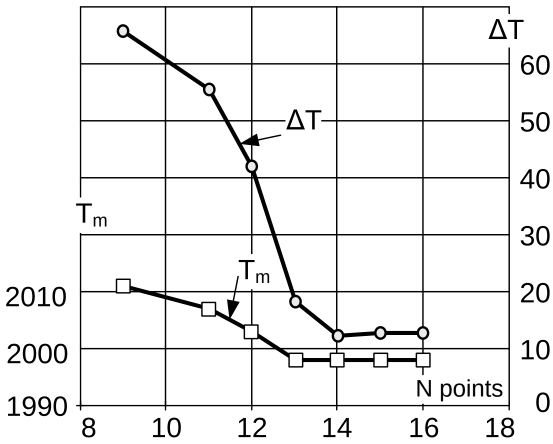

Figure 9. Dependence of the estimated values from the amount of data

So, to parameterize the “increasing” parameters it is required to collect data (verifying their validity), to identify a complex parameter, to determine its limit, to perform parameterization using different number of basic data, to define the validity area.

3.2 The systems with “decreasing” complex parameter.

The next step is to consider the systems with “decreasing” complex parameter. An example of such systems is a system of fabrication of microelectronic components. Their complex parameter is a feature size. The first components had the feature size of 10 microns, then this size became less and less. But there exist a physical limit for the feature size. Indeed electronic cheap is composed mainly of transistors. But to make a transistor work it must consist of several tens of atoms. Consequently the size of these atoms specifies the feature size. Figures 7A and 7B shows a feature size-year curve in line and logarithmic scales correspondingly.

But although the complex parameter decreases system ideality increases. Therefore in estimating ideality this parameter should be placed in denominator. Besides, a mechanism determining a value of ideality at the time of the system birth shall appear in a formula of ideality estimation. At the system birth its ideality low value. In the present case this low value will be considered as being equal to zero. Then the formula of ideality estimation for “decreasing parameter” will be given by:

$$\text{Ideal} = \ln(Ymax/Y) \qquad (5)$$

here Y is value of “decreasing” parameter.

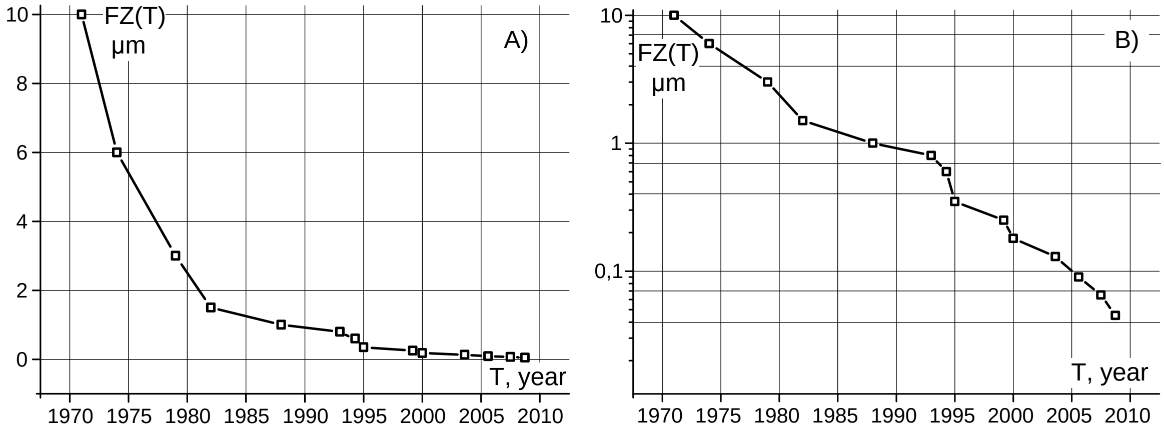

Figure 10. Feature size-time (year) curves: in a line scale (A), in a logarithmic scale (B)

In this case a diagram of system ideality presenting feature size will take the following form

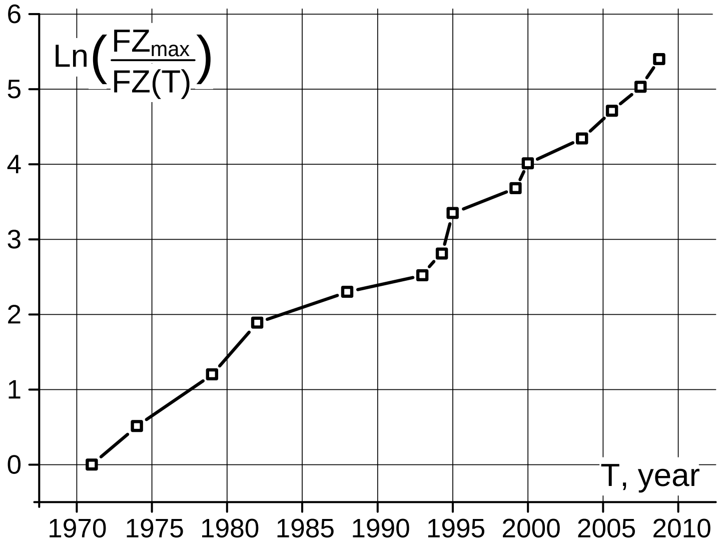

Figure 11. Time dependence of system ideality estimation presenting the feature size

Now it is necessary to perform parameterization of growth curves of "decreasing" parameter in case of different quantity of basic values. Diagrams at Figure 12 show that time parameters (T_m and ΔT) change a little (in the limit of 10%) but maximum limit (K) varies significantly especially if its changes are led to feature limit.

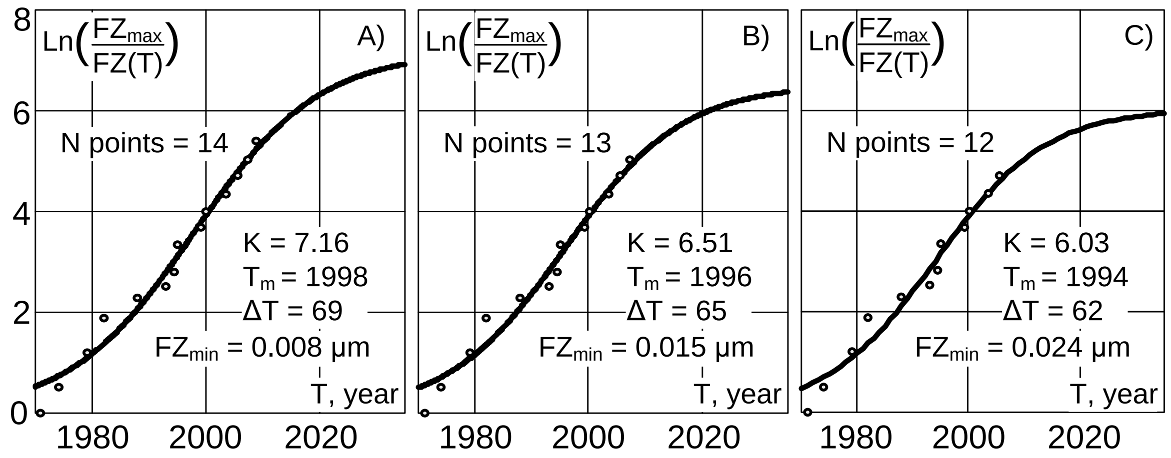

Figure 12. The results of parameterization of time dependence of "decreasing" parameter, in case of different quantity of basic data (values T_m, ΔT, K); A) – 14 dots, B) – 13 dots, C) – 12 dots.

Then as it was done before it is required to fix high value at a level of 0.006 µm (6 nm) (Braun, 2008) and to investigate dot dependence of time parameters. Maxima of logistic curve of the presented feature limit is equal to K=7.42.

The results of the research are shown in Figure 13.

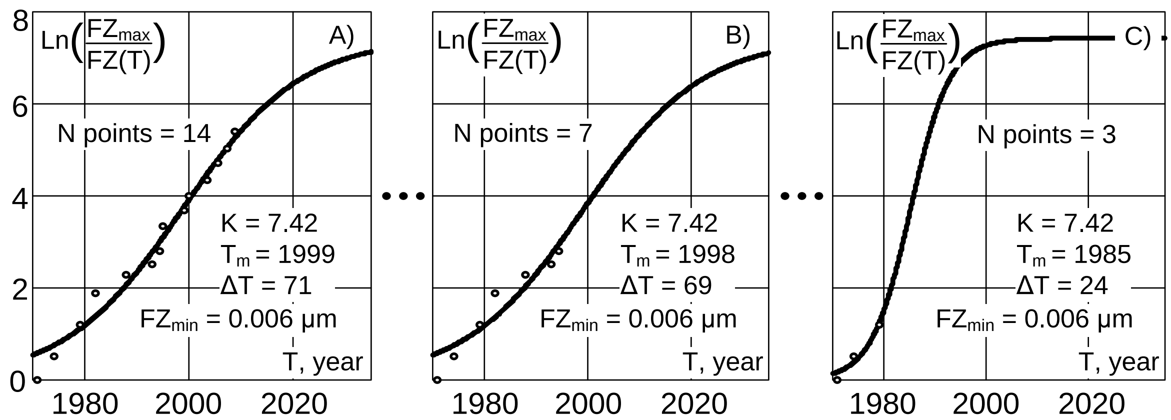

Figure 13. The results of parameterization (values T_m, ΔT) of time dependence of system ideality estimation providing the feature size in case of different quantity of basic data; A) – 14 dots, B) – 7 dots, C) – 3 dots.

Analyzing the results it can be concluded that while decreasing quantity of dots from 14 to 7 values T_m and ΔT changed a little and were located in tolerance range of practical use. Further decrease of dots quantity made T_m and ΔT changes significantly increased. Dot dependence of T_m and ΔT is pictured in Figure 14.

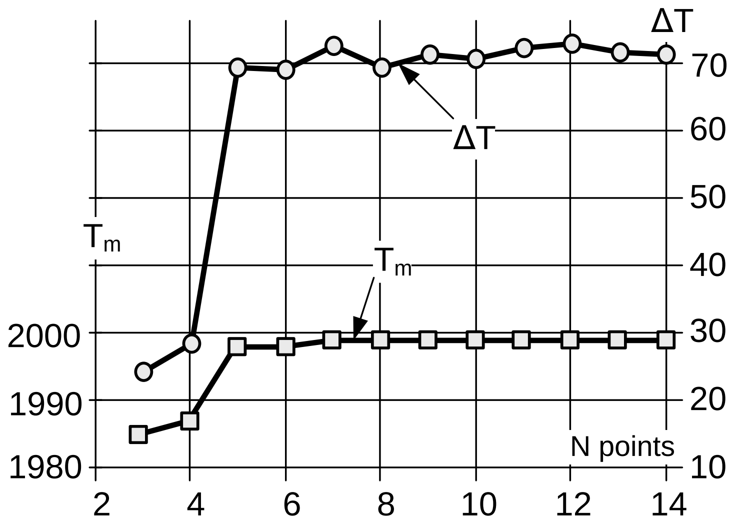

Figure 14. Data dependence of estimated parameters.

Based on this research it can be found out that it is possible to use the same algorithm of basic data integrity estimation for the systems with "increasing" parameter as it was used for the systems with "decreasing" parameters. That is to build certain functional connection of T_m и ΔT from the amount of the basic data; to consider the values researched as being valid enough if while decreasing the amount of data the deviation of the estimated values do not exceed a preset value (for example, 10%)

As it was mentioned in the Introduction the most interesting for investigation of "growth curves" is system transition from the second to the third stage. Following is a diagram where it is pictured a year when a system providing feature size moves to the third stage.

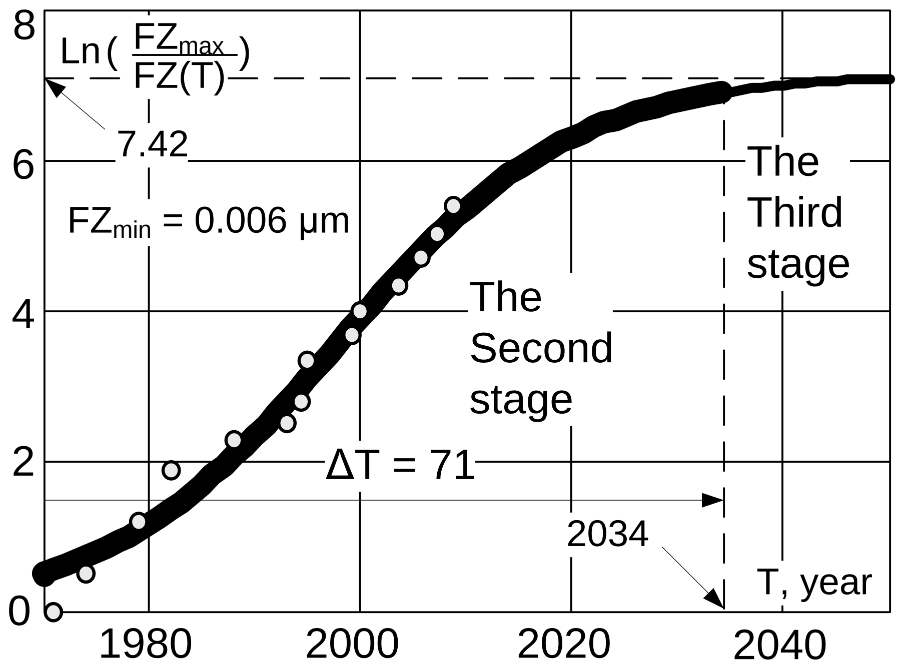

Figure 15. The forecast of transition time of system providing a feature size from the second to the third stage

3.3 Content of the technique.

In conclusion, we can suggest the following method of the estimation of the Growth-curves parameters of the researched system (consisted of 13 stages):

1) To determine an integrated parameter, that characterizes the system.

2) To gather as possible maximal amount of data available, that characterizes the chosen integrated parameter.

3) To estimate values of physical, technical, or social limitation of the growth of the integrated parameter of the chosen system (limiting value).

4) To check reliability of the basis data.

5) To check out falling data for "increasing" parameter and growing data for "decreasing" parameter from the basic information.

6) To draw a tentative curve of time dependence of the complex parameter (for "decreasing" parameter to draw a curve of the complex parameter being modified according to the formula 5),

7) Based on the tentative curve to estimate which of the mono- be- or poly-logistic functions should be used for approximation.

8) Based on the tentative curve to estimate starting values of the researched parameters: the middle or duration of the central block (to determine the “point of initial approximation”).

9) Using software approximation functions (like a “genfit”-function of MathCAD) to determine the values of the researched parameters.

10) Repeating stage 9) (in order to reduce the amount of data), to clarify basic data dependence of the estimated parameters.

11) To determine a field in the dependence (from stage 10) in which the estimated values do not differ more than the preset percent (for example 10%) – if there is such a field, of course.

12) To assume the values from stage 11 as being valid. If there is no such a field – to assume that there is no way to get valid data based on the current set of basic data.

13) To determine a transition line between the “maturity” (the second stage) and “senility” (the third stage) stages as a sum of the middle of the central block and a half of the width of the central block.

4. Conclusion

In the report:

It is defined the goal of parameterization of the “Growth-curves”, which is: to determine the limits of transition between “maturity” and “senility” stages.

It is researched possible variants of approximation of “Growth-curves” by applying mono- be- and poly logistic curves.

It is considered the approximation of systems with “increasing” complex parameter by the example of illumination devices (from electric lamps up to organic light- emitting diodes)

It is considered the approximation of systems with “decreasing” complex parameter by the example of systems providing a feature size of microelectronic components.

It is also offered a methodic of estimation of “growth-curves” parameters.

It is determined transition time from the second to the third stage for OLEDs and systems providing a feature size.

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Paper ID: 150

Extracting a Theoretical System Architecture based on Contradictions

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Abstract

The paradigm change that rules our industry (currently evolving under quality paradigm) requires for an enterprise to organize innovation in a pragmatic way. Beyond theoretical discourses around Innovation's necessity, methods and tools, grounded in theory should now be translated in engineering practices to be efficiently applied (William & all, 1999). One of the consequences of this necessary evolution is that R&D departments (and especially project teams) familiar with methods and tools inherited from quality era, are pushed toward changes in their practices sometimes far from their respective cultures. This article proposes an approach to integrate two design modes opposed in many points "optimization" and "invention", with a methodology to automatically extract an optimized system architecture starting from the set of polycontradictions of a given technical system.

Keywords: Inventive Design, Contradiction, System architecture, TRIZ.

1. Introduction

Regarding the design of new products and technical systems, our industry is in perpetual search for new methods and tools to serve as a frame for conducting R&D activities. In this quest, TRIZ focuses an increasing interest provoked mainly by the fact that its foundations fundamentally differ from classical methods inherited from quality era. Among these differences, the theoretical and practical groundings of TRIZ leads logically to the formulation of a set of contradictions and towards a way of thinking which invariably refuses to be satisfied with a compromise between parameters in balance in the contradictions (Altshuller, 1986). TRIZ industry practices are therefore rather oriented towards invention and are intended to identify inconsistencies in existing technical systems in order to exceed them by the use of new knowledge, often distant from the origin of the problem domain. Nevertheless, design activities aiming at overcoming contradictions and justifying the use of distant knowledge are still marginal in R&D practices. Reversely, other optimization approaches such as Value Engineering-oriented methods (Miles, 1972) or QFD (Cohen, 1995) still serve as the framework for driving design activity. They have been built to highlight the best possible compromise to meet the requirements of a set of specifications.

In the research activities carried out in cooperation with a set of industrial partners called "TRIZ Consortium", we observed that a duality in scenarios typologies proposed by synthesized solutions in a study was often targeted by enterprises. Indeed, even if innovation is claimed as a goal and innovations do not obviously pass through invention (Fagerberg & all, 2004), it is also necessary to provide decision-makers with a panel of developments directions based on inventive concepts ranging from simple optimization up to invention.

1.1 The paradox of the requirements on project teams

Paradoxically, this transitional period our industry lives remains focused on cost reduction but at the same time requires a breakthrough, synonym of potential innovations, in terms of R&D results (Leon-Rovira & all, 2004). Such results, as an output of project teams, are so different in nature that they impose to use alternately or in parallel, different design methods.

Although most of current design methods usually claim to be inventive ones, their notion of inventiveness only refers to a phase of ideas generation (also called Ideation) extracted in brainstorming sessions based on a set of problems having been more or less formally identified. TRIZ, for its part, strongly supports problem formulation by its contradiction formalism but does not provide a frame for the construction of optimization scenarios in its philosophy.

To face with this impossibility, we propose in this article to contribute to inventive design practices with a new approach for automatic extraction of optimization scenarios when conducting a study inventively oriented. This contribution will then be translated into a method leading to the enumeration of theoretical technical system architectures based on the use of polycontradictions structure.

2. Extracting a system architecture from a set of polycontradictions

2.1 General structure of inventive design study

The purpose of this article is not to detail each of the stages of an inventive design process. Nevertheless, to locate our contribution more accurately, we briefly remind in this paragraph, its following 4 main phases.

Phase 1: Initial Situation Analysis: this phase is to investigate all knowledge related to the study and transpose these knowledge (tacit and explicit) residing in text documents or in experts mind, in a graphical model mathematically exploitable to facilitate decision-making.

Phase 2: Problems Mapping: decisions from phase 1 having been studied for implementation, a reduced set of problems related to the study must then be detailed by a larger set of contradictions. These formulated contradictions represent bottlenecks standing on the way of the studied system's evolution. In this phase, we find sub-steps like polycontradictions formulation, contradictions extraction and classification of the importance of contradictions in accordance with a specific scenario.

Phase 3: Solutions Concepts Synthesis: each contradiction declared as a priority for the solving phase becomes an entry point on the use of techniques and tools built upon TRIZ. They must be resolved without compromises. At the end of these multiple process which may be successive or iterative, we can include the use of Altshuller's matrix associated with inventive principles, Substance-Field modeling associated with the system of Inventive Standards or even ARIZ-85C (Altshuller, 1999). Expectations regarding this phase are the generation of a limited number of solution concepts and keeping track of their origin for the follow-up of the study.

Phase 4: Feedback between Solution Concepts and Initial Situation: in this phase, we measure the impact of each solution concept with the problem graph elaborated in phase 1. This stage is built to assess the hypothetical impact of each Solution Concept within the general problematic and choose which ones will be subjected to further developments.

Our contribution debated in this article is located at the interface between Phase 2, including the step to use polycontradictions, and Phase 3 for solutions concepts synthesis.

2.2 Problem Formulation

The logical sequencing of an inventive design mode relies on a robust and comprehensive problematic formulation. TRIZ taught us that problems could be reduced to the formulation of contradictions. Starting from this postulate, we found that the complexity of multiple links between contradictions had poorly been treated in contributions on this subject, so as the exhaustivity of contradictions synthesis associated to a given observed technological perimeter. We have therefore implemented a methodological process to exceed these two limits of TRIZ not only in using the symbolic representation of contradictions but also in making possible the addition of several action parameters when a link with a specific side of their states was relevant.

2.3 The use of polycontradictions methodology

The notion of polycontradiction is partially derived from E-N-V concept presented in (Cavallucci & Khomenko, 2008). In our case, it essentially consists in adding all potentially influenced Evaluating Parameters to a given Action Parameter. At the end of the constitution of these polycontradictions, our process performs an automatic extraction of all potential "basic" contradictions (as represented figure 1) in order to select resolution priorities before entering in phase 3. It is at this point, in the process of contradiction clouds representation, that resides the tasks to identify which polycontradictions are candidate for being part of the optimization scenario.

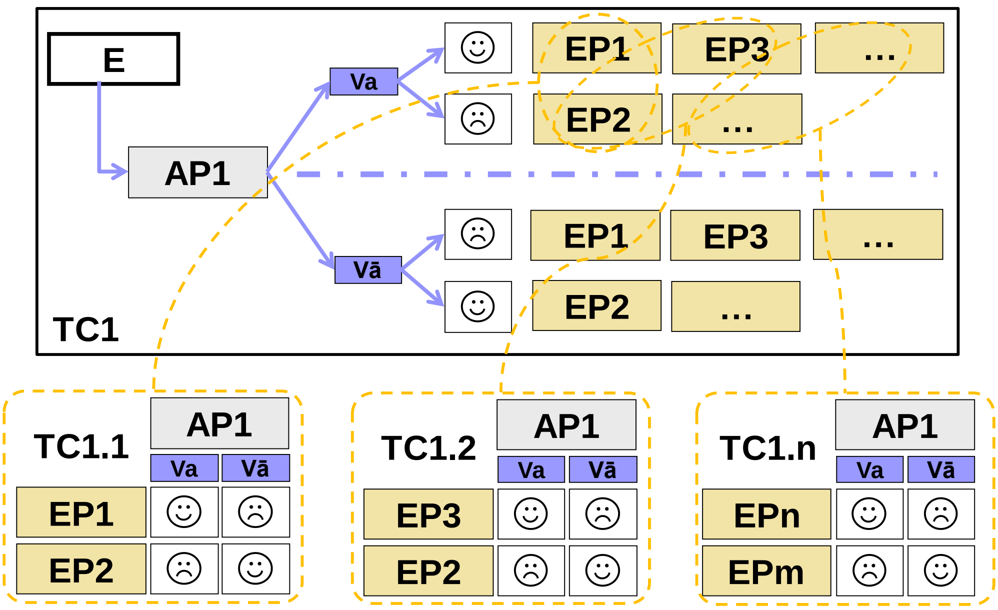

Figure 1: From polycontradictions to a set of “mono” contradictions

2.4 Notion of «balance» of a polycontradiction

In our past experiences when conducting inventive case studies, we noted that some polycontradictions were highly unbalanced regarding the quantity of evaluating parameters impacted either by Va or Vā (figure 2). This situation is symptomatic of a strong dominance of Va (in the chosen example) on Vā. This situation do not induces doubt regarding the relevance of basic contradictions synthesis out of its related polycontradiction but is also symptomatic of imbalance between AP's Va and AP's Vā respective impacts. We conclude that the concerned AP may not be at the heart of really contradictory issues so as other AP on which the addition of the impacted EP would be more balanced. In addition, when polycontradictions are numerous, this situation can be found on several occasions. TRIZ, which states that one should not accept a compromise between Va and Vā, suggests that contradictions should be considered as equivalent. We believe that this produces a loss of information revealed by this imbalance and the search for a solution that will satisfy Va and Vā, including on poor basis, will contribute to it.

To characterize the importance of an imbalanced situation and take into account the relative value of evaluation parameters to this extent, we have established a small graphical representation. The next paragraphs set out how calculate imbalances and represent them.

2.5 Self-extracting architectures and classification

At this stage in the formulation, we are able to apply a script to the relational structure of polycontradictions and classify the most evident imbalances. To complete this classification, the first calculated data is their weight according to the following formula:

$$(\sum Val\ |EPi| \ / \ (\sum Val\ |EPj|)$$

Where :

EPi = all EPs associated to a given polycontradiction;

EPj = all EPs associated to the polycontradiction having the higest score.

Thereafter, the state of Va or Vā is kept and we can perform a proposal for an ideally optimized hypothetical architecture as follows:

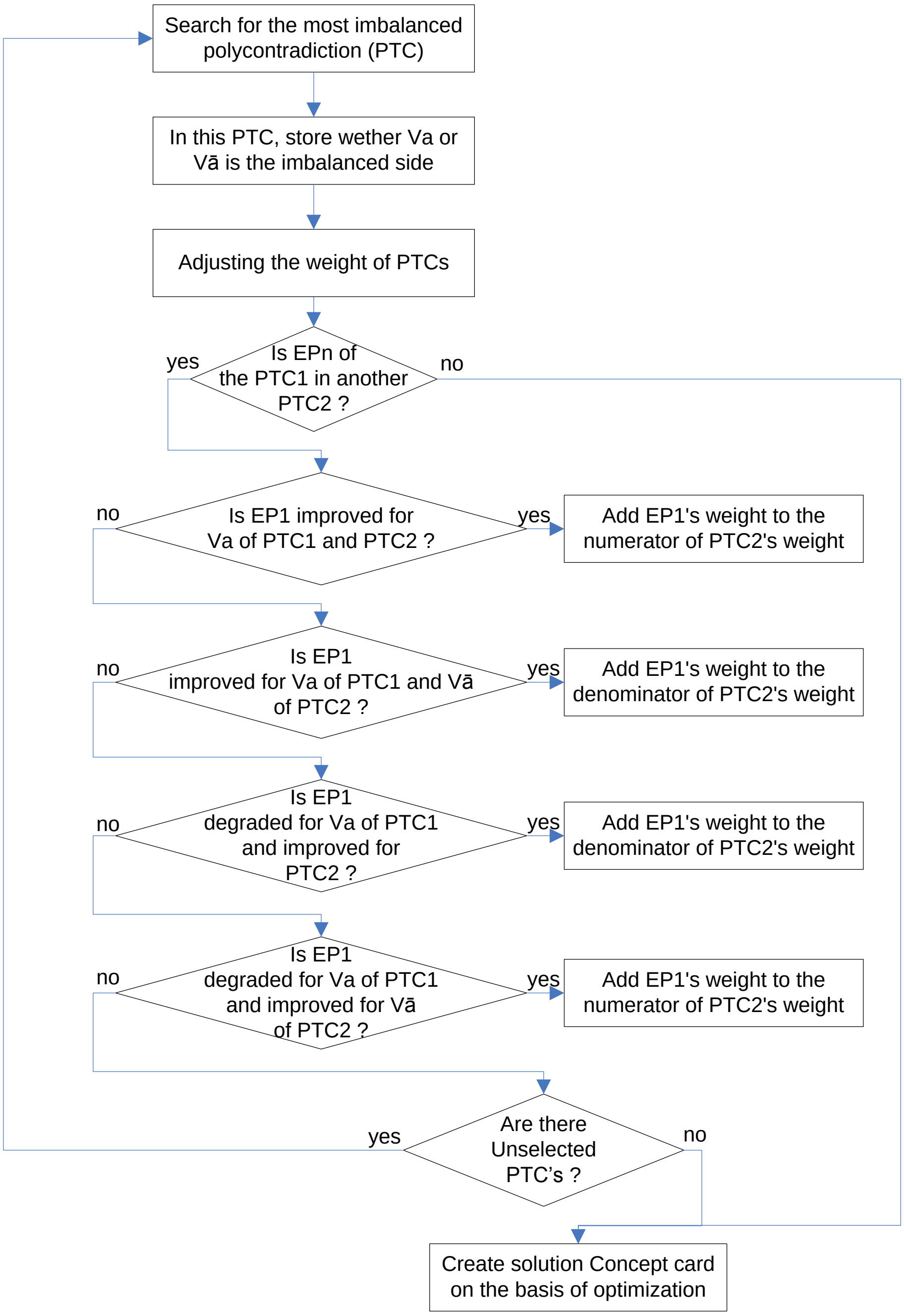

Figure 2: Algorithm for optimized architecture construction

2.6 Decision mechanisms

Finally, the rules outlined in the preceding paragraph are reproduced on each scenario and the most relevant optimized hypothetic architectures are exposed to the experts in the project. Thus these literally expressed architectures provide an image of what might be an ideally optimized system. The systems seemingly more realistic through the eyes of experts will be recorded as Solution Concepts and will appear in the tree that summarizes the results of the phase 3.

3. Software developments related to our approach

A software environment assisting the conduction of an inventive design project is, since three years, supported by a prototype namely “TRIZAcquisition”. Its development has been possible thanks to the cooperative work of large scale companies and INSA Strasbourg. This cooperative work evolves under the name “TRIZ consortium”. The main features of this prototype have already been the subject of publications (Zanni & all, 2009). The overall architecture of TRIZAcquisition is given figure 3.

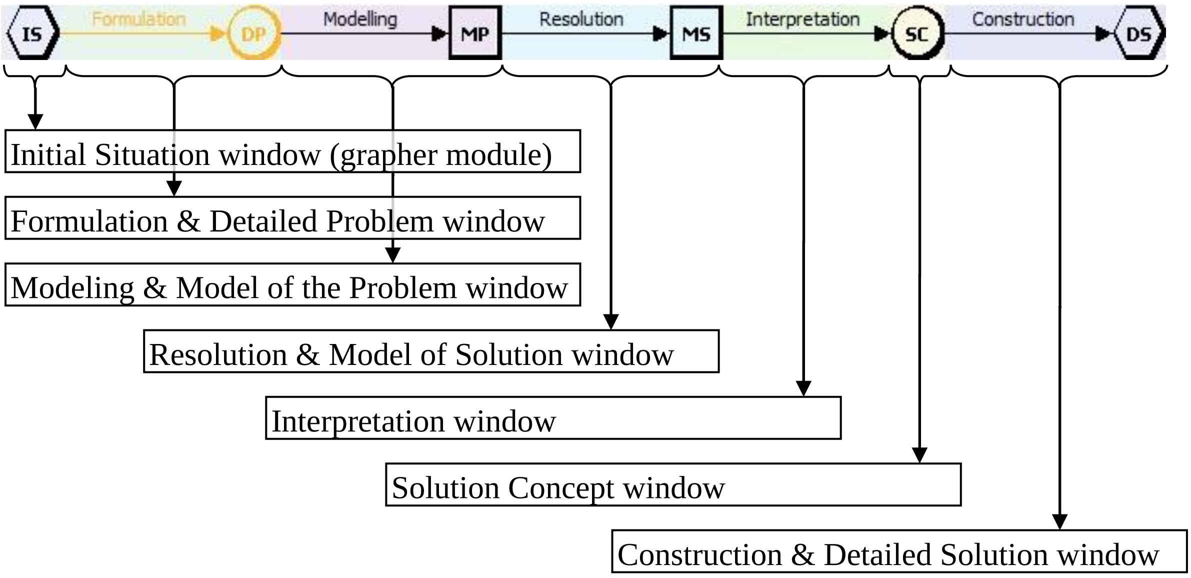

Figure 3: Overall architecture of TRIZAcquisition software prototype

The results of our work were introduced in TRIZAcquisition software prototype and added to the existing menus with a new set of features consistent with its implementation logic.

In the contradictions tab, the following items have been added:

- An "Optimized Solution" button: it automatically generates a "Solution Concept" card placed in the SC-tree linked to phase 3. This software menu is proposed to collect and structure concepts families as well as the traceability of their emergence.
- A visualization of the “weight” of the imbalance level: it displays a bar-like pictogram. This bar shows the total weight of each polycontradiction.

- A level of the importance of the imbalance: it displays a bar-like graph this bar shows the polycontradiction's balancing level: The relationship between positive and negative values for an AP. This balance shows how much Va or Vā dominates the imbalanced character of the polycontradiction.

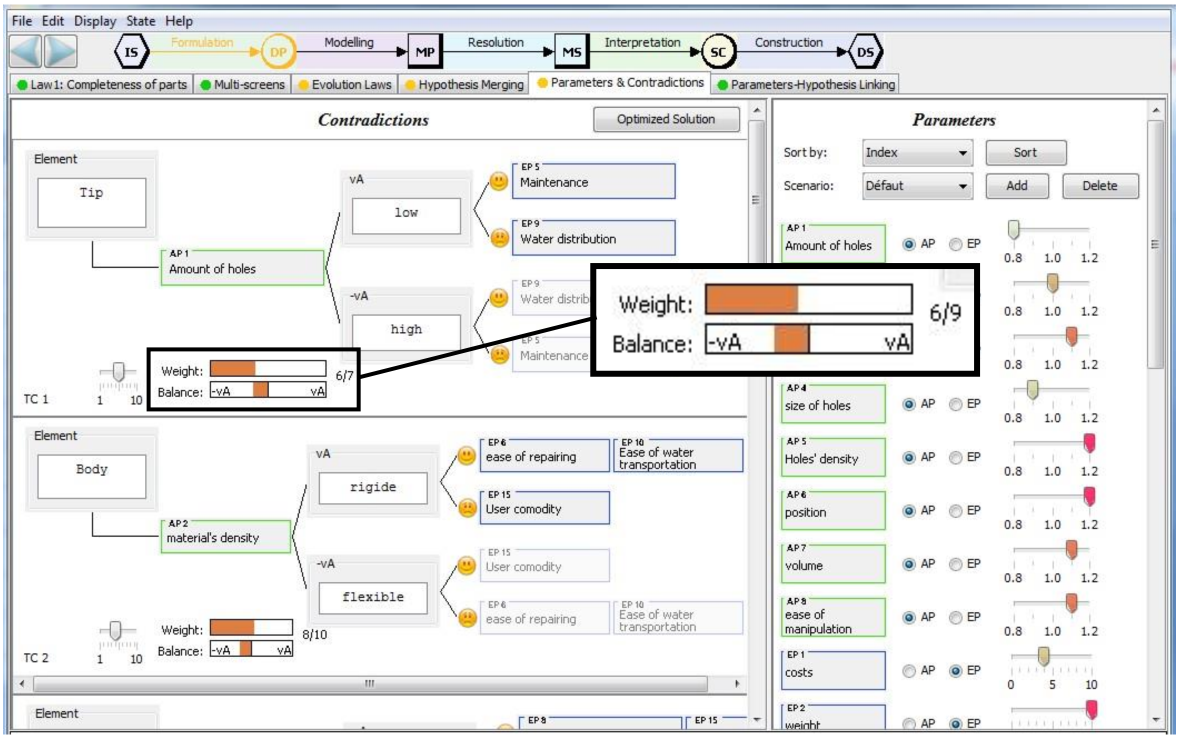

Figure 4: Screenshot of polycontradiction building module

In the "solution concept" cards automatically generated, a paragraph summarizes, depending on the chosen scenario, the architecture ordered by relevance of the AP associated to their preferential states.

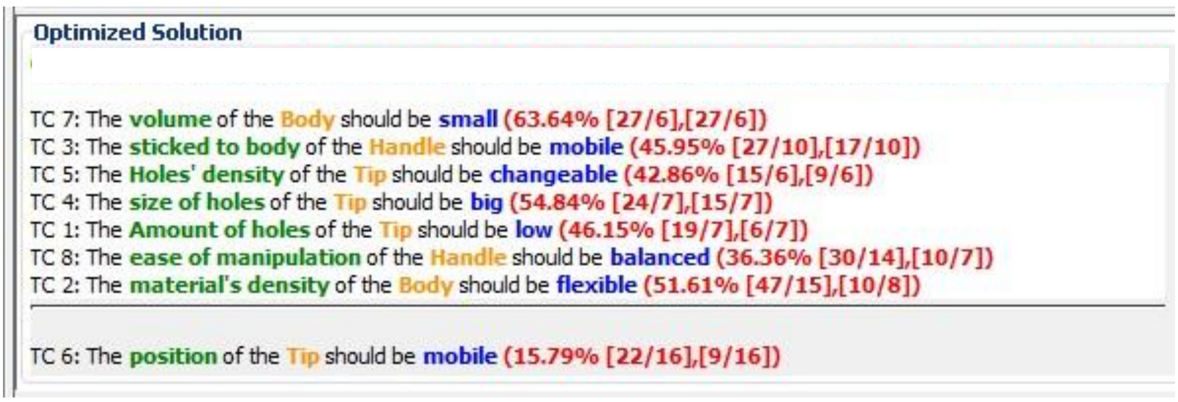

Figure 5: Automatically extracted architecture description

The phases recall also Elements that are linked to APs and form a set of phrases (see figure 5) followed by the scores recorded in the two bar-like graphs of the previous screen. It should be noted that a separation between highly imbalanced polycontradictions and others is displayed.

4. Discussions

The case studies on which we tested our approach are confidential but the methodological results can be discussed, especially how they have been perceived by project leaders in charge of the study teams. They confirmed that architectures, automatically highlighted by the software, provide a solution that was already partially in the mind of engineers without an optimized structure with enough clarity to be drawn. The ultimate choices have been induced by this module and subsequently underwent a finer definition and a sufficient physical characterization to achieve a prototype.

Furthermore, the inventive study has synthesized other concepts and breakthrough solutions have emerged. These solutions are currently under calculation processes to be confirmed and eventually pushed further. In light of this experience, we can now postulate that a study having initially an inventive vocation can coexist with an optimization-oriented study and enter into the logic of R&D activities in industry. But even if this type of multi-direction study provides results with differences in their level of maturity, the task of deciding which direction to follow remains to company's decision-makers.

As a consequence to our approach, it is now possible to draw and prototype solutions resulting from an optimization process and validate by calculating solutions whose technical feasibility present no doubt in the minds of project team members. While breakthrough concepts of this same study may be patented after having clarified certain scientific aspects before to be pushed further in dimensioning and prototyping if appropriate regarding company's strategy.

A clear limit for our approach is that it has been conducted by a process having inventive aims, whose foundations have not yet well penetrated industry. The recent arrival of invention theories such as TRIZ and its associated techniques and tools have, until now, only been taught in universities through introductory module and as a result engineering syllabuses are not massively providing the required skills for a wider TRIZ practice in industry. The result is that only 0.02 % of engineers have at least once used TRIZ while 13 % are able to use functional analysis techniques in projects (Cavallucci, 2009).

A few attempts based on a reverse reasoning have emerged (Durand & all, 2007), they consist in using value engineering as a frame but these approaches do not guarantee the production of inventive results in the same way as a study carried out extensively using TRIZ. Generally, these approaches offers to replace creative phases (also called ideation) by the use of TRIZ techniques (most of the time the inventive Matrix associated to inventive principles) and are neglecting other techniques or foundations such as the laws of evolution, inventive standards, or ARIZ.

5. Conclusions

Through this article, we have analyzed and reported that design approaches in R&D services were different when projects were oriented toward optimization (sometimes called cost reduction) or when the aim of the enterprise was to provoke significant breakthrough, thus potentially future innovations. We later proposed a methodology that integrates these two approaches fundamentally differing in a common methodological frame not imposing to separate projects. We postulate that the effects of our proposals reside in reducing time dedicated for R&D without sacrificing either one or the other approaches' benefits. Nevertheless, our proposal limit is that the company must agree to engage in a jointed effort (pursue as much optimization as invention) so that the combining aspect we propose makes sense. Conducting change in companies also remains a limit in our proposal. Assuming that it took almost three decades to train a large part of project engineers to routine design approaches, the arrival of another design mode should take a considerable time to penetrate the daily lives of designers and impact on R&D activities. As it is searched now to systematically innovate (Sheu & all, 2009), new ways of designing must be disclosed. To treat this educational and practical problem associated with the dissemination of new ways of designing, the deliverable of one of our research project presented in this article consists in building a software tools aiming at significantly facilitate the implementation of such approaches in a near future.

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Paper ID: 161

Improvement on Molten Zinc Corrosion Tester by TRIZ Methodology

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Abstract

There are many rolls used in a steel mill. Some need special surface treatment. For example, sink roll in a zinc pot of a continuous galvanizing line (CGL) is usually thermal sprayed with a special coating. In order to study the mechanism of molten zinc corrosion on specific materials, a molten zinc corrosion tester was developed to simulate the working condition in a zinc pot. However, the tester may cause severe oxidation of zinc which becomes dross floating on the surface. Once the dross was accumulated to a certain level, the molten zinc became viscous and affected the movement of the samples in the tester. This study applied TRIZ methodology to improve the design of the tester so as to solve the oxidation problem. After several attempts, the oxidation of molten zinc was a lot improved and the tests can be performed successfully and efficiency.

Keywords: molten zinc corrosion test, sink roll, thermal spray, TRIZ

1. Introduction

In a CGL, the galvanized steel sheets are coated with a layer of zinc in the molten zinc pot. Sink rolls are used in the zinc pot to transport the steel sheets. However, molten zinc corrosion would occur on the roll surface and affect the quality of the galvanized steel sheets. In other words, molten zinc has special capability of corrosion on the metal material (Dong et al. 2006; Noda et al. 2008; Wang et al. 2007; Wang et al. 2007). In order to develop a highly resisting coating against molten zinc corrosion so as to extend the service life of the rolls and to maintain the quality of the galvanized steel sheets (Huang 2008;

Mizuno et al. 2006; Sidhu 2006), a molten zinc corrosion tester was set up to simulate the working condition in a zinc pot. This tester was developed for long testing, such as two weeks or six weeks. Figure 1 is a schematic plot of the tester (Mizuno et al. 2005). The samples in the zinc pot rotate continuously to simulate the movement of a sink roll in a CGL.

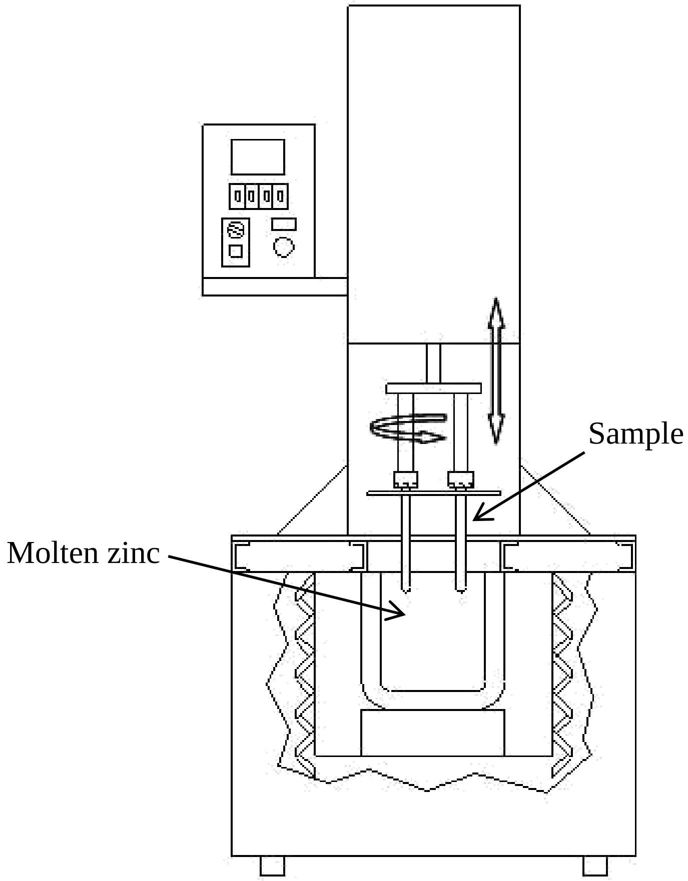
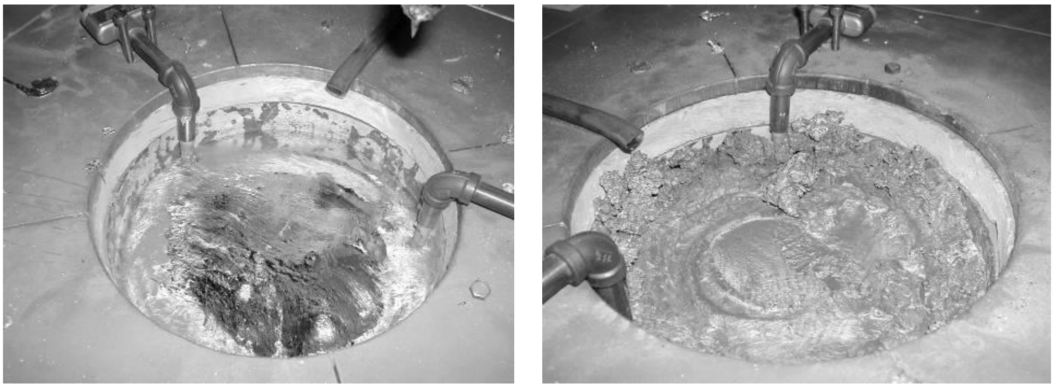


Figure 1. A schematic plot of the molten zinc corrosion tester.

The melting temperature of zinc is 420°C and the operating temperature is 460°C in the tests (Dong et al. 2006; Huang 2008). Usually, molten zinc is easily oxidized on the surface. Once a layer of zinc oxide is formed, it can separate the fresh zinc from the air and prevent further oxidation. However, when the samples are rotating, they agitate the molten zinc and break the oxide layer. As a result, more fresh zinc will be exposed to the air which causes more oxidation. The melting temperature of zinc oxide is 1975°C which is a lot higher than the operating temperature. The more zinc oxide forms, the more viscous the molten zinc becomes. Zinc oxide will become thicker and thicker and eventually affects the rotation of the samples. Figure 2 shows the fresh zinc and zinc oxide formed on the surface.



(a) **(b)**

Figure 2. Molten zinc surface. (a) Fresh zinc. (b) Zinc oxide.

Due to the oxidation problem, frequent cleaning zinc oxide and refilling zinc material is needed. In less than 40 hours, zinc oxide will reach to a critical thickness which hinders the sample rotation. Once the tester detects the unusual movement of the samples, samples will be lifted up by a protective device and the test will be intermitted. In other words, daily cleaning and refilling is required. However, too many interruptions will affect the experiments. If the oxidation can be minimized which prolongs the time to reach the critical thickness of the zinc oxide layer, the experiments can be better organized and performed. For example, if the samples are expected to be examined every seven days, it is better that the zinc oxide layer grows to the critical thickness longer than 7 days. As a result, cleaning and refilling can be performed when the samples are examined.

TRIZ is a well-structured and unique systematic problem solving methodology (Li and Huang 2009; Lin and Su 2007; Robles et al. 2008; Shirwaiker and Okudan 2008; Srinivasan et al. 2006). It includes different problem solving tools, such as Contradiction Matrix, Inventive Principles, IFR (Ideal Final Result), S-Field (Substance-Field) analysis, Inventive Standards and 76 standard resolutions (Mann 2007). In this study, TRIZ was used to look at the oxidation problem of the molten zinc corrosion tester. The goal is to minimize the oxidation so as to decrease the frequency of interruptions and to improve the test efficiency and accuracy. Inventive Principles and S-Field analysis were used in this study as well as the concept of Function Attribute Analysis. Inventive principles of #24 Intermediary, #29 Pneumatics and hydraulics and #39 Inert environment were sorted out. Referring to the cases of the three principles and applying them onto the molten zinc corrosion tester, improvement is observed, although not 100%. According to the three principles, a better solution to improve the oxidation problem of the molten zinc corrosion tester was reached. Not only the experiments can be performed more accuracy, but the waste of zinc material can also be minimized.

The remainder of this article is divided into three sections. One describes several tools in the TRIZ methodology. Another describes related works in this study. The other is a conclusion including results of this study, contributions and future work.

2. Methodology

2.1 Basic Overview of TRIZ

TRIZ was developed by Genrich Altshuller, a former Soviet inventor. By reviewing over 200,000 patents, Altshuller ended up with a concept of ideality of a system and numerous other theoretical and practical approaches. TRIZ offers a systematic creativity process built primarily on the concept of abstraction (Mann 2007). From a specific problem to a generic framework, out of which comes a generic solution requiring translation back to the specific. As detailed in the previous chapter, the process is illustrated in Figure 3.

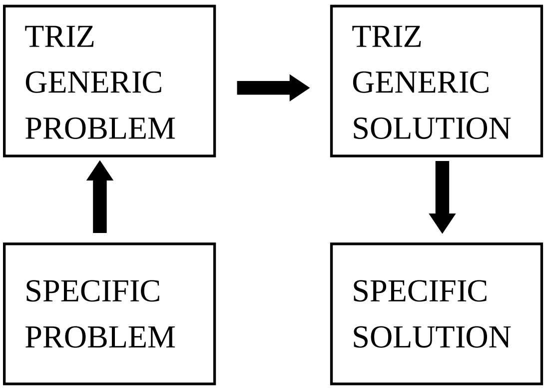


Figure 3. The general model for TRIZ problem solving.

In 1946, at the age of 20, Altshuller worked as a patent inspector in the “Inventions Inspection” department of the Caspian Sea flotilla of the Soviet Navy. Through his job, he had noticed that every innovation of a technical system came with a certain pattern and process. He also found that a creative patent basically is to solve a creative problem. The creative problem here contains the conflict-base problem and is called Contradiction by Altshuller. Furthermore, he noticed that in order to solve the conflict problems, some basic solutions were used repeatedly. In other words, same principle can be applied on different problems.

2.2 Contradiction Matrix

Altshuller has concluded 39 Engineering Parameters and 40 Inventive Principles. They were combined to derive the Contradiction Matrix. Inventors who have knowledge on problem solving in the early stage will find it easier on their inventive works. Altshuller pointed out that inventors usually have problems on Technical Contradiction and Physical Contradiction when working on engineering projects. Technical Contradiction means that one parameter is changed when the other is changed at the same time in a system. For example, power vs. fuel consuming and weight vs. strength in a car system. Technical Contradiction related problems can be solved through Contradiction Matrix and corresponding Inventive Principles. Without the concept of TRIZ, compromises and tradeoffs are usually used (Lin and Su 2007). However, compromise cannot derive invention always. Physical Contradiction relates to physical properties of an element, such as cold vs. hot, long vs. short, and big vs. small. Altshuller proposed the Separation Principles, such as time separation, space separation and system separation, to solve the Physical Contradiction related problems. For example, a folding bike is applied to time separation principle. It is a real bike when using while it is folded when carrying it in mass transportation.

2.3 S-Field

S-Field (Substance-Field) Analysis is part of the TRIZ toolkit. It separates a system into 2 substances and 1 field, shown in Figure 4. Substance 1 and substance 2 represent the system tool and system article respectively. They can be any kind of complicated objects or systems. The field is the power or force of the system. S-Field Analysis provides a fast and easy model to list any possible solutions.

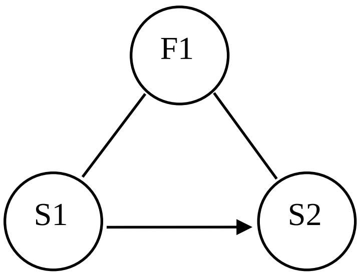


Figure 4. Basic S-Field Model.

There are 5 categories on substance types, including material, tool, device, people and environment. Types of field can also be grouped into 5 categories, including mechanical force, heat, chemical force, electricity and magnetic force (Mann 2007). Figure 4 is a very basic S-Field Model. Two substances and one force form a triangle.

The connections can be in different types to make the system more completed. Figure 5 illustrates types of interaction. The solid line represents an effective reaction. The dash line means an insufficient reaction. The curved line means a harmful reaction. An arrow represents an answer. If an S-Field triangle Model contains a dash line or a curved line, it means that this system needs to be improved.

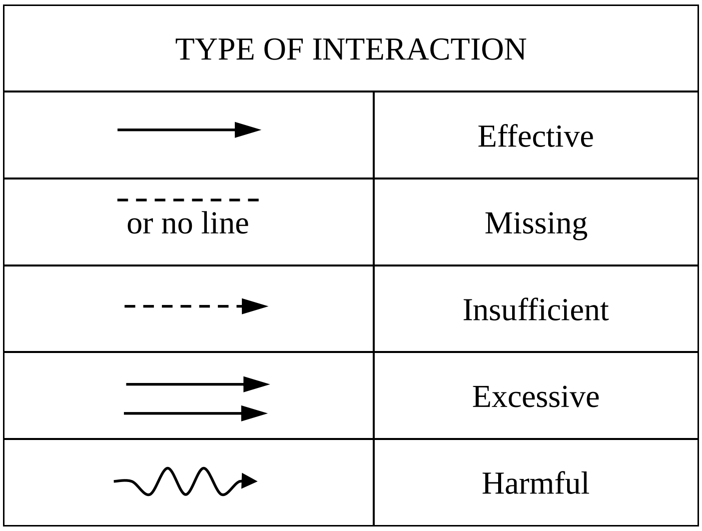


Figure 5. Type of S-Field Model Connecting Line.

A systematic creativity process may consist of four major steps (Mann 2007). As shown in Figure 6, definition is the first step. The second step is to select the most appropriate tools. The third step is to try to generate solutions. The last step is to evaluate and down-select. These steps can be a looping process which repeats until a solution is obtained (Lin and Su 2007; Mann 2007; Srinivasan and Kraslawski 2006; Robles et al. 2008).

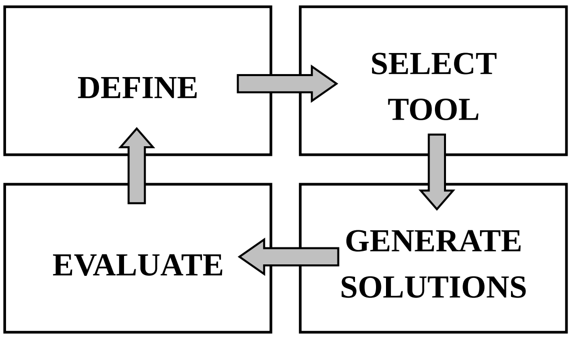


Figure 6. Four major “Systematic Creativity” steps.

3. Experiment and Results

Different from static test, the molten zinc corrosion test is to dynamically simulate the environment in a zinc pot of a CGL (Huang 2008; Wang et al. 2007). When samples are immersed statically in molten zinc, the local concentration near the samples will be different from the bulk due to inter diffusion between molten zinc and samples. This non-uniform concentration is far different from the real environment and will affect the testing results. Dynamic test with a relative movement between molten zinc and samples can better uniform the concentration so as to simulate the operation of sink rolls in a zinc pot (Mizuno et al. 2005).

Usually molten zinc is active and will be oxidized easily on the surface. The specific gravities of zinc and zinc oxide are 7.17 and 5.61 respectively. The melting point of zinc oxide is 1975°C, which is far above the melting point of zinc at 420℃. Therefore, zinc oxide will float on the surface of the molten zinc. Once a layer of zinc oxide is formed on the surface, it will help to protect the fresh zinc beneath from further oxidation. However, if the layer of zinc oxide is agitated, more fresh zinc will be exposed to the air and results in forming more zinc oxides. Zinc oxide is in solid phase at 460°C, which is the operation temperature. When solid zinc oxide is accumulated to a certain level, it will hinder the movement of the samples and affect the testing results.

3.1 Define

The occurrence of zinc oxide is because that fresh zinc reacts with oxygen. In the case of this study, if the layer of zinc oxide on the surface does not break, fresh zinc will not be exposed to the air. On the other hand, if oxygen is prevented from getting into the testing environment, zinc oxide will not formed either. Therefore, two factors were defined. One is zinc oxide layer breaking. The other is oxygen intrusion. If one of the factors can be eliminated from the testing system, the problem can be solved.

3.2 Select Tool

In this study, no any Inventive Principle can be obtained from the Contradiction Matrix because no appropriate parameter was found to fit 39 Engineering Parameters. Therefore, S-field analysis was used to acquire useful ideas and directions.

In order to solve the oxidation problem, the S-Field Model was applied to analyze the system. Sample S1 is driven by mechanical force F1 to agitate molten zinc S2. However, this will cause unexpected oxidation from S1 to S2 and will lead to a harmful effect.

According to TRIZ, when system appears harmful effect, there are seven directions to solve the problem. They are (a) modify exist substance, (b) modify the Field, (c) add a new substance (d) add a new field, (e) add a new substance and field, (f) transition to the super-system, and (g) transition to the sub-system (Mann 2007). “Add a new substance” was used in this study. In other words, if an object S3 is inserted between S1 and S2, the harmful element may be removed from the system, as shown in Figure 7.

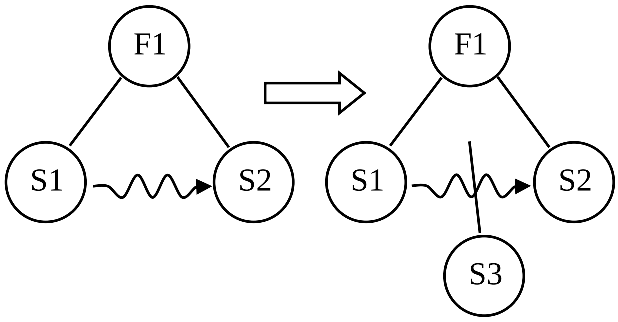
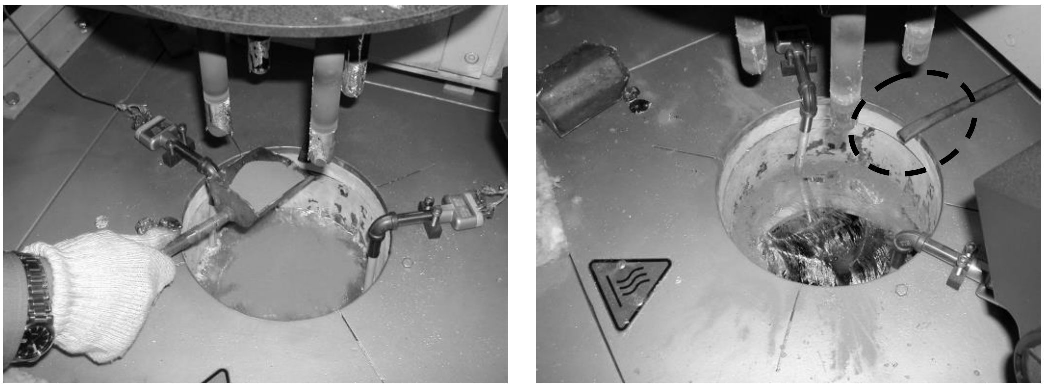


Figure 7. Suggestion of solving harmful effects.

3.3 Generate Solutions

Zinc oxide is originally a protecting object on the molten zinc surface. However, the problem here is that agitation by the samples will break the static oxide layer and lead to more fresh molten zinc to be exposed to the air. A static protecting layer between the molten zinc and the air is needed to prevent further oxidation. It was found that #24 Intermediary and #39 Inert Environment in the 40 Inventive Principles are possible solutions to this problem. By referring to similar cases, a layer of zinc oxide powders was sprayed on the molten zinc surface and nitrogen gas was injected, as shown in Figure 8. Although a protective layer was introduced to the system, the problem remains. It is because that the protective layer is still not static. It will be broken by the agitation of the samples. The protecting ability of nitrogen injection is also limited because it is not a closed system.



(a) **(b)**

Figure 8. (a) Spray zinc oxide powders. (b) Inject nitrogen to the system.

Since zinc oxide breaking is not avoidable, a non oxygen or reduced oxygen environment will be required to solve the problem. To vacuum the whole tester is not easy. However, to make the crucible a closed space is possible. An object was added to cover the gap between the rotating device and the crucible. By injecting nitrogen to keep the space a positive pressure, oxygen will be blocked from getting into the system effectively. The objective function, reduce zinc oxide, can be achieved.

3.4 Evaluate

A steel ring shown in Figure 9(a) was added to the system. It is to cover the gap between the rotating device and the crucible when samples were descended for testing. It can be seen from Figure 9(b) that a closed space on the crucible can be reached.

(a) **(b)**

Figure 9. Equipment improvement. (a) A steel ring. (b) A closed space formed when samples was descended.

After the steel ring was installed, oxidation of zinc is a lot improved. Tests can be performed for 3 days or more without any interruption. Except the improvement on the test, it also saves a lot of zinc materials. It used to form 2.6 Kg of zinc oxide every day, but now is 2.52 Kg every three days. A total zinc of 12.32 Kg is saved every week. This is a one year project; molten zinc corrosion test will be performed for more than 40 weeks. An estimated zinc waste with and without steel ring is shown in Figure 10. In other words, waste of zinc will be reduced to one third after improvement. It is proven that tests are more efficiently and effectively after improving by TRIZ Methodology.

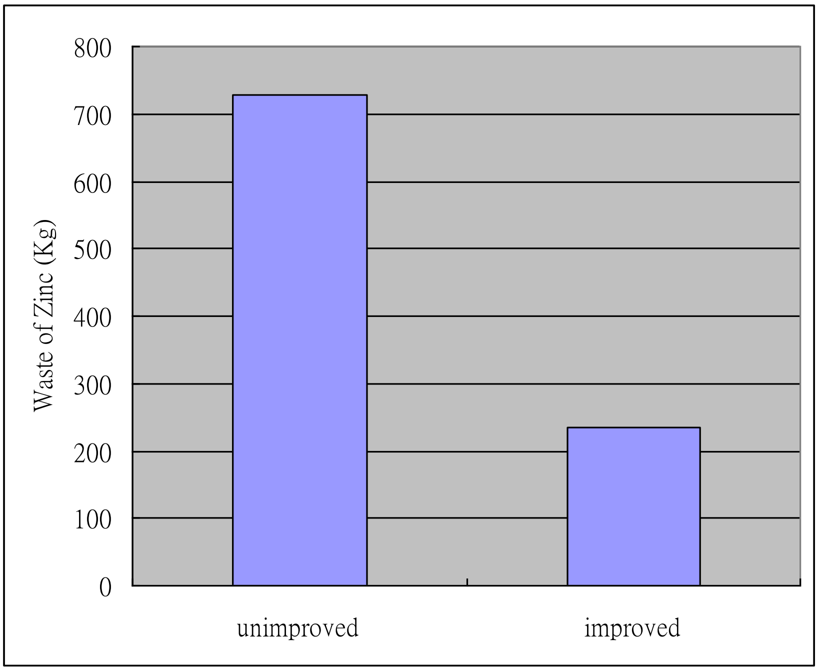


Figure 10. An estimated zinc waste for 40 weeks with and without the steel ring.

4. Conclusion

By correctly defining the problem, the solution to solve the problem can be quickly found. Define, select tool, generate solutions, and evaluate are four major steps related to the systematic creativity and are formed a loop. When a problem is defined differently, different solution and effect could be obtained. Therefore, it is suggested to go through the steps for more than once in order to obtain a better solution.

TRIZ is equipped with various methods. According to each specific problem, an adequate solving tool can be found. Different solution packages make TRIZ a systematic and complete methodology, leading toward the correct direction step by step. In this study, the problem was defined through the S-Field Model, referring to cases of the 40 Inventive

Principles. Through the systematic analysis, it was re-applied to the S-Field Model. A new and complete S-Field model was developed and leads to the ideal final solution.

40 Inventive Principles are derived originally from 200,000 patents, including solving techniques and methods in every field. If a problem is not complicated, a similar solution can be found quickly by TRIZ. General speaking, the more complicated the problem is, the longer time it is needed. It is more efficient through the systematic analysis thinking than try and error. By TRIZ, the oxidation problem of the molten zinc corrosion tester is solved.

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Paper ID: 169

A study of the creativity training with systems thinking approach

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Abstract

With the rapid movement of technology and information, pluralism and diversification are the future points of the industrial development. When people face up to those changes of industry and information, humans' creativity has gained attention. Creativity theory actually applies into a variety of different industries and areas, and how to integrate the systems thinking together to meet the challenge should be taken as an important issue.

Using an example from Taiwan's current policy such as "Intelligent Taiwan", this paper proposes, in order to create future intelligent systems with sustainable humanism, aesthetics, and evolving nature in mind, to introduce the "Human、Nature、Aesthetics" – bud of a blooming multi-value infrastructure as a third dimension to interact with all systems levels and systems life cycle time, presented as a further extend 5-layer model. Equipped with systems engineering thinking education and creativity training, one might be able to define new concepts, to generate new principles, and to develop new systems, and also to build new environment to meet sustainable humanism with evolving nature.

Keyword ： Creativity training、Systems thinking、 Intelligent Taiwan

Ⅰ、 Introduction

With the development of high-tech industry, the business evolves into a fast-changing global competition. To face the great challenge of the new knowledge based economics, innovation and application, they are all indispensable to this difficult environment. We can see that the industry, business and school education are all advocate to creativity training. No matter the individuals or groups, the creativity is the target from all the subjects of active research. We could tell the future needs from Taiwan's current policy "Intelligent Taiwan". These multi-talented people, who will response our country, become more integrated, towards the development of technology science and the protection of environmental conservation.

To confront today's complex systems and social environment, it is important to know how to use the principle of systems thinking, to know the applications of "Systems Engineering and Management", from the point of view like "open or soft system", to simulate the nature while putting forward original and creative concepts. Effective using all of the technical resources would bring up the feasible scheme to make our society more harmonious.

Ⅱ、 The application of creativity

Creativity is the knowledge foundation of innovation; innovation is the concrete practice of creativity. The initiation of creation depends on the exertion of intelligent creativity; the effectiveness of creation relies on the exhibited results of innovation. (Taiwan Ministry of Education, 2002)

In recent years, the opinions of creativity study are tending to generalized theory, which shows creativity is not only single capability but multiple capabilities. Creativity sometimes behaves irrationally, but sometimes rationally. The basics of creativity capabilities need intelligence, but also perceptual, cognitive, association, competent and symbols for the other things into conceptualization. Conclusion for all of this, we could confirm that creativity is a unique ability which also is a comprehensive ability.（L.A. Chan, 2002）。

Therefore, the meaning of creativity should be dependent on the field where the creativity been applied, because different areas and background factors would construct different creativities. The only similar ways are its unique and non-traditional problem-solving capabilities.

Rhodes (1961) analyzed the definition of creativity, he defined 4-P's model that involved: person, process, product and place (press).Since this, the creativity researches focus from the individual towards the construction overall and a link with the whole development.

· Sternberg (1984) suggested that the development in intelligence consists of increases in the efficiency of quite discrete mental operations which he calls “components”. A component is an elementary information process that operates on internal representations of objects or symbols (Sternberg, 1984).The research has entailed breaking subjects' responses down, impressionistically, into various steps and comparing individuals' performance on them. The steps or components have included as encoding, inference, mapping, applying, evaluation and response.

· Creativity is the production of novel and appropriate ideas in any realm of human activity (Amabile, 1997). Creativity is the first step in innovation, which is the successful implementation of those novel and appropriate ideas.

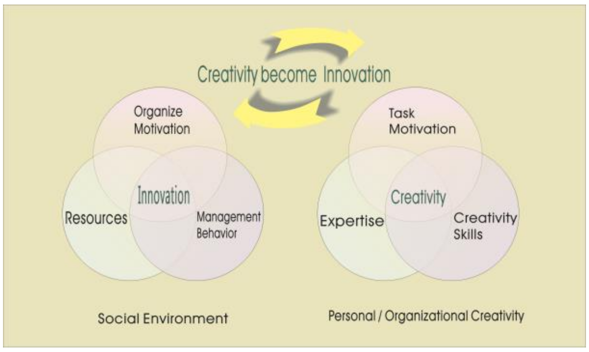

Fig1. Component Model of Innovation and Creativity (adapted to Amabile, 1997)

Fig1 explains Amabile's (1996) social psychology theory. It provides creativity as "the quality of products” or responses judged to be creative by appropriate observers. Amabile (1996) divided creativity into three components essential for the production of creative responses and works. Creativity-relevant skills and domain-relevant skills are cognitive skills. Domain relevant skills apply to the specific content or domain area in which creative performance is being pursued, while creativity-relevant skills are more generally applied to a variety of domains (Amabile, 1996).

Ⅲ、 Creativity relevant to systems thinking

Evidence is presented through some basic training; some aspects of creative behavior can be enhanced. We know that the thoughts are purported to be the seat of the perceptual, intuitive, synthetic, visual, and irrational activities. So it follows five important training targets: sensitivity, fluency, flexibility, originality and elaboration. “Innovation” and “creation" are involved in value judgments, but “creativity” is involved in capability, motivation and behavior.

Each person has different trajectory of development in the creativity, and so do the various fields. Every stage of education is also for the next generation of education, which can provide the well foundation for the human future.

The table 1 shows that the creativity behaviors and systems thinking are close related to each other. Sometimes, the behaviors of creativity are piecewise and not continuous, but not exhibited in the systems thinking.

In systems thinking, we usually process thoughts more complete and consider in a top down and highly comprehensive way. The next step would be to connect the creativity training with the addition of systems thinking approach. We must be aware that the higher the level, the more need of a broader systems engineering point of view. We recommend combining the creativity with systems thinking skill. It allows us to have overall thinking from top to bottom, and from past experience to future to enhance creativity and the progress in modern technology.

Table 1: Correlation of cognitive ability in the behaviors with systems thinking terms

Cognitive	Behaviour	Systems thinking
Sensitivity	It is an ability to find problems and to be aware of need for change or for new devices or methods.	To make a description of issues.
Fluency	It is an ability to give multiple answers to the same given information in a limited time or the quantity of meaningful solutions.	Build up the necessary requirements and core systems capacities.
Flexibility	It is an ability to change instructions, be free from inertia of thought, and be spontaneous in switching between concepts.	Building the multi-core systems architectures and operating process with effectiveness.
Originality	It is an ability to consider distinctiveness.	The balance of performances, and net contributions.
Elaboration	It is an ability to consider how well the participants explain the usage of their object and the depth of detail.	The evaluation of potential preferred solutions of the whole systems.

◦ Sensitivity- Sensitivity is an ability to find problems (Urban, 1995) and to be aware of need for change or for new devices or methods (Guilford and Hoepfner, 1971). It also is an ability to identify critical issues and observe the extents which affect the users or environments. In fact, this is the most important step to discover the problems which is equivalent to solve the problems.

◦ Fluency- Fluency is an ability to give multiple answers at the same given information in a limited time (Guilford and Hoepfner, 1971), and the quantity of meaningful solutions (Urban, 1995). Fluency is a kind of ability counting the number of ideas each participant produced. This is an ability to identify the overall capabilities in core systems at the same time.

◦ Flexibility- Flexibility is the adaptation ability to change instructions, be free from inertia of thought, and be spontaneous in switching between concepts (Guilford and Hoepfner, 1971). Flexibility also provides conceptual distances between their ideas and the symbols. It is the same ability with the development of the core architectures with the capacity of operating process with effectiveness.

◦ Originality- Originality is rarity in the population to which the individual belongs; its probability of occurrence is very low (Guilford and Hoepfner, 1971; Urban, 1995). It related to the originality and considering its distinctiveness of a solution's novelty. This is equivalent to the creation of a core system with the capacity to achieve balanced effectiveness with net-contributions to all systems.

◦ Elaboration- Elaboration is the realization or transformation of an idea, which may become very general or simple or, conversely, very fantastic or detailed (Urban, 1995). Elaboration is to consider how well the participants explain the usage of their object and the depth of detail. It is an ability required to evaluate the potential preferred solutions using the core system architectures.

General speaking, the goal of creativity is to educate creative, multiple talent with a humanitarian quality and nature conscious goal. The purpose is similar to the goal in applying systems thinking. Starting from the top with the right direction, could help to understand the lower level controversial environmental and related issues. The systems thinking could provide continuous thoughts using conceiving systems approaches. One more thing, the future industries must be based on humanitarian quality and nature conscious goal in order to create products or services. At the same time, the enterprise value would be created and the industries survival would be sustainable with contribution to human well-being.

Fig2. Prospective thinking education (Humanism quality and nature conscious goal)(Willy Y.S. Peng and Victoria Hsu,2009)

While the final goal of the creativity training is committed to educate people to live in a humanitarian quality and nature conscious world (Fig2.), it tries to link the past experience to develop future thoughts, so as to explore the future direction with quality life. This is very similar to a prospective of future education with systems thinking approach. In addition, systems thinking could treat more complex systems, effectively and thoroughly with life cycle concept, and provide clear systems architectures. This will offer not only some thoughts in mind, but also an effective interpretation to share with others with better understanding. Therefore, the next step after creativity training is to combine with a future education with systems engineering thinking prospective, such that one could make better systematic judgments.

Ⅳ、 The sustainable humanism with evolving nature

The development of systems (products or services) is a way of using the systems thinking approach to integrate cross-disciplinary sciences and technologies, and to connect all stakeholders and related databases. Systems development needs not only to response to the social, personal psychology, behavior, cognition, and management, and also to involve with local cultural, political factors, and environment. Through the knowledge based networks, tech-integration, industrial innovation, the enterprises could link the systems value chain together closely in promoting the systems value and triggering for more systems innovation opportunities.

In fact, even the principles of systems thinking and creativity are very closely associated. One individual may have very good creativity, but may be not effective in one’s organization. If the enterprises could attach the systems thinking contents as part of their training, it is easier for one to find original and creative concepts (ideas) while still coping with the natural evolution, because of the understanding of the multi-aspects of “systems thinking” with a "open or soft systems" point of view. With no restrictions in creativity or only the fantasy of innovation, it is useless to develop complex systems today. In order to bring up feasible innovative systems, one has to make use of all available technical resources with integrated systems team approach. Both the creativities of one individual as well as from the groups, they are all the innovative cornerstones in the organization. The individual creative capability could be trained up by creativity education; but the capability to put it into act requires additional and continuous systems thinking training.

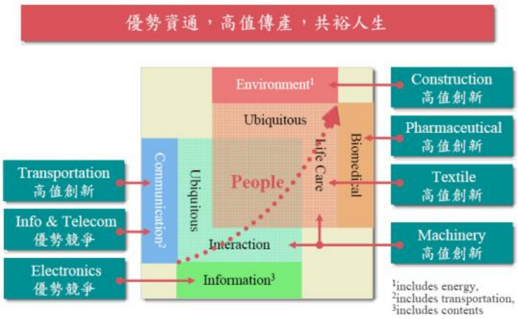

Fig3. Humanistic future industries with quality InfoComm Tech (ICT) infrastructure (Pei-Zen Chang and Mei-Fang Sun)

Recently, fig3 shows that the directions of future technology strategies are "prospective innovation" and "humanistic and people oriented development". This framework will be centred with the future life science and technology development focus for the next 20 years. While we are concentrating on the development of humanistic industries, we also have to face the energy conservation and environmental reservation issues.

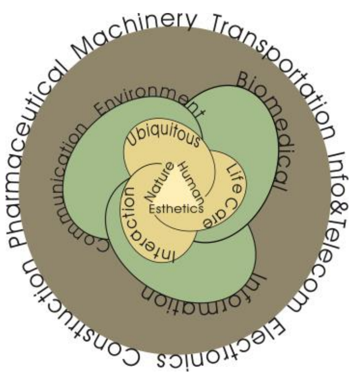

Fig4. "Human、Nature、Aesthetics" – Bud of a blooming multi-value infrastructure (Willy Y.S. Peng and Victoria Hsu, 2009)

The primitive guide for the next generation revolutionary technologies would be to achieve the sustainable humanism with evolving nature. While promoting the advantages of quality ICT, we should know that the true core value for the development of humanistic future industries is "Human、Nature、Esthetics" as well (Fig4.). The bud with " Human、Nature、Esthetics" as a triangular core, which looks like the bud of a blooming flower, would effloresce the multi-values, continuously, which interact across different environmental and system level boundaries with reciprocal effects.

In order to keep the triangular core bud to grow and radiate in systems life-cycle, we propose to educate the multi-talents with the systems thinking approach to meet the complex technology challenges in the future. Creativity would be stimulated by the interactions among human, products, and environment, which none of the three could be spared. It is necessary for human to endorse the nature conscious goal and to enrich the esthetics which is the only way to retain the core values of sustainable development. In another words, the enterprises, society, and government would all try to devote to the multi-talents education with the "Human、Nature、Esthetics" – bud of a blooming multi-value infrastructure systems thinking approach. Through the efforts of all parties together, it might make a better living environment, generate more outstanding creative works with new future.

Ⅴ、Intelligent Taiwan

"Intelligent Taiwan" is one of the "12 Love-Taiwan (i-Taiwan) Projects". The "Intelligent Taiwan" project includes the following:

◦ Manpower cultivation,

◦ Cultural and creative industries

◦ Building Taiwan into the world’s number one wireless broadband country

◦Constructing intelligent transportation systems and intelligent living environments

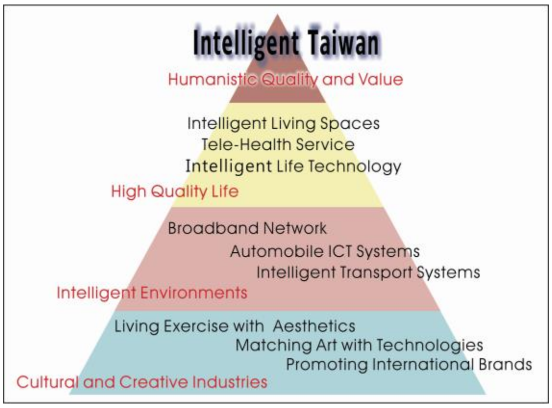

Fig5. "Intelligent Taiwan"

This is a project to transfer people’s attitude in life and thereby changing our life with better quality, taste with more comfortable living. And let the people have a reliable high-speed ICT environment, ubiquitous network; enjoy a variety of value-added transportation services at the same time. Also make people enjoy the intelligence of living space, and the elderly population could have a proper health care in Taiwan. In the end, the Intelligent Taiwan project would lead the new technologies which enable to benefit qualities of life in our country.

To integrate the cross-disciplinary technologies from different industries, in order to consider the common problems, assembly of old technologies will be no longer enough, additional cross-disciplinary researches from systems thinking approach would be required. Among researchers, the interactions and information sharing using systems thinking approach would be essential. Thorough future market studies and evaluation utilizing systems requirements analysis could remedy the high risk innovation. Breakthrough the cultural differences in technologies to reduce the integration conflict would be also important. In response to social changes, the development of humanistic education programs integrated with technology should be valued. Therefore, the "humanitarian quality and nature conscious" goal should be selected as the foundation for the development of science and technology in our education programs. We would pay more attention to the "future education with systems thinking prospective" in order to be prepared to train the required multi-talent people for the Intelligent Taiwan project. To fit the future vision we try to introduce the bud of a blooming multi-value infrastructure as a third dimension to interact with all systems levels and systems life cycle time.

Because of the complexity of the systems problems, Hitchins introduced a 5-layer model with increasing scales, namely product level, project or system level, business level or enterprise systems engineering, supply chain level or industrial systems engineering, and socio-economic level or socio-economic systems engineering. It is easier to describe where the system of interest fits in the model. Later on, the Hitchins's model was extended by Kasser and Massie with a temporal dimension and some systems methodologies could be mapped onto it.

The development of human being with the future intelligent systems should be closely combined with the evolution of nature. When exploring and creating the new intelligent systems to increase the human value with aesthetics, the evolution of nature also could not be ignored. Only following with the laws of nature and ecology, the sustainable humanism with evolving nature could be achieved.

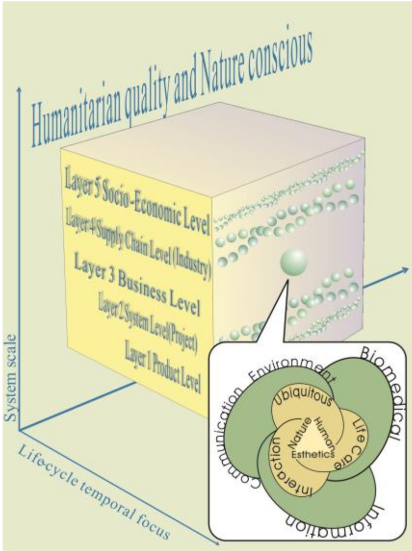

Fig. 6 Further extended 5- layer model(Willy Y.S. Peng and Victoria Hsu,2009)

We understand that all systems (products or services) have life-cycle with different level of complexity. In order to create future intelligent systems with sustainable humanism, aesthetics, and evolving nature in mind, it is also important to introduce the "Human、Nature、Aesthetics" – bud of a blooming multi-value infrastructure as a third dimension to interact with all systems levels and systems life cycle time. A further extend 5-layer model is presented in Fig. 6. In addition, the creativity training program could be generated together using the above further extended 5-layer model with systems thinking approach.

In view of the “Intelligent Taiwan" project with its new policies and tools, it could be seen the "Human、Nature、Esthetics" core value everywhere under the systems thinking approach. To meet the requirements for the transformation to new industries for Intelligent Taiwan, we propose to follow the three steps from systems thinking, innovation and creativity, to systems thinking and creativing, in reference to the further extended 5- layer model.

With such a large national project, we have to focus from the highest point of view, like the arrangement of the policy priorities, the allocation of limited resources, and needed information…etc. We must develop the consensus of problem issues together, emphasize the importance of the overall front-end integrated systems planning, understand the application of innovation skills, to draw up the new goals and policies accordingly, and carry out with total systems thinking approach.

Ⅵ、 Conclusion

The critical multi-talent requirement for the future "Intelligent Taiwan" project could be expected. These multi-talented people should take shoulder for guiding the nation towards the development of integrated science, technologies, and environmental conservation systems. Facing with the global competition, we need the creativity and multi-talented people ready in the front-end of "Intelligent Taiwan" project. How to adjust the school education program to cope with the global competition is a necessity. We have to train the future students to be more with humanitarian quality and nature conscious goal in mind, to make the best use of their own experience linking the past with the future, to explore self-improvement for meeting the future challenge.

Utilizing both the cognitive and non-cognitive factors, sometimes it is still difficult to produce creative systems solutions. In treating complex systems, requires an integrated top-down view with systems architecture and conducts requirement analysis and functional analysis to all systems layers, executes synthesis process to all systems layers through out the systems life cycle. We propose in this paper to introduce a future creativity training program with systems thinking prospective with the humanitarian quality and nature conscious goal in order to meet the future development policy of Taiwan.

Equipped with systems thinking approach education with creativity training one might be able to define new concepts, to generate new principles, and to develop new systems, and also to build new environment to meet sustainable humanism with evolving nature.

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Paper ID: 184

Towards Agility: the Pathway of "IE+IT" for Enterprise Integrated Innovation

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Abstract

Basing on the information technology application, this paper initially not only analyses the factors that affect the integration level and the further development of manufacturing enterprise, but presents systematic reference architecture of Industrial Engineering (IE) and Information Technology (IT) as a methodology to adapt to complex business environment. The architecture of "IE+IT" system originates from enterprise integration (EI) methodology and lean thinking, then extends the methods and tools of IE into IT application, so it is beyond the scope of integration or lean management. It contains the construction of integrated management platform (IMP), the path selection of enterprise development, the relationship between the information system and management system, and modeling of interaction between IE and IT. From traditional enterprise to agile enterprise, there are two different path selections. IMP, which comes from original management system (OMS) and applied information system, is viewed as a core of enterprise. The relationship describes the attributions: consistency, matching level, contradictions and interactions about IE and IT. The aim of modeling is to illustrate the essence of information system application, the innovative mechanism of IMP, and the functions of IE to promote the application of IT.

Keywords

Enterprise integration; lean management; Agile system; Integrated management platform (IMP); "IE+IT" system

Content

1. Literature

Some classical theories have been proposed for enterprises based on the information technology in order to promote the integration, leanness and agility. The study of integration mainly involves several theoretical models.

With the developing of information technology and industrial engineering，some classical theories have been presented for enterprises to promote the integration, leanness and agility.

CIM (Computer Integrated Manufacturing) is an earlier advanced philosophy of manufacturing. CIMOSA as an open system architecture for CIM was established by ESPRIT Project. CIMOSA model has defined three levels (generic, partial and particular) and four different views (function, information, resource and organizations) to support complete life circle of enterprise operations (requirements definition, design specification and implementation description) [1,2].

GERAM (Generalised Enterprise Reference Architecture and Methodology) was developed by the IFAC/IFIP Task Force which illustrates that all "complete" enterprise reference architectures should map together and should have comparable characteristics and capabilities. It is represented as a three-dimensional structure exhibiting seven life-cycle phases including identification, concepts, requirements, design, implementation, operation and decommission, three levels of instantiation and the identification of model views. The reference architecture provides the necessary elements for the instantiation of the particular enterprise architecture identified by each life-cycle phases[3].

PERA (Purdue Enterprise Reference Architecture) was developed by Purdue University during the period 1989-1991.The simplifying concepts of systems engineering in enterprise integration involves the mission, separation of functions, networks of tasks, the place of the human, the life cycle, planning and organization of the integration effort (the master plan). The Methodology of PERA presents a set of instructions, for example text, computer programs and tools, models, graphical diagrams, etc. which give a step-by-step aid in carrying out all needed aspects of the execution of the life cycle phases or steps of the enterprise entity integration project [4,5].

Generally, many integrated models and methodologies tended to solve the enterprise issues by information technology application, so, the aims of integration were not only to optimize the data and information flow, but also to integrate a variety of resources together as new applications and to enlarge the set of business processes involved. Many integration projects yielded only partial results [6,7], while others were given up completely, because of the difficulties in paying back the huge investments that were often required (Kaplan, 1986)[8]. Even more important was that the demand-supply relationship was neglected when the original management system and information system was used in firms.

Since 1960's, Toyota production system (TPS), an advanced manufacturing style, was known as a way to make more money[9,10]. Taiichi Ohno considered that TPS is really just a practice of American industrial engineering in Japan, especially in Toyota Motor Corporation[11]. TPS was initially known as the JIT (Just-in-Time) in Europe and United States, and later was named as Lean Production (LP) [12]. The wastes elimination, ongoing process, continuous improvement, team work, 5S, and pull system, etc, are the results of industrial engineering application. So, TPS/LP is not only a technical system, but a management system, which has been widely used in almost all industries and achieved more than other systems.

Agile manufacturing (AM), as the most competitive manufacturing and management system in the 21st century, is likely to be a combination of integration and lean production [13]. According to the web[14] of Lehigh, AM is the ability to thrive in an environment of continuous change, which required: to realize short product-cycles; to quickly out-source and partner with other firms; to excel at low-volume and high-variety production; to utilize empowered teams; have customer responsiveness pervading every aspect of the organization. To a great extent, AM has to base on modern information technology which involves all alliance components. Goldman suggests that Agility has four components: delivering value to the customer; being ready for change; valuing human knowledge and skills; forming virtual partnerships, and definite that the first three of these are also attributes of lean manufacturing [15].

In recent years, almost all successful manufacturers have implemented advanced manufacturing technology, such as JIT, mass customization (MC), CIMS and lean production. With the development of information technology, enterprise integration is becoming a favorite style. In fact, though the information integration plays an important role, the integration is not the unique effective way to utilize recourses. H.W. liu has summarized six main issues of enterprise integration, and indicates that the combination of information integration and lean manufacturing should be a better choice too [16].

2. Mechanism of Enterprise Innovation

Agility means the firm can quickly respond to market changes by reengineering its business processes, reconfiguring the manufacturing systems and innovating in its products. The characteristics of AM at least include：greater product customization; rapid introduction of new modified products; increased emphasis on knowledgeable; highly trained and empowered workers; interactive customer relationships; dynamic reconfiguration of production processes; greater use of flexible production technologies; rapid prototyping; innovative and flexible management structures; an integrated and open information environment; rapid collaboration with other firm’s to form a virtual company. So, in current continuously, rapidly and changing competitive environment, agile manufacturing, as the most ambitious manufacturing and managing style, will be the one of the best choice for most of enterprises.

The priority of traditional enterprise (TE), which is still a mass production, a low-efficiency varieties and small batch production, is to realize the rapid transition to the agile enterprise (AE). How to achieve this goal with less risk?

To build an agile manufacturing system needs a series of necessary factors, which refer to the fundamentals and operational environment, development mechanism, strategy, potentials and performance. Fundamentals, involving in general engineering technologies and management methods, are the base for survival and development of any type of business. Environment refers to the common operation platform for reality and virtual alliances. Mechanism emphasizes the adaptability and predictability of the institutional system. Strategy and Potential mean that enterprise will achieve the objectives and get the abilities ahead of the competitors. Performance measures for the output levels of the key elements. There are multi-complex relationships within five factors. These factors and their relationships together constitute a high level organizational system. The contents and logics are showed as figure 1.

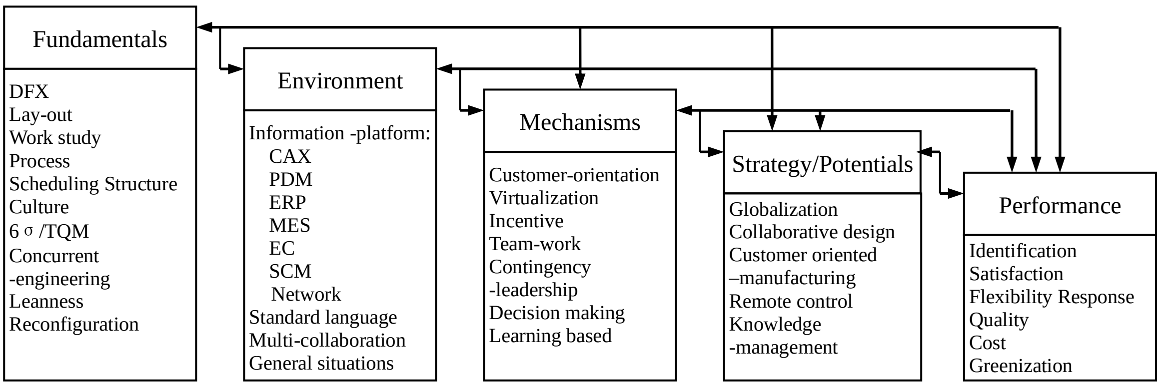

Figure 1. Characteristics of agile manufacturing & management system

It is known that if enterprise lacks of a good base for management and operation, it would be like water without source, a tree without root. So, the Fundamental is the primary factor. Meanwhile, the information platform is used to integrate resources and to make rapid response to market changes. It becomes especially important for enterprise to apply the modern technologies and to fuse the advanced management concepts. Mechanisms and strategies are the innovation of thinking and the re-planning of objectives, institutions or methods basing on above two. And then, they will enhance the fundamentals and improve the resources utilization. In any case, the transformation from TE to AE must be established on the fundamentals and environment.

3. Analysis of Path Selection

Theoretically, there are five ways for TE to choose, just as figure 2. Five ways are the followings:

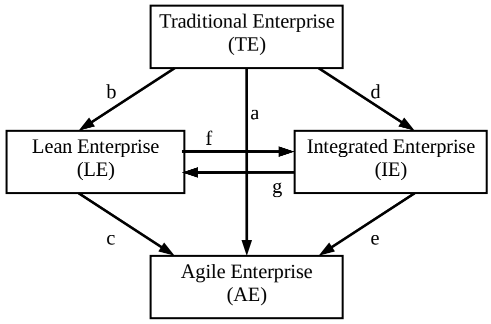

Figure 2. Multi-pathways for transition from TE to AE

Path 1: TE - a - AE. It is considered as a shortcut, but not an ideal way because of great risks. In fact, some firms attempt to rearrange their business process to realize the agility. Most of them took long time, spent a lot of money and were not successful. Obviously, BPR (business process reengineering) is not suitable for weak fundamentals.

Path 2: TE - b - c - AE. Path 2 is a good choice,when the AE is lack of capital or do not intend to spend too much money to realize the AE. Lean management focuses on the added value process and continuous improvement. Leanness includes some profound connotations: quality, cost, response, safety, flexibility, collaboration, morale, loyalty, et al. Generally, lean enterprise (LE) seldom encourages using expensive instruments, equipments, even information system, but reform in thinking, tools and methods is always conventional. In this way, the base of management and techniques has been to a higher level, and it is easy to get excellent performance. The weak point is lack of advanced information platform to enhance its business flexibility.

Path 3: TE - d - e - AM. Many firms have applied modern information systems that include either of operation and management system such as ERP, or the technical support system such as CAD, et al. For modern enterprises, the perfect information infrastructure should include internal information system and external information system. Internal system is able to plan and allocate organizational resources to optimize the value process and create qualified products and service. ERP is a typical internal system. External system is mainly used to get outside resource and achieve priority over competitors, such as electronic commerce (EC), supply chain management (SCM). Viewed from integration, internal and external information systems should be unified as an information platform. Thus, it would take advantage of all resources efficiently.

Though the information platform has been built, it does not mean that company already has a good management and operation foundation. Leanness and agility are more complex than information integration. Under this circumstance, the most important thing is to improve the flexibility of organizational structure and the effectiveness of operational processes.

Path 4: TE - b - f - e - AM. This model indicates that TE try to construct information platform to improve agile environment after the completion of the lean transformation. This strategy makes a clear and significant improvement to path 2.

Path 5: TE - d - g - c - AM. Comparison with path 4, path 5 is priority to establish an integrated information platform and then implements lean management to reach the agility. This strategy makes a huge progress in taking a clear follow-up strategy to path 3.

For above five paths, different strategies have been adopted for different requirement, and will achieve different outcomes. That can be defined as five effects. Path 1 is the most direct and the most risk method among the five, so it could be called “risk-based effect”. Path 2 seeks to obtain the leanness firstly, and than makes efforts to get agile enterprise. It can be seen a “lean-driven effect” or “push effect”. Path 3 firstly establishes the soft environment for enterprise development, which requires the business processes (materials, equipments, men, capital) to meet the information flow towards agility. Therefore, “pull effect” or “info-driven effect” is suitable for path 3. Path 4 and path 5 are the integrations of lean system and information system. The main difference lies in the different order of implementation. According to the principals of path 2 and path 3, path 4 can be defined as “push-integrated effect” and path 5 as “pull-integrated effect”. These are listed in table 1.

Table 1. Effects of different pathways

Pathway	Type	Effect
1	TE – AE	risk-based effect
2	TE – LE – AE	lean-driven effect / push effect
3	TE – IE – AM	Info-driven effect / pull effect
4	TE – LE – IE – AM	push-integrated effect
5	TE – IE – LE – AM	pull-integrated effect

4. Essence of “IT+IE” Integrated Innovation

According to the experience and general law, Path 1 is a risk decision, while path 2 or path 3 is an uncertainty decision. Selection from path 1 to path 3 means that enterprise has to experience hard process to find an effective way to achieve its objectives. The time, resources, chances may disappear.

Path 4 and path 5 are both the certain decision. They are designed as orderly or reversal arrangement from TE to AE via lean enterprise (LE) and integrated enterprise.

Firstly, LP, which is known as one of the most flexible manufacturing system and the most profound management system, has made significant application outcomes and is still the development model pursued by the majority.

Secondly, LP widely applies the methods of classical industrial engineering (CIE) and the thinking of modern industrial engineering (MIE) to get low-cost, low-risk, high-quality and high-efficiency products and service.

Thirdly, basing on the basic management and operational techniques, LP focuses on people-oriented culture, devotes to integrate man and thing, and pays attention to the flexibility and continuous improvement.

In addition, LP does not exclude the application of information technology. In Toyota Motor Corporation, MRP (material requirement planning) was applied in 1960’s. CAD is wildly used in any type of companies at the same time. Nowadays, information systems have become applied tools and integrated platforms and form an operational environment. Information system enlarges the commercial fields, standardizes the process and flows, optimizes organization structure, promotes technical Innovation, deeply enriches the culture and management thinking. So, implementation of the information technology has become a strategic choice. A model, illustrating the transition from TE to AE, is showed as figure 3.

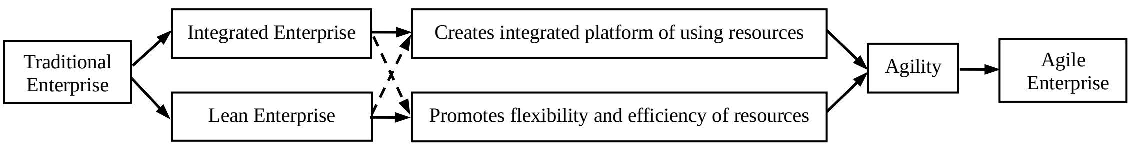

Figure 3. The logic of manufacturing & management system innovation

There is an issue, namely, what is the relationship between the lean system and the information system or why we should integrate lean system with information system.

Industrial engineering becomes the fundamental of leanness because lean management is based on industrial engineering system， which includes thinking, techniques, methods and tools. Meanwhile, Information system is an express of information technology application. So, the relations between leanness and integration can be attributed to industrial engineering and information technology. In the firms, industrial engineering techniques and information technologies do not play the roles separately; on the contrary, two systems combine to play important roles doubly. Therefore, a cooperative relationship model is built to analyze the industrial engineering and information technology, and then the "IE+IT" innovative architecture is presented.

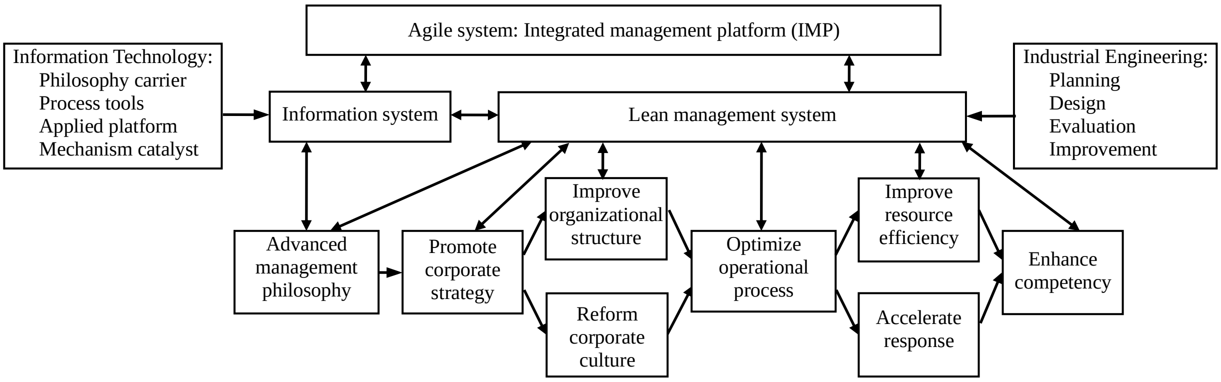

Figure 4. Cooperative relationship model of agile system

Decrypted as figure 4, to achieve agility is a series of complex processes from advanced thinking to the organization reform, even to the operational process improvement. The Interaction between IE and IT produces the integrated management platform (IMP), which could achieve higher performance than lean system or information integrated system separately. Agile manufacturing and management system is just founded on the IMP.

5. Policies of "IE+IT" Implementation

Since there are five general paths and two ideal paths for firms to choose, what is the principle for path selection? Basing on above analysis, path 4 and path 5 are discussed as the following.

Because the strategies, resources, industries, technologies and markets are distinctly different, enterprises must keep a clear difference in requirements and capabilities for realizing agility. In comparison, path 4 highlights the construction of fundamentals, but the abilities of original management system (OMS) are not highly demanded. With the increasing level of leanness, the requirements of information integration will gradually emerge. In this time, the conditions of integration are content. Under such circumstances, lean system can obtain greater flexibility, and the information system is also able to achieve more efficient integration of internal and external resources. The effectiveness of "IE+IT" is able to appear.

Path 5 focuses on the effectiveness of integration, and the better management and operation capabilities are highly demanded. If it is not a excellent OMS, the functions of information system are rarely showed. The main reason is that the virtual processes within the info-systems do not match with the real processes controlled by management system.

To choose the right way to access to the agility for traditional enterprises, an evaluation system based on four dimensions is proposed. This evaluation system is a quantitative model to assess firm's capability of OMS and the requirement of development. The four dimensions are overall requirements and strategic objectives, Organization effectiveness, capacity of operation and management, Level of resources. For each dimension, a sub-system of systematic indexes and measurement standards is set up, so the evaluation system includes four sub-systems. By measurement, the outcomes include not only the value of each dimension, but also a comprehensive value. Comprehensive value, which lies in a numerical interval ,reflects the degree of overall ability to meet the future demand, and the initial decision to choose the path can be made. The size of the dimension index value reflects not only the level of a certain dimension, but also whether it is the bottleneck relative to the whole system. To a large extent, dimension index value is essential in decision-making. Figure 5 is the model of path selection.

According the comprehensive value and dimension value, path 4 or path 5 should be a unique choice.

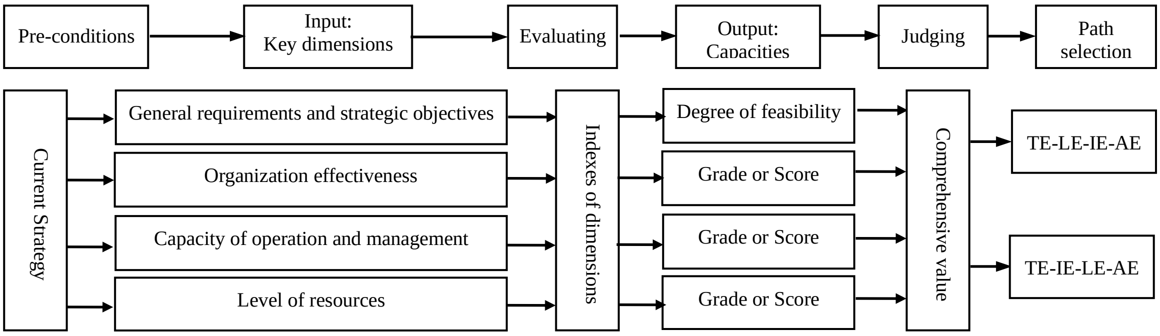

Figure5. Model of capacity evaluation and path selection

6. Conclusion

This paper systematically analyzes the architectures, methodologies and models of enterprise's advanced manufacturing system, especially discusses the pathway selection from traditional enterprise to agile enterprise. In this study, the transition of TE to AE has been considered as an innovative process. There are five inherent links in the process. Among which, fundamentals and operational environment are the key factors, which deeply affect other three factors. Leanness and integration are just the core expression of fundamentals and operational environment. Following the mechanism analysis, five paths have been proposed for the agile manufacturing and management. The two paths have been modeled in detail due to their most importance. Views of the cooperative relationship between lean system and information system, IE and IT play an important role in the innovation. So, the "IE+IT" innovative architecture is put forward. Combination of "IE+IT" thinking and the final path selection, a series of policies, basing on the capacity evaluation, is emerged.

In this way, a complete methodology is constructed for enterprise manufacturing and management systematic innovation.

In the future，some relevant issues will be further studied. At least, these include the risk and the cost of integrated innovation with the path selection, the evaluation of organization effectiveness.

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Paper ID: 205

Development of the Design Attributes for Green Product in Compliance with EU Environment Directives Using TRIZ

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Abstract

This study explores the design attributes of notebook computer in compliance with the European Union (EU) environmental directives using the theory of Invention Problem Solving (TRIZ). First of all, we survey the literature for environmental efficiency elements and design attributes for the notebook computer. Then we convert these design attributes to the corresponding design (engineering) parameters in the TRIZ. This study also determines the weight of these design parameters using the Analytic Hierarchy Process (AHP) and develops a relationship matrix between the design parameters and the environmental efficiency elements. Based on the environmental constraints for notebook computer, we can obtain the design parameters sequence using this matrix and questionnaire from the experts in this field. Finally, we propose an inventive principle table that resolves conflicts in design parameters, which can be served as a reference in green product design for notebook computer.

Keywords: Green Product Design, TRIZ, AHP, Notebook Computer

1. Introduction

With recent rising awareness of environmental protection, European Union (EU) requires the enterprises selling products into Europe to comply with three green directives: Restriction of Hazardous Substances Directive (RoHS), Waste Electrical Electronic Equipment (WEEE), and Energy Using Product (EuP). RoHS requires that Member States shall ensure that new electrical and electronic equipment (EEE) put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE). The first priority of WEEE is to prevent the waste of electrical and electronic equipment, including the reuse, recycle and other forms of recovery to reduce waste disposal. EuP establishes the eco-design requirement framework for energy-using products with the aim of ensuring free movement of products within the internal market. To comply with the three directives, industries are focusing their efforts on green product design. Therefore, green product design to achieve eco-friendly and energy-saving design is a crucial topic. This research explores the design attributes of notebook computer products in compliance with the EU environmental directives using the TRIZ and develops an innovation principle table in order to provide some design principles as a reference in green product design.

2. Green Product Design

Green product design (also known as design for environment, design for eco-efficiency, or sustainable product design) is a proactive business approach to address environmental considerations at the earliest stage of product development process in order to minimize negative environmental impacts throughout the product's life cycle. Green product design includes material selections, production requirements and the final disposition (recycling, reuse, or disposal) plans of a product. It is not a stand-alone methodology but one that must be integrated with a company’s existing product design approaches so that environmental parameters can be balanced with traditional product design attributes such as quality, manufacturing-ability, and functionality. Green products may be designed to be more easily upgraded, disassembled, recycled, or reused than their conventional counterparts as well as to use fewer materials and easy to break down into replaceable modular parts.

Implementing green product design can provide a number of benefits to a company. By focusing on resource efficiency, one can reduce costs and shorten production time. Alternatively, diverse functional groups in the design table can bring product innovation. For this reason, more and more companies are making green product design a critical element of their sustainable business agenda. (B.S.R, 2009)

3. Research Methodology

The procedure of the proposed methodology for green product design is shown in Figure 1. We use notebook computer as an example to illustrate the methodology. Step 1 is to identify environmental efficiency elements, which are based on the survey from the literature. Step 2 is to identify notebook computer product design attributes, and then we convert these design attributes to the corresponding design (engineering) parameters in TRIZ. The information gathered is either from the literature or experts in practices. In Step 3, we determine the weight of these design parameters using the method of AHP. Step 4 is to construct a relationship matrix between environmental efficiency elements and design parameters in terms of linguistic description from experts' questionnaire. Step 5 is to determine the significance of environmental efficiency elements. In Step 6, we obtain the priority list of these design parameters with consideration of the environmental constraints for notebook computer. Step 7, we propose the inventive principles through the TRIZ contradiction matrix from the sequence order of these design parameters and the rank of frequency of occurrence for inventive principles. Based on this procedure, we provide a reference of green design principles for notebook computer designers.

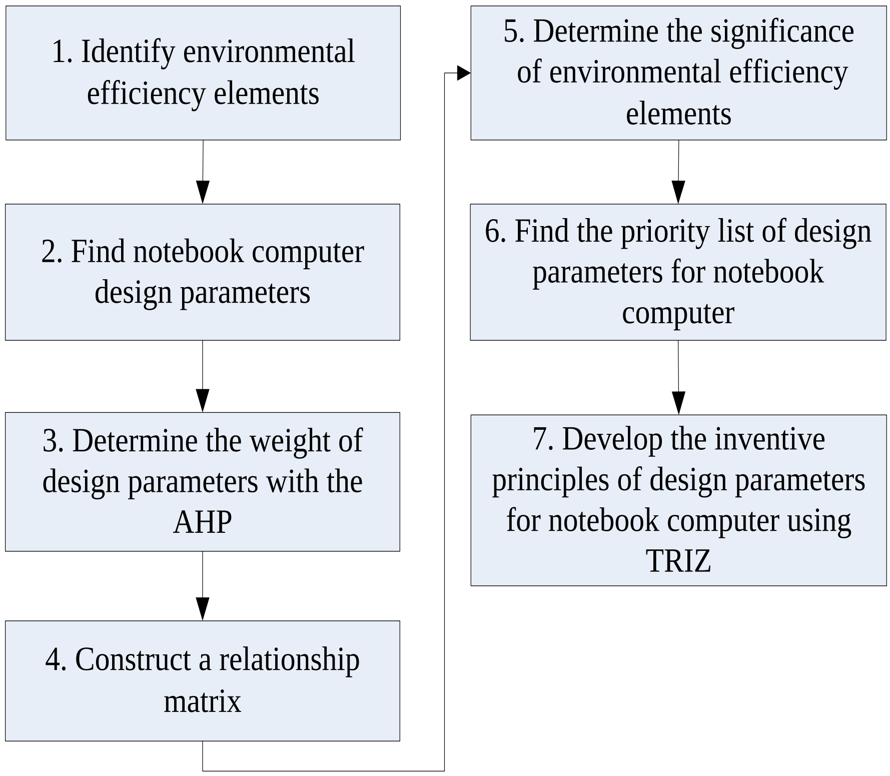

Figure 1. Proposed Methodology

4. Example Illustration

This section uses notebook computer as an example to illustrate green product design for the proposed methodology discussed in Section 4 step by step.

4.1 Identify Environmental Efficiency Elements

From the literature, we identify eight important environmental efficiency elements as shown in Table 1. After considering the scope of EU environmental directives RoHS, WEEE and EuP, we adopt six important environmental efficiency elements as the foundation of the model developed in this study. They are "harmful material", "material retrieval”, “material reduction”, “energy consumption”, “resource sustainable”, and “product durability”.

Table 1. Environmental Efficiency Elements Survey

Environmental Efficiency Elements / Literature: Source	Year	Harmful Material	Material Retrieval	Material Reduction	Energy Consumption	Resource Sustainable	Product Durability	Product Service	Product Package
World Commission on Environmental and Development, (WCED)	**1998**	☆	☆	☆	☆	☆	☆	☆	
Chih-Chen Liu	**2002**	☆	☆	☆	☆	☆	☆	☆	
Ren Wang	**2003**	☆	☆			☆			
Chih-Yuan Chuan	**2004**	☆			☆	☆	☆		
WEEE Directive	**2005**		☆						
RoHS Directive	**2006**	☆							
U.S Environmental Protection Agency, (EPA)	**2006**	☆	☆	☆	☆		☆		☆
EuP Directive	**2007**	☆	☆	☆	☆	☆	☆		
This Study		☆	☆	☆	☆	☆	☆		

4.2 Find Notebook Computer Design Parameters

Table 2 shows the TRIZ engineering parameters with six classifications: geometry, physics, resources, ability, control, and harm. Checking these parameters with the notebook computer product design attributes surveyed from the literature, we can identify notebook computer design parameters under six classifications, as shown in Figure 2. We can use this to develop an AHP hierarchical framework for notebook computer product design. The six classifications are the level 1 factors and design parameters are the level 2 factors (A1, A2, B1, …, F2) for notebook computer product design.

No.	Geometry	No.	Physics	No.	Resources
3	Length of moving object	1	Weight of moving object	19	Energy spent by moving object
4	Length of nonmoving object	2	Weight of nonmoving object	20	Energy spent by nonmoving object
5	Area of moving object	9	Speed	22	Waste of energy
6	Area of nonmoving object	10	Force	23	Waste of substance
7	Volume of moving object	11	Tension, pressure	24	Loss of information
8	Volume of nonmoving object	17	Temperature	25	Waste of time
12	Shape	18	Brightness	26	Amount of substance
		21	Power		
No.	**Ability**	**No.**	**Control**	**No.**	**Harm**
13	Stability of object	28	Accuracy of measurement	30	Harmful factors acting on object
14	Strength	29	Accuracy of manufacturing	31	Harmful side effects
15	Durability of moving object	33	Convenience of use		
16	Durability of nonmoving object	36	Complexity of device		
27	Reliability	37	Complexity of control		
32	Manufacturability	38	Level of automation		
34	Reparability				
35	Adaptability				
39	Productivity				

Table 2. TRIZ Engineering Parameters with Six Classifications (Domb, 1998)

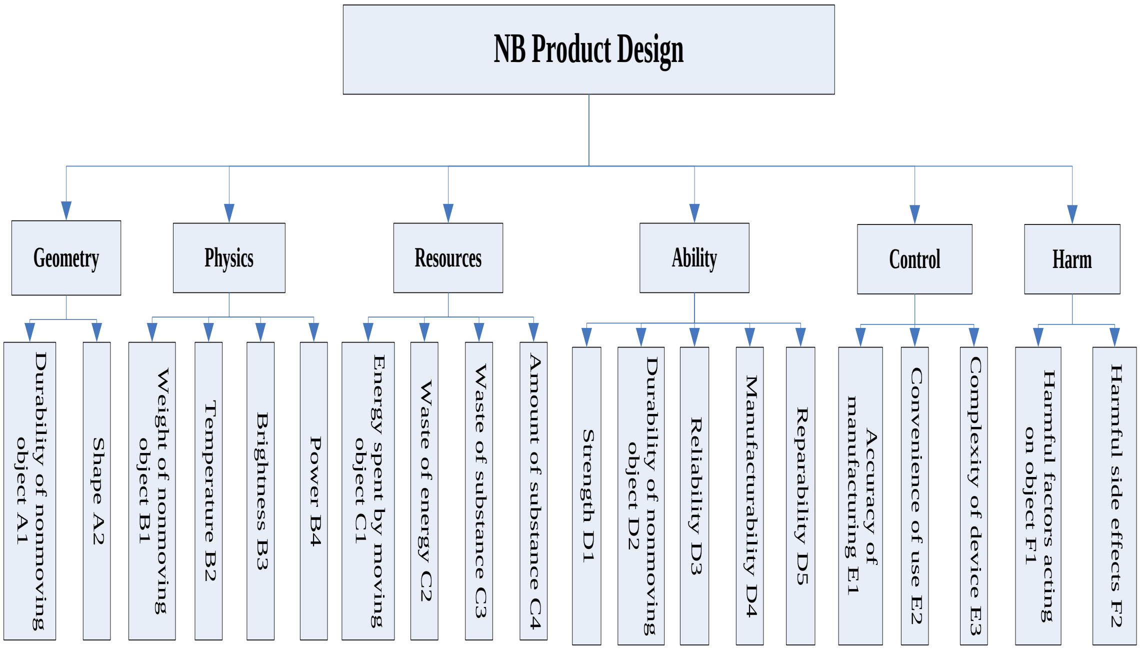

Figure 2. Notebook Computer Product Design Hierarchical Structure

4.3 Determine the Weight of Design Parameters with the AHP

Using the AHP, we can determine the relative weight for the factors of notebook computer design. This study uses the AHP module in the Web-HIPRE (HIerarchical Preference analysis) software, which is a web-version of the HIPRE 3+ software. The software provides an implementation of AHP to support the different phases of decision analysis, namely, structuring of the problem, prioritization and analyzing the results. In the AHP, the overall priorities from each group member's model are weighted and then averaged to obtain composite group priorities. (Mustajoki and Hämäläinen, 2000)

When all the pairwise comparisons from the questionnaire of an expert for the importance of design parameters have been given, the weight for each attribute can be found. As shown in Figure 3, after the relative importance between A1 (Durability of nonmoving object screenshot) and A2 (Shape) is given, the weight of A1 and A2 can be determined. Following the same procedure, we can determine the relative weight of other factors of each group in Level 2, and that of each factor in Level 1 as well. Then we can determine the absolute weight for each factor (design parameter) in Level 2. The consistency measure (CM) proposed by Salo and Hämäläinen (1997) is used in the Web-HIPRE. It is derived by transforming the inconsistent replies into an extended set of feasible preference statements, and using the properties of this set to measure the inconsistency of the pairwise comparison matrix (Mustajoki and Hämäläinen, 2000). If the value of CM is larger than 0.1, there is a warning against unintentional judgmental errors. In this study, we have CM=0.073.

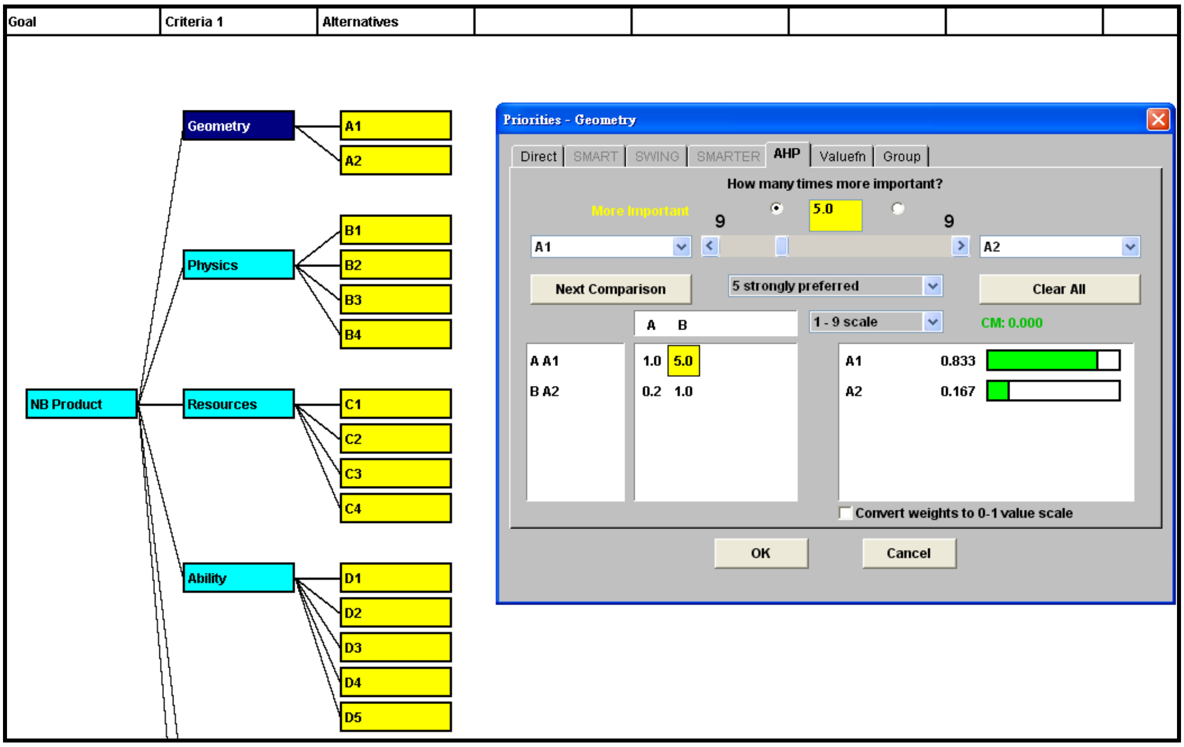

Figure 3. A snapshot of HIPRE 3+ software

4.4 Construct a Relationship Matrix

This study would like to explore how the environment consideration affects the product design for notebook computer. Using the environmental efficiency elements and design parameters obtained in the previous sections, we can construct a relationship matrix between them. By collecting linguistic evaluation for the relationship from experts, we can determine what kind of the relationship between the environmental efficiency elements and design parameters for notebook computer. One expert opinion for this relationship is shown in Table 3. This research sets the evaluation description for the relationship as either “very low,” “low,” “medium,” “high,” or “very high” as shown in Table 4.

Table 3. Relationship Matrix between Environmental Efficiency Elements and Design Parameters

Design Parameters		**Environmental Efficiency Elements**	**Harmful Material**	**Material Retrieval**	**Material Reduction**	**Energy Consumption**	**Resource Sustainable**	**Product Durability**
Number	**Parameters**	**Weight**						
#8	Volume of nonmoving object	0.041	VL	H	VH	VH	H	
#12	Shape	0.008		M	H	M		VL
#2	Weight of nonmoving object	0.040		H	VH	L	M	
… …	… …	… …						
#36	Complexity of device	0.033	L	H	VH	H		M
#30	Harmful factors acting on object	0.009	VH	VH	M		VH	H
#31	Harmful side effects	0.037	VH	VH	M	M		H

Table 4. Linguistic variance and its relative weight value

Linguistic Variance	Variance Symbol	Relative Weight Value
Very Low	VL	1
Low	L	3
Medium	M	5
High	H	7
Very High	VL	9

4.5 Determine the Significance of Environmental Efficiency Elements

After we average evaluations from experts, we can discover the significance of environmental efficiency elements for notebook computer design. Table 5 shows “Energy Consumption,” “Material Retrieval,” and “ Product Durability” are the top three environmental efficiency elements .

Notebook computer has been walking into our life since 1975 and nowadays, it becomes one the most commonly used modern communication and word-processing tools. However, the life of notebook computer in the market is very short, usually last for only 3 to 4 years, and while newer models have been constantly introduced with additional features and greater capabilities. It leads to higher product replacement rate and higher energy consumption. Therefore, we need to find the effects of product durability and material recovery to ensure environmental efficiency.

Table 5. The significance of environmental efficiency elements

Design Parameters \ Environmental Efficiency Elements		Harmful Material	Material Retrieval	Material Reduction	Energy Consumption	Resource Sustainable	Product Durability
Number	**Parameters**						
#8	Volume of nonmoving object	3%	21%	27%	27%	21%	
#12	Shape		28%	39%	28%		6%
#2	Weight of nonmoving object		29%	38%	13%	21%	
… …	… …						
#36	Complexity of device	9%	21%	26%	21%	9%	15%
#30	Harmful factors acting on object	27%	27%	15%		9%	21%
#31	Harmful side effects	24%	24%	13%	13%	8%	18%
Notebook Product Design		10%	**18%**	17%	**21%**	15%	**18%**

4.6 Find the Priority List of Design Parameters for Notebook Computer

Similarly we can find the priority list of design parameters for notebook computer from the information shown in Table 4. The top three design parameters under the consideration of environmental efficiency elements are “manufacturability”, “accuracy of manufacturing”, and “reliability”, as shown in Table 6. Observation tells that higher manufacturability results in higher quality and lower cost for the product. If the manufacture accuracy is low, the product features will differ from their design specifications, which will lead to higher damage rate, higher return rate, and a higher chance to shorten the product life-time. In addition, lower reliability will shorten the product life cycle too and create more replacements that result in damage to environment.

Table 6. The priority list of design parameters

Number	Design parameters	Score	Priority	Percentage
#32	Manufacturability	5.910	1	22.2%
#29	Accuracy of manufacturing	4.776	2	18.0%
#27	Reliability	3.363	3	12.6%
… …	… …	… …	… …	… …
#12	Shape	0.188	18	0.7%
#18	Brightness	0.103	19	0.4%
#22	Waste of energy	0.065	20	0.2%

4.7 Develop the Inventive Principles of Design Parameters for Notebook Computer Using TRIZ

In TRIZ, the matrix of contradictions can be built by 39 pairs of improving features and worsening features (parameters) with their corresponding inventive principles, which have 40 in total. Table 7 shows the top six improving features (design parameters) with their inventive principles. Figure 4 shows the frequency of occurrence of inventive principles in a descending order. The top six are ＊35, ＊01, ＊10, ＊02, ＊03, and ＊27. The explanation of inventive principles is shown in Table 8. A designer should pay more attentions to the inventive principles that occur more frequently.

Table 7. Inventive Principles for Top Six Improving Features

Improving Feature	Inventive Principles
＃32 Manufacturability	＊01、＊27、＊35、＊14、＊13 ...
＃29 Accuracy of Manufacturing	＊32、＊35、＊10、＊26、＊02 ...
＃27 Reliability	＊35、＊11、＊40、＊01、＊10 ...
＃26 Amount of Substance	＊35、＊03、＊10、＊25、＊31 ...
＃31 Harmful Side Effects	＊35、＊22、＊39、＊02、＊24 ...
＃08 Volume of Nonmoving Object	＊35、＊10、＊34、＊01、＊02 ...

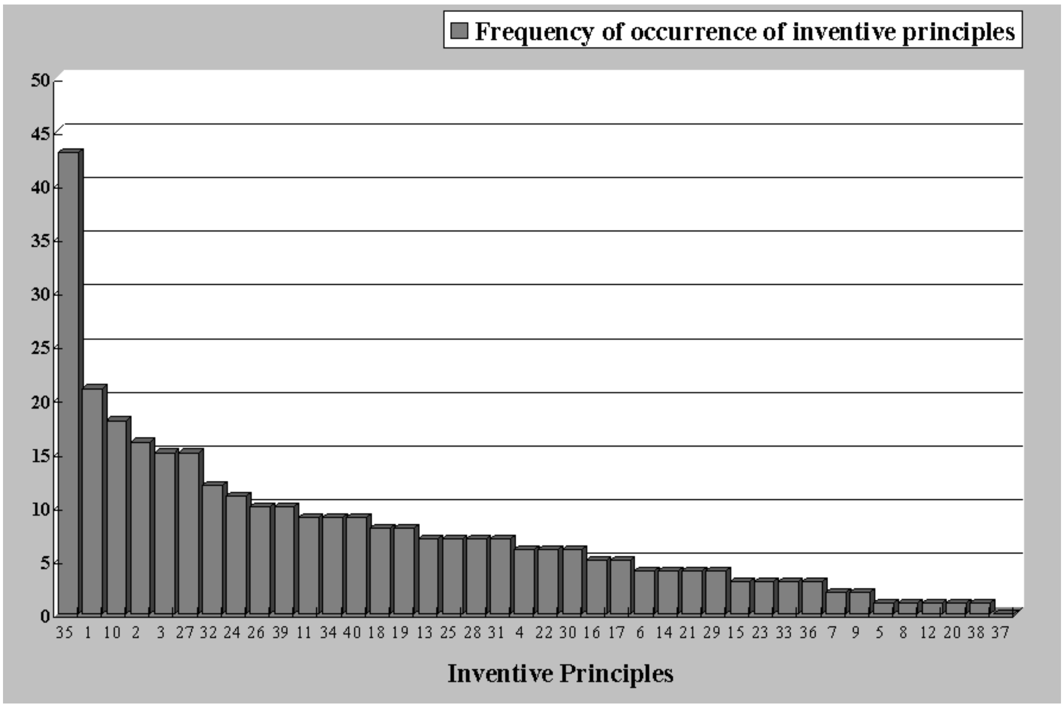

Figure 4. Frequency of Occurrence of Inventive Principles

Table 8. Explanation of Inventive Principles

Inventive Principles Number	Inventive Principles Explanation	Inventive Principles Number	Inventive Principles Explanation
∗35	Transformation of physical or chemical states of an object	∗11	Cushion in advance
∗01	Segmentation	∗34	Rejecting and regenerating parts
∗10	Prior action	∗40	Composite materials
∗02	Extraction	∗18	Mechanical vibration
∗03	Local quality	∗19	Periodic action
∗27	An inexpensive short-life object instead of an expensive durable one	∗13	Inversion
∗32	Changing the color	∗25	Self-service
∗24	Mediator	∗28	Replacement of a mechanical system
∗26	Copying	∗31	Use of porous material
∗39	Inert environment	∗04	Asymmetry

5. Conclusion

This study developed the design attributes for green notebook computer design in compliance with EU Environment Directives. First of all, we obtained information from the literature about environmental efficiency elements and design attributes for notebook computer design. Then we went through a proposed methodology that included the AHP and TRIZ. Finally, we developed the inventive principles of resolving conflicts in design parameters for notebook computer. We believe that the methodology proposed by this study can provide innovation ideas for designer as a reference in green product design even for products besides notebook computer.

Acknowledgments

This work is supported in part by National Science Council of Republic of China under the grants NSC 95-2221-E-033-048-MY3 and NSC 98-2221-E-033-031-MY3.

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Paper ID: 223

An Integrated Model of Value Creation Based on the Refined Kano's Model and the Blue Ocean Strategy

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Abstract

It is not sufficient for a contemporary firm to satisfy its customers; to be really successful, a firm must create *value* for its customers. In so doing, it will also derive value *from* its customers. The pursuit of both value *for* customers and value *from* customers is thus a 'win-win' strategy. In this regard, the present study first redefines the categories of customer value by suggesting a new category of 'creative value', and then discusses how this category of 'creative value' relates to other forms of 'value'. The paper then explores the concepts inherent in the refined Kano's model and the actions associated with the 'blue ocean' strategy. Using these concepts, the study presents an integrated model of 'value creation' and explains how this model can be used to select appropriate practical actions to enhance customer value, and by implication, also enhance customer retention, customer acquisition, and customer margin—all of which make significant contributions to company profits. A case study is presented to illustrate the ease of application of the model in practice.

Keywords: customer value, value of customer, refined Kano's model, blue ocean strategy, creative value

1. Introduction

In the past two decades, the pursuit of 'quality' has become a growing concern for many companies throughout the world. Because 'quality' ultimately involves an understanding and fulfillment of the requirements and expectation of customers, enterprises have been pursuing product and service quality with the aim of satisfying customers (Yang, 2004). The close relationship between customer satisfaction and customer loyalty has been confirmed by many studies (Gorst et al., 1998, Sirohi et al., 1998). In turn, increased customer loyalty (and a high retention rate among those customers) is associated with an enhanced intention of future purchases (Eklőf and Westlund, 1998). Satisfied customers purchase more frequently (and in greater amounts), transaction costs decrease, and new customers are attracted with lower costs. For these reasons, customer loyalty and retention are becoming more important to the achievement of enhanced business performance and financial profits.

To raise the quality of their products and services, enterprises are increasingly making use of a variety of quality-management systems, methodologies, and tools—including quality control circle (QCC), business process re-engineering (BPR), Six Sigma, and ISO 9000—all of which can, essentially, be integrated with total quality management (TQM). The successful implementation of TQM does result in improved business performance and increased profits, as firms expect (Hendricks and Singhal, 1996; Gunasekaran, 1999; Hansson and Eriksson, 2002). The benefits come from enhanced customer satisfaction, cost reduction, and enhanced competitiveness (Youssef et al., 1996, Gunasekaran, 1999). However, the literature also contains reports of several cases in which the implementation of TQM has apparently failed (Hubiak and O'Donnell, 1996; Anonymous, 1996; Hellsten and Klefsjő, 2000). These studies have asserted that the implementation of TQM does not necessarily result in significant financial benefits, and can even have a negative impact on profits (Anonymous, 1996).

The major objective of the implementation of TQM is to satisfy customers (Hellsten & Klefsjő, 2000; Hansson & Klefsjő, 2003), and thus to enhance customer loyalty. However, the assumed relationship between customer satisfaction and customer loyalty has been challenged by some studies. Although satisfying customers would seem to be an effective means of enhancing customer loyalty, some studies have suggested that, in many industries, satisfied customers are not necessarily loyal customers (Reichheld, 1994; Schneider and Bowen, 1999). It would seem that customers are becoming increasingly demanding in their requirements, and that they are therefore searching for suppliers who are continuously improving their supply of quality products and their provision of excellent service (Willis, 1996). Woodruff (1997) described this purchasing behavior as a search for 'customer-perceived value'. In seeking such value, customers desire products and services that possess the attributes and performance that will facilitate the customers' achieving their purposes in using the product or service.

An increasing number of scholars and practitioners have become interested in this concept of 'customer-perceived value'. Research on customer-perceived value rests upon the presumption that customers want to maximize the perceived benefits and minimize the perceived sacrifices (Payne and Holt, 1999; Kotler, 2000; Lindgreen and Wynstra, 2005). This means that a given firm must continuously strive to create value for its customers—value that is perceived as being superior to the competition in terms of the customers' benefits and sacrifices (Tzokas and Saren, 1999). In doing so, the firm is also likely to deliver superior value to its shareholders (Doyle, 2000; Rust et al., 2000). All other things being equal, customers who are satisfied with the perceived value of a firm's goods or services will remain loyal to that firm and place their future purchases with that firm (Fornell, 1992; Eriksson and Lőfmarek-Vaghult, 2000; Lindgreen and Wynstra, 2005).

In discussing the related concepts of 'customer-perceived value' (from the perspective of the customer) and the 'value of a customer' (from the perspective of the firm), it is important to appreciate that the financial value of customers is an output of the overall value-creating process. In other words, customers become valuable to a firm only when that firm has something of value to offer to the customers (Lindgreen and Wynstra, 2005). It therefore follows that the aim of a supplier in providing value to customers is to gain financial value from those customers.

The present study explores these issues with a view to extending the understanding of the categories of 'customer value'. In this regard, the main purpose of the study is to analyze and integrate a refined Kano's model (Yang, 2005) with the 'blue ocean' approach (Kim and Mauborgne, 2005a; 2005b). The various categories of 'customer value' contained in these approaches affect customer acquisition, customer retention, and customer margin directly and indirectly. Because only a small proportion of valuable customers account for most of a firm's profits (Sherden, 1994; Ulrich and Smallwood, 2004), it is important that firms adopt effective approaches to the acquisition and retention of these valuable customers. The integrated model of creating customer value and firm value presented in the present study can be a useful reference for firms that wish to create greater value for customers—and hence for the firms themselves.

2. Categories of 'customer value'

The basic concept of 'customer value' is not new in marketing; it essentially reflects the fact that buyers and sellers seek to gain value from their business relationships (Lindgreen and Wynstra, 2005). According to the early studies, 'value' can be understood as: (i) a core attribute of a product or service; (ii) a psychosocial attribute of consumers as they interpret the core attributes of the product or service; or (iii) an economic attribute of satisfied and/or loyal customers in terms of their economic potential to the supplier.

Various authors have offered differing definitions of ‘value’ (Johanson et al., 1993; Park, 1998; Anderson and Narus, 1998; Kotler, 2000). In essence, the term ‘value’ can be said to imply a judgment of preference on the basis of certain criteria as assessed during an interactive, relativistic experience (Holbrook, 1994). Such an interactive. relativistic experience means that ‘value’ resides in a trade-off between the perceived benefits and the perceived sacrifices that are associated with a given good or service (Rokeach, 1973; Holbrook, 1994; Lindgreen and Wynstra, 2005). In monetary terms, ‘value’ can also be understood as the minimum amount that must be expended in purchasing or manufacturing a product to create the appropriate factors that determine its usefulness and esteem (Miles, 1961). In this regard, a simple definition of value, as endorsed by such authors as Park (1998) and Browning (2002), is given by the following sorts of equations:

$$Value = \frac{Functions}{\cos ts} = \frac{\text{Benefits}}{\text{costs}} \tag{1}$$

Essentially, this equation perceives ‘value’ in terms of involvement with the product (or service). This perceived value consists of the perceived benefits offered by the supplier’s product set against the costs (the price of the product and the other costs of using/owning it) (Lindgreen and Wynstra, 2005).

Because the value of a product (or service) to a customer is dependent on customer preferences and alternatives (Browning, 2002), any meaningful analysis of ‘value’ must be conducted from the perspective of the customer. According to Browning (2002), such ‘customer value’ depends on: (i) the intrinsic value of the product (or service) in terms of how well its attributes address customer needs; and (ii) any variation in the product’s value as a result of the existence of competing or alternative solutions to customer needs (that is, a substitute product). Such an analysis of ‘customer value’ goes beyond traditional measurements of customer satisfaction (Browning, 2002). Indeed, the measurement of ‘customer value’ in these terms represents a strategic marketing tool that can be used to clarify a company’s proposition to its customers in comparison with that of the competition (Lindgreen and Wystra, 2005).

Understanding ‘customer value’ in these terms enables a firm to design effective marketing programs (Gupta and Lehmann, 2005). Such programs recognize that a product can provide: (i) economic value; (ii) functional value; or (iii) psychological value. The first, ‘economic value’, is provided when a company can demonstrate to customers that they will save money by using its products rather than by using competing products. The second, ‘functional value’, assumes greater importance when it is difficult to show a clear economic benefit; in these cases, the value of the product usually resides in the benefits that can be gained from its functions or features. The third, ‘psychological value’, resides in brand names and related intangible factors (Gupta and Lehmann, 2005). In summary, according to Gupta and Lehmann (2005), value to the customer can be classified into three categories:

(1) economic value: the financial benefit that a customer derives from using a product—understood in terms of the net monetary advantage from using a given product as opposed to alternatives (over the life of the product);

(2) functional value: measurable functional or utilitarian benefits that accrue to customers from the performance features of a given product; and

(3) psychological value: psychological benefits gained from intangibles—such as brand names, image, and other associations with a certain brand.

It is the contention of the present study that these three types of value, although useful, do not exhaust all potential sources of value to customers. As Hamel & Getz (2004) have argued, the basis of any competitive advantage can be changed by radical ideas and innovations, and the present paper therefore contends that radical innovation can result in another kind of customer value—‘creative value’. The concept of ‘creative value’ is derived, at least in part, from the ‘blue ocean’ strategy of Kim and Mauborgne (2005a). In the development of the conceptual framework of their ‘blue ocean’ strategy, Kim and Mauborgne (2005a) emphasized that value innovation was the cornerstone of the blue ocean strategy. According to their viewpoints, value comes through innovation only if companies align innovation with utility, price, and cost. The present study takes up these ideas, and defines ‘creative value’ (or the value created by radical innovation) as the value of a ‘breakthrough’ new product that is designed as a result of radical ideas or sophisticated concepts. Such a product offers customers entirely new experiences, and thus creates new demand. The new value that is perceived by the customers is created by consumers’ positive feelings towards the novelty of the idea and its distinctive features.

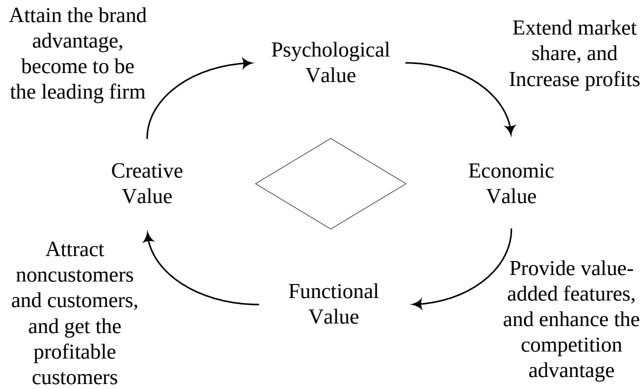

Figure 1. Rotation of the four categories of customer value.

The relationships among the four types of 'value' described here—'economic value', 'functional value', 'psychological value', and 'creative value'—can be visualized as a 'rotation', as depicted in Figure 1. Competition is usually the catalyst for a quest for enhanced value. Competition first causes most firms to embark on a quest for 'economic value'. This is especially the case with firms that possess a well-known brand name with which the firm wishes to extend market share. Firms thus adopt strategies that increase capacity, reduce costs, and improve productivity. As a result, supply increases and price decreases. However, in pursuing such 'economic value', profits are likely to be threatened, and some firms might even suffer a loss. Faced with these potential outcomes, some firms might choose to pursue 'functional value'. In these cases, firms aim to improve the product by adding new functions or improving the performance of existing functions. Pursuit of 'functional value' in this way is a popular strategy among firms; however, such a strategy does not guarantee enhanced profits. There is therefore increasing interest in pursuing a strategy of increasing the 'creative value' of goods and services. Indeed, some firms invest huge amounts of resources in the development of an innovative product that produces 'creative value' for customers. If such a distinctive product is enthusiastically embraced by consumers, the brand name of the product and the firm's image are both dramatically enhanced. As a result, significant 'psychological value' will be perceived by the firm's customers.

However, it is worthwhile for firms to pursue enhanced value for customers only if those customers are valuable to the firm. That is, value for the customer and value of the customer are complementary. Anderson et al. (1994) developed a framework for 'value of the customer' (see Figure 2). According to this model, the 'value of a customer' is obtained from the 'customer margin', which is affected by both 'customer retention' and 'customer requisition'.

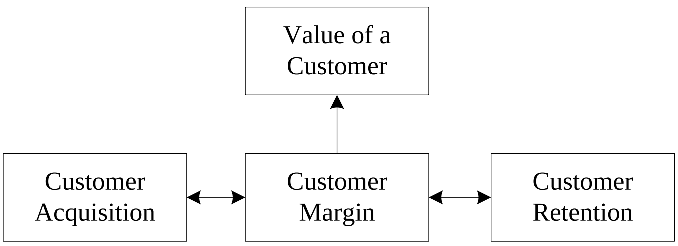

Figure 2. Framework of 'value of customer' (Anderson et al., 1994).

In terms of the concepts of value already presented in this paper, it is apparent that 'economic value' and 'psychological value' will directly affect the constructs of 'customer retention', 'customer acquisition', and 'customer margin' as depicted in Figure 2. In addition, 'functional value' and 'creative value' will affect 'customer retention' and 'customer acquisition' directly, and have an indirect effect on 'customer margin'.

3. Refined Kano's model and 'blue ocean' strategy

It is apparent from the above discussion that the critical questions for firms to address are what decisions to make about enhancing value, and when to make them. The concepts and constructs of a refined Kano's model (Yang, 2005), together with elements of the 'blue ocean' strategy (Kim and Mauborgne, 2005a; 2005b), can provide guidance for firms in addressing these questions.

3.1 Refined Kano's model

Kano et al. (1984) proposed that two aspects of any given quality attribute require assessment—an objective aspect as to whether a given quality attribute is fulfilled, and a subjective aspect of the customers' perception of satisfaction. These two aspects were used by the authors to construct a two-dimensional (or 'two-way') model. Using this model, quality attributes can be identified in five categories:

(1) attractive quality attributes: attributes that give satisfaction if present, but that result in no dissatisfaction if absent;

(2) one-dimensional quality attributes: attributes characterized by a linear relationship between the customers' perception of satisfaction and the degree of fulfillment of the attributes;

(3) must-be quality attributes: attributes whose absence will result in customer dissatisfaction, but whose presence does not significantly contribute to the customer satisfaction;

(4) indifferent quality attributes: attributes whose presence or absence does not cause any satisfaction or dissatisfaction to customers; and

(5) reverse quality attributes: attributes whose presence causes customers' dissatisfaction, but whose absence results in customers' satisfaction.

Kano's model has many applications (Miyakawa and Wong, 1989; Schvaneveldt et al., 1991; Matzler and Hinterhuber, 1998; Yang, 2005). However, Kano's model has a deficiency that prevents firms from precisely evaluating the influences of various quality attributes. The weakness of the model is a failure to consider the degree of importance of various attributes (Yang, 2005). In response to this problem, Yang (2005) refined Kano's model by taking account of the degree of importance of attributes as perceived by customers. The refined model effectively subdivided each of Kano's first four categories ('attractive', 'one-dimensional', 'must-be', and 'indifferent' quality attributes)—thus making a total of eight categories from the original four. The resulting eight categories (and the implications of the modifications) can be summarized as follows:

(1) by subdividing 'attractive' quality attributes in terms of importance:

- (a) highly attractive quality attributes ('attractive' quality attributes of high importance): strategic attribute offerings that represent effective means of attracting potential customers; and
- (b) less attractive quality attributes ('attractive' quality attributes of less importance): because these quality attributes have little attraction to customers, they can be reduced if cost considerations demand this.

(2) by subdividing 'one-dimensional' quality attributes in terms of importance:

- (a) high value-added quality attributes ('one-dimensional' quality attributes of high importance): attributes that make a significant contribution to customers' satisfaction and can therefore lead to increase revenue; firms should therefore make efforts to provide such attributes to customers; and
- (b) low value-added quality attributes ('one-dimensional' quality attributes of less importance): attributes that make a limited contribution to customer satisfaction; firms can reduce their provision of these attributes, but should avoid providing so little that customers become dissatisfied.

(3) by subdividing 'must-be' quality attributes in terms of importance:

- (a) critical quality attributes ('must-be' quality attributes of high importance): attributes that are critical to customers; firms must provide sufficient fulfilment of these attributes to customers; and
- (b) necessary quality attributes ('must-be' quality attributes of less importance): firms can meet these at a level sufficient to avoid dissatisfying customers.

(4) by subdividing 'indifferent' quality attributes in terms of importance:

(a) potential quality attributes ('indifferent' quality attributes of high importance): although few in number, these attributes will gradually become attractive attributes; firms can consider providing these to attract customers in the future; and

(b) care-free quality attributes ('indifferent' quality attributes of less importance): firms need not offer these attributes if cost considerations preclude this.

The refined Kano's model thus contained the following eight categories of attributes: (i) 'highly attractive'; (ii) 'less attractive'; (iii) 'high value-added'; (iv) 'low value-added'; (v) 'critical'; (vi) 'necessary'; (vii) 'potential'; and (viii) 'care-free'. In addition, the existence of a ninth category, Kano's category of 'reverse' attributes, should be noted.

3.2 'Blue ocean' strategy

The 'blue ocean' strategy of Kim and Mauborgne (2005a; 2005b) has attracted much interest among academics and practitioners. In presenting this strategy for retaining existing customers and attracting non-customers, Kim and Mauborgne (2005a) utilized a four-action framework, which they referred to as the 'eliminate-reduce-raise-create grid' (see Figure 3).

Eliminate	**Reduce**
Those factors or elements that no longer have value or may even detract from value for customers.	Those attributes that have been over-designed in the race of competition or those have little attraction of customers.
Raise	**Create**
Those attributes that can result in significant value for customers or those that have high attraction to customers.	Those factors that can discover new sources of value for customers or those that can create new demand and attract non customers.

Figure 3. Eliminate-Reduce-Raise-Create Grid (Kim and Mauborgne, 2005a).

The four aspects of the grid can be briefly summarized as follows:

(1) eliminate: to reduce costs, any factors or elements that no longer have value for customers (or might even detract from value for customers) can be eliminated;

(2) reduce: any attributes of products or services that have been over-designed in an attempt to match and beat the competition, or attributes that have little attraction to customers, and which are therefore increasing their cost structure for no gain, should be reduced;

(3) raise: attributes that can result in significant value for customers, or those that have high attraction to customers, should be assessed with a view to raising their fulfillment;

(4) create: factors that can produce entirely new sources of value for customers, or factors that can create new demand and attract non-customers, should be created.

4. Integration of refined Kano's model and 'blue ocean' strategy

It will be apparent from the above discussion that the critical issue in applying the framework of the 'blue ocean' strategy is to identify the attributes or factors that should be eliminated, reduced, raised, or created. It is the contention of the present study that integration of these categories of actions with the categories of attributes identified in the refined Kano's model (as described above) will facilitate such identification. The following integrated categories of attributes and actions are therefore posited:

(1) highly attractive attributes: these factors are highly attractive to customers, and are unlikely to be offered by competitors; firms should raise these factors, and even create new highly attractive attributes to acquire non-customers;

(2) less attractive attributes: these attributes have some attraction to customers, albeit limited; firms should maintain the existing level of these attributes, but fulfillment levels of these attributes can be reduced if required by cost considerations;

(3) high value-added attributes: these attributes make a significant contribution to customer value; the fulfillment levels of these attributes should be raised;

(4) low value-added attributes: these attributes make a limited contribution to customer value; firms can reduce the fulfillment levels of these attributes to reduce costs. but care should be taken to avoid reducing these attributes to a level that will cause customer dissatisfaction.

(5) critical attributes: these attributes are of great importance to customers and are usually important competitive weapons for firms; the fulfillment levels of these attributes should therefore be raised;

(6) necessary attributes: these attributes are necessary for customers, but cannot raise customer satisfaction significantly; these attributes should therefore be maintained at existing levels; however, as in the case of low value-added attributes, care should be taken to avoid reducing these attributes to a level that will cause customer dissatisfaction.

(7) potential attributes: there are actually few attributes in this category (that is, 'indifferent attributes of importance' in the refined Kano's model); however, if some potential attributes do appear, firms should improve their level of fulfillment level of these attributes—because they do have potential to satisfy customers in the near future;

(8) care-free attributes: firms should eliminate these attributes in view of cost considerations;

(9) reverse attributes: firms should eliminate these attributes to avoid dissatisfying customers.

Figure 4 illustrates a model of 'value of customer' based on integration of the refined Kano's model and the actions of the 'blue ocean' framework. The nine attributes noted above appear along the bottom-right of this diagram. The other three attributes, which are associated with new innovative products, are discussed later in this paper.

As can be seen in the diagram, the effects on the various categories of 'customer value' (as defined above) are as follows:

(1) creating or raising 'highly attractive' attributes should contribute to both 'psychological value' and 'creative value';

(2) the maintenance of 'less-attractive' attributes will result in a small contribution to 'creative value', and reducing these attributes will have some positive effect on 'economic value';

(3) raising 'high value-added' attributes can contribute to both 'psychological value' and 'functional value'; raising 'critical' attributes has similar effects;

(4) conditionally reducing 'low value-added' attributes can reduce costs ('economic value');

(5) reducing 'necessary attributes' is good for 'economic value', but might have negative impact on 'functional value'; in contrast, raising 'necessary' attributes makes a small

contribution to 'functional value', but will increase costs; firms therefore need to make a 'trade-off' between 'functional value' and 'economic value' in deciding on an appropriate level of fulfillment of these attributes;

(6) improving the 'potential' attributes will affect 'functional value' in the near future, but the effect is not very significant; and

(7) eliminating the 'care-free' attributes and the 'reverse' attributes should contribute to 'economic value'.

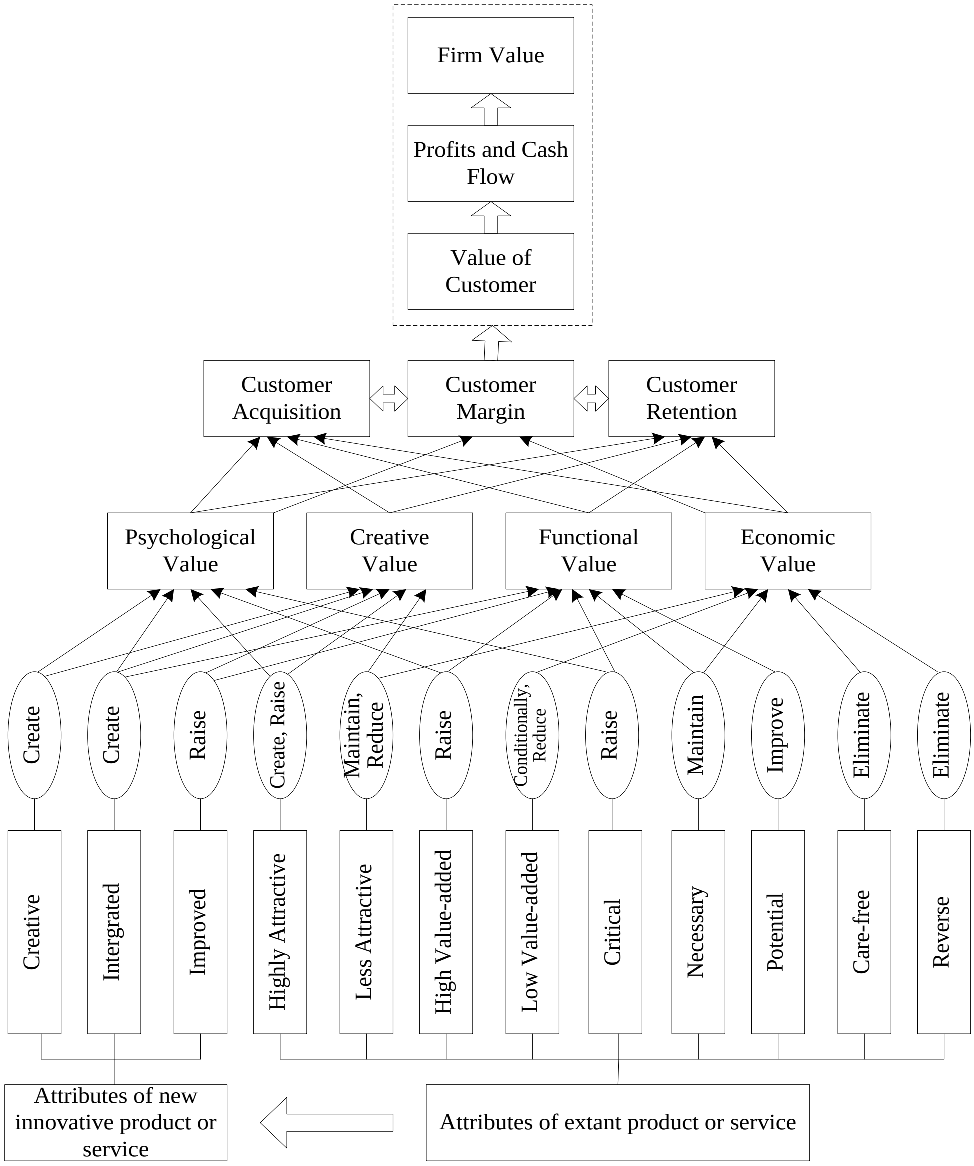

Figure 4: Model of "Value of Customer" based on the integration of refined Kano's model and "Blue Ocean" framework.

The applicability of this integrated model to innovative products is worthy of special consideration. Because the identification of the categories of the refined Kano's model is achieved by using a questionnaire survey of customers (Kano et al., 1984; Yang, 2005), and because customers complete the questionnaire on the basis of their past experience of using existing products or services, it is difficult for firms to perform the 'create' action of the 'blue ocean' strategy by using the Kano's methodology. However, new products are critical if firms are to survive and develop in today's competitive environment (Pun & Chin, 2005), and new products are drivers of progress in a firm's attempts to fulfill customers' wants and needs (Dimancescu and Dwenger, 1996). Moreover, 'value innovation', which places equal emphasis on value and innovation, is the cornerstone of the 'blue ocean' strategy (Kim and Mauborgne, 2005a).

Such 'value innovation' occurs only when companies align innovation with utility, price, and cost (Kim and Mauborgne, 2005a), and incremental product innovations are effective in 'locking in' only current customers (Treacy, 2004). It is therefore apparent that breakthrough product innovations are required to acquire new customers.

In the development of new products, there are three options to be considered by firms.

(1) Improve the features of product: Companies might choose to improve an extant product or service by enhancing (or 'raising') the important features of the product. This option matches the 'raise' action noted above, and has effects on 'creative value' and 'functional value'.

(2) Integrate critical features into a new product: Firms are increasingly facilitating the development of new products by integrating several critical features—especially the 'highly attractive attributes' and 'high value-added attributes'—into new products or services. This strategy matches the 'create' action noted above, and will contribute to 'psychological value' and 'creative value' significantly.

(3) Create innovative products: To acquire new customers and non-customers by researching and developing an innovative product is the best initiative of the 'create' action of the 'blue ocean' strategy. This has significant effects on 'psychological value' and 'creative value'.

This leads to the identification of a further three types of attributes—'improved' attributes, 'integrated' attributes, and 'creative' attributes—which are all related to new innovative products (see bottom-left of Figure 4).

5. Application of the model

Many recent studies have investigated aspects of the possible integration of new product design (NPD), research and development (R&D), and marketing (Griffin and Hauser, 1996; Gemser and Leenders, 2001; Pun & Chin, 2005); others have attempted to identify the factors affecting the success or failure of NPD and/or to measure the performance of NPD (Mullins and Sutherland, 1998; Pun and Chin, 2005). It is the contention of the present study that the integrated model presented here is a powerful strategic tool for firms to utilize in seeking to achieve the goal of integrating NPD, R&D, and marketing.

The critical aspects of the application of this integrated model are: (i) the identification of the categories of the refined Kano's model; (ii) the identification of the appropriate actions (from the 'blue ocean' strategy) applicable to those categories; and (iii) the actual NPD, involving the integration of all critical features. The identification work can be conducted by using a questionnaire survey of customers, as illustrated in the following example.

The present author cooperated with a home-appliance manufacturer with regard to the development of an air-conditioner. To determine the appropriate quality attributes to be included in a questionnaire, approximately 20 key customers were first interviewed, followed by two internal panel discussions with front-line employees. As noted above, the refined Kano's model incorporates consideration of importance of attributes into Kano's original classification. Two kinds of questionnaires were therefore designed:

(1) the categorization of quality attributes according to Kano's model; and

(2) the degree of importance of quality attributes (as assessed by customers).

The questionnaires were mailed out to 1400 random customers; in all, 150 valid completed questionnaires were used in the analysis. The results are presented in Table 1.

As can be seen in the second column of Figure 5 in appendix, 17 attributes were identified; of these, five were categorized as 'high value added' attributes, three as 'critical' attributes, one as a 'highly attractive' attribute, four as 'lower value-added' attributes, two as 'less attractive' attributes, and two as 'care-free' attributes.

Following identification of the categories of the attributes in terms of the refined Kano's model, it was possible to suggest appropriate actions for each, according to the model described above (Figure 4). If followed, these suggested actions for each of the attributes are likely to have significant effects on some of the various categories of 'value'. If the firm implements these suggested actions effectively, the overall value (including value for customers and value from customers) is likely to be increased significantly. This is illustrated on the right side of Figure 5 in appendix.

Table 1. Air-conditioner quality attributes.

Ranking	**Quality attribute**	**Importance (mean)**	**Satisfaction (mean)**	**Category in Kano's model**	**Category in refined Kano's model**
1	Compressor noise	4.46	3.46	One-dimensional	High value-added
2	Outlet noise	4.33	3.54	One-dimensional	High value-added
3	Anti-erosion of heat exchanger	4.32	3.76	One-dimensional	High value-added
4	Stainless base	4.15	3.90	Must-be	Critical
5	Ease of maintenance and cleaning	4.07	3.75	One-dimensional	High value-added
6	Air-cleaning efficiency	4.04	3.65	One-dimensional	High value-added
7	Temperature display (room and setting)	4.02	3.87	Must-be	Critical
8	Inverter compressor	3.95	3.63	Must-be	Critical
9	Negative ions	3.95	3.76	Attractive	Highly attractive
10	Material accordance of base and internal compressor surrounding	3.93	3.71	Attractive	Less attractive
11	Free wind control and auto louver function	3.92	3.65	One-dimensional	Low value-added
12	Ease of portability and installation	3.80	3.65	One-dimensional	Low value-added
13	Attractiveness and design for external looks	3.77	3.73	One-dimensional	Low value-added
14	Wired and wireless control function	3.68	3.77	Attractive	Less Attractive
15	Universal remote control	3.57	3.65	Indifferent	Care-free
16	Cleanliness of surface	3.56	3.66	One-dimensional	Low value-added
17	Pre-order function of starting time	3.35	3.55	Indifferent	Care-free
	Mean	**3.941**	**3.678**		

Note: Ranking is according to level of importance. If two or more attributes have the same importance level, the attribute with a smaller deviation is ranked higher.

Because the survey using the refined Kano's model is based on the attributes of extant products, the attributes appearing in Figure 5 represent existing attributes provided by the home-appliance industry. For obvious reasons, the creative attributes of a new innovative product are not included. Nonetheless, the firm can create appropriate attributes for the new innovative product on the basis of the attributes of existing products.

Daikin is a well-known manufacturer of air conditioners, and Daikin air-conditioners have demonstrated excellent performance features in recent years. One of the important factors in the company's success is that it developed the core technologies and materials required to raise the fulfillment level of the 'high value-added' and 'critical' attributes—for example, reduced compressor noise, reduced outlet noise, air-cleaning efficiency, and ease of maintenance and cleaning. Moreover, to reduce power usage, the firm also developed high value-added attributes in their 'reluctance DC compressor motor' and the 'inverter compressor power controller'. In addition, the following attributes and functions should be noted:

(1) lot-set design: integrated indoor units and outdoor units for customized demands (as an 'integrated' attribute);

(2) anti-fungus function: a 'highly attractive' attribute;

(3) intelligent touch-control-web function: a 'creative' attribute;

(4) intelligent sensor to control temperature and reduce power usage: a 'high value-added' attribute.

(5) self-detection and automated display of broken parts: this function can assist in undertaking repair work quickly and effectively; it is thus a 'highly attractive' attribute.

As previously explained, these attributes can all contribute to 'creative value', 'psychological value', and 'functional value', see the first five items in Figure 5.

6. Conclusion

It is not sufficient for a firm to satisfy its customers; to be really successful, a firm must create value for its customers. In so doing, it will also derive value from its customers. The pursuit of both value for customers and value from customers is thus a 'win-win' strategy. In this regard, the present study has developed an integrated model of value based on a combination of the refined Kano's model (Yang, 2005) and the framework of actions associated with the ‘blue ocean’ strategy (Kim and Mauborgne, 2005a; 2005b). This integrated model can enable firms to navigate their way to a ‘win-win’ strategy.

Although a case study illustrating the application of the integrated model has been provided in the present paper, more empirical studies of the proposed model are required. In addition, because certain attributes are especially applicable to new products, the integrated model presented here should be linked with new product development, especially the development of innovative new products. Another issue to be noted is that this integrated model can also be combined with a performance-management system—such as the ‘balanced scorecard’. The issues associated with this will be examined in future studies.

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Appendix

Attributes	Categories of Refined Kano model	Suggested action
a. Lot – set design	Integrated	Create & Raise
b. Anti – fungus function	Highly attractive	Raise
c. Intelligent touch – control – web function	Creative	Create
d. Intelligent sensor to control temperature	High value – added	Create & Raise
e. Self – detection and automated display of broken parts	Creative	Create
1. Compressor noise	High value-added	Raise
2. Outlet noise	High value-added	Raise
3. Anti-erosion of heat exchanger	High value-added	Raise
4. Stainless base	Critical	Raise
5. Ease of maintenance and cleaning	High value-added	Raise
6. Air-cleaning efficiency	High value-added	Raise
7. Temperature display (room and setting)	Critical	Raise
8. Inverter compressor	Critical	Raise
9. Negative ions	Highly attractive	Create & Raise
10. Material accordance of base and internal compressor surrounding	Less attractive	Maintain or reduce
11. Free wind control and auto louver function	Low value-added	Conditionally reduce
12. Attractiveness and design for external looks	Low value-added	Conditionally reduce
13. Ease of portability and installation	Low value-added	Conditionally reduce
14. Wired and wireless control function	Less attractive	Maintain or reduce
15. Universal remote control	Care-free	Eliminate
16. Cleanliness of surface	Low value-added	Conditionally reduce
17. Pre-order function of starting time	Care-free	Eliminate

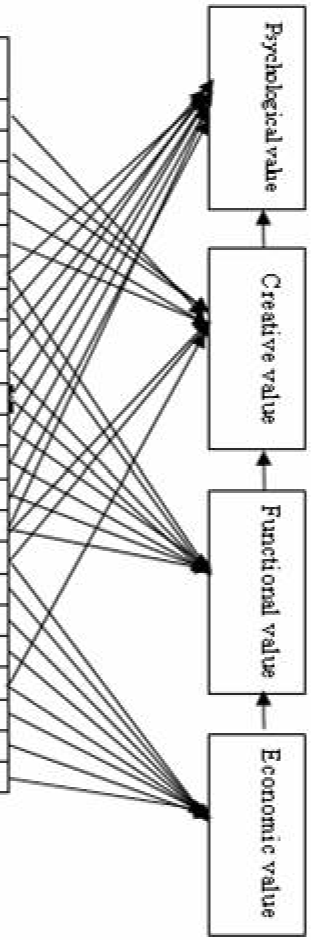

Figure 5. The display of the refined Kano's model of air-conditioner and the suggested actions, and the resulting customer values.

Paper ID: 276

TRIZ stories and experiences at Samsung

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Abstract

TRIZ had been introduced to Samsung Advanced Institute of Technology(SAIT) since 1999. For ten years, TRIZ has solved bottleneck problems in almost all fields in Samsung Electronics, Samsung Electro-Mechanics, Samsung SDI, Samsung Corning Precision Glass and Samsung Mobile Display.

Samsung Mobile Display (SMD) introduced TRIZ methodology to solve the difficult problem and organized TRIZ promotion team to propagate TRIZ in 2009. In the first years, SMD achieved remarkable results. We successfully conducted 48 projects, brought up 28 TRIZ experts, introduced TRIZ methodology based on modern TRIZ and developed TRIZ supporting system etc.

In this paper, we explain the successful launching stories of TRIZ in SMD and Samsung relatives.

Keywords: TRIZ, Samsung, Samsung Mobile Display, OSTM, Problem Solving, Creativity

1. Introduction

1.1 About Samsung Mobile Display[1]

Samsung Mobile Display is newborn corporation founded in January, 2009 through joint financing from Samsung Electronics and Samsung SDI.

The core technological capabilities for the display industry have being concentrated in Samsung Mobile Display, which drew upon Samsung Electronics’ market-leading capabilities for LCD panels and its large-scale AMOLED R&D, and from Samsung SDI’ s AMOLED mass production technology and its development capabilities for LCD modules.

Samsung Mobile Display has three places of business (in Cheonan, Busan, Giheung), one research center (in Giheung) and two foreign corporations (in Tianjin and DongGuan) in China.

One of the vision of SMD is to be the No1. company in the small-and-medium display panel market such as AMOLED, PMOLED, STN LCD, TFT LCD and TSP (touch screen panel) and the other is to be the first company in the world to commercialize laptop computers, large televisions, and flexible displays based on AMOLED panels.

Every CEO considers that the creativity is the most important thing of several ingredients for innovation. Mr. Kang Ho Moon, CEO of SMD, is no exception. He always says "TRIZ will be matched to solve our business problems" because SMD is a frontier company in the area of AMOLE and LCD. We must solve difficult problem by ourselves because SMD has no benchmarking solutions. Therefore, he strongly recommends TRIZ to solve the problem and organizes TRIZ promotion team to propagate TIRZ.

1.2 Basic approach to solving problems using TRIZ

Our basic approach to solving problems using TRIZ has been described by simple words as "Right projects + Right peoples + Right tools + Right support = Right results" [2]. 'Right projects' means best project which is solved by TRIZ methodology. 'Right peoples' can be explained the people who has TRIZ Level. Also, 'Right tools' means the most coincident solving tool with SMD problems among methodological tools. 'Right support' is TRIZ education process and effective interaction system between TRIZ promotion team and researchers in the real consulting projects.

In this paper, we describe in detail our experience and features of realization TRIZ implementation process in the view point of our basic approach.

2. Right project

2.1 The feature of SMD TRIZ project

Generally, the special feature of SMD TRIZ is that projects are drawn through top-down process – (1) CEO, team leader and group leader propose projects related with real problem in SMD. And then (2) TRIZ promotion team organizes Task Force

Team(TFT) consisted of engineer, TRIZ experts, computer-aided engineers and analyzer. Finally (3) CEO approves constitution of TFT. This process is very effective way to introduce TRIZ in an early stage.

Figure 1 shows the classification of TRIZ project which is successfully conducted in 2009. There are four kinds of classification; Persistent problem over 2 years, Large-size AMOLE display problem, Preceding technology for small-size display problem and Defect improvement problem. Persistent problem takes over 50%. That means TRIZ is good methodology for the unsolved problems for a long time.

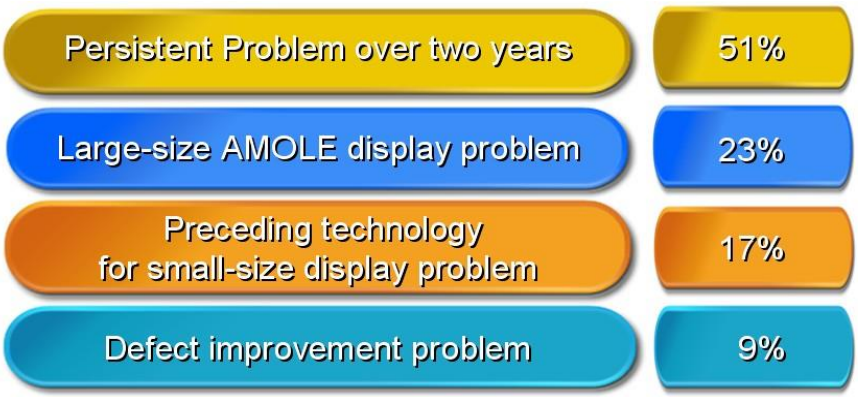

Figure 1. Classification of TRIZ Project which are conducted in 2009

2.2 Typical problem applied TRIZ

Typical problems can be applied TRIZ application are:

- Improvement quality and productivity of technological process :
e.g. AMOLED LTPS process, Evaporation and Encapsulation etc
- Development of the core and new technologies or process :
e.g. large-size AMOLED display etc
- Development of new business : e.g. Flexible Display, X-lay Display etc
- Combined types of problems
- Circumventing patent

All projects happened in SMD are divided into 2 main categories. Comparison of these categories is exhibited in the following table.[3]

Table 1. Comparison 2 kinds of projects

Criteria	Main object of project	
	Mass production technology process	Research & Development
Possibility of changes of initial technical system	Restricted	Possible
Main criteria of concept evaluation	Simplicity, easiness for realization	More effective solution for mid and long term
Level of description of the proposed solutions	Detailed as mush as possible	Brief but clear description

3. Right people

‘Right people’ is the engineer who has TRIZ Level and we call them ‘creative elite’. Figure 2 shows the condition of creative elite. They must have following talent such as core ability, high technical sense, leadership, service mind and English ability. .

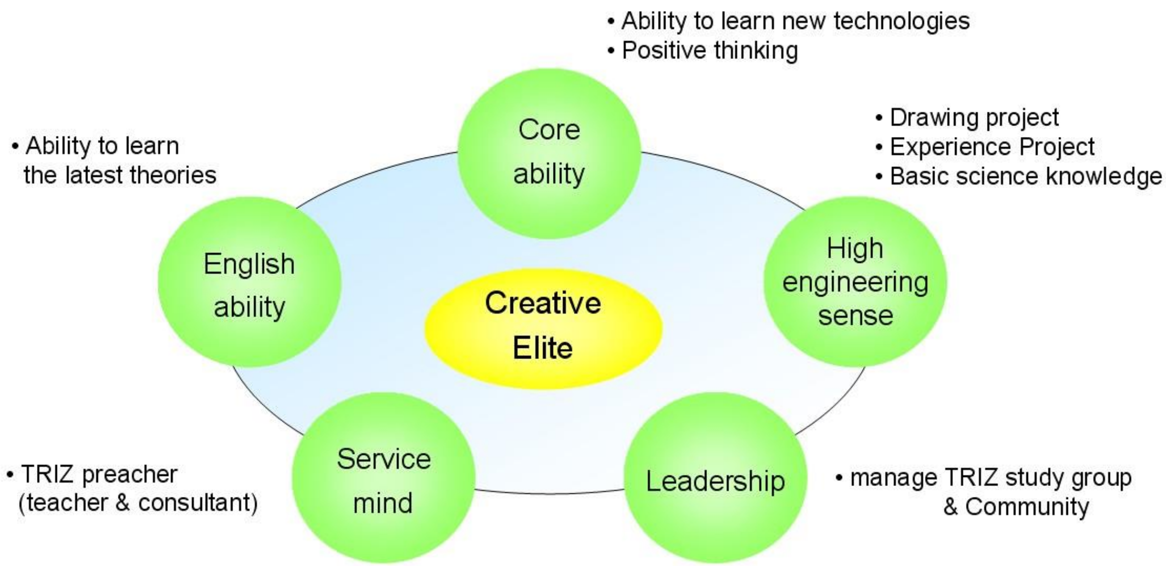

Figure 2. Conditions of Creative Elite

We made program to bring up excellent ‘creative elite’. This program is managed by TRIZ expert who has level 3 or level 4 during two weeks. In other words, ‘Right people’ teaches the new ‘Right people’. ‘creative elites’ have to carry out two projects during 6 months as they are consulted by TRIZ expert including Russian TRIZ expert.

After completing this program, the roll of ‘Creative elite’ is to propagate TRIZ methodology at their team. In last year, twenty engineers had been qualified as ‘creative elite’

4. Right tool

4.1 TRIZ Methodology

We introduced TRIZ methodology based on modern TRIZ[4] in SMD. Solution process of problems using modern TRIZ is schematized in Figure 3. The most problems happened in SMD are complex and non-typical. In order to solve these problems, the first of all, we redefine about real problems and project's goals in details with the tool of WIW(What I Want) and ENV. Secondly, we examine current states of caused problems with tool of MST(Multi Screen Thinking), OT(Operation Time) and OZ(Operation Zone). Thirdly, through RCA(Root Conflict Analysis) and Function Analysis, we try to change these complex problems to simple problems. After all of these processes have done, a lot of solutions are generated by useful tools such as effects, inventive standards, 40 principles, separation rule and ARIZ.

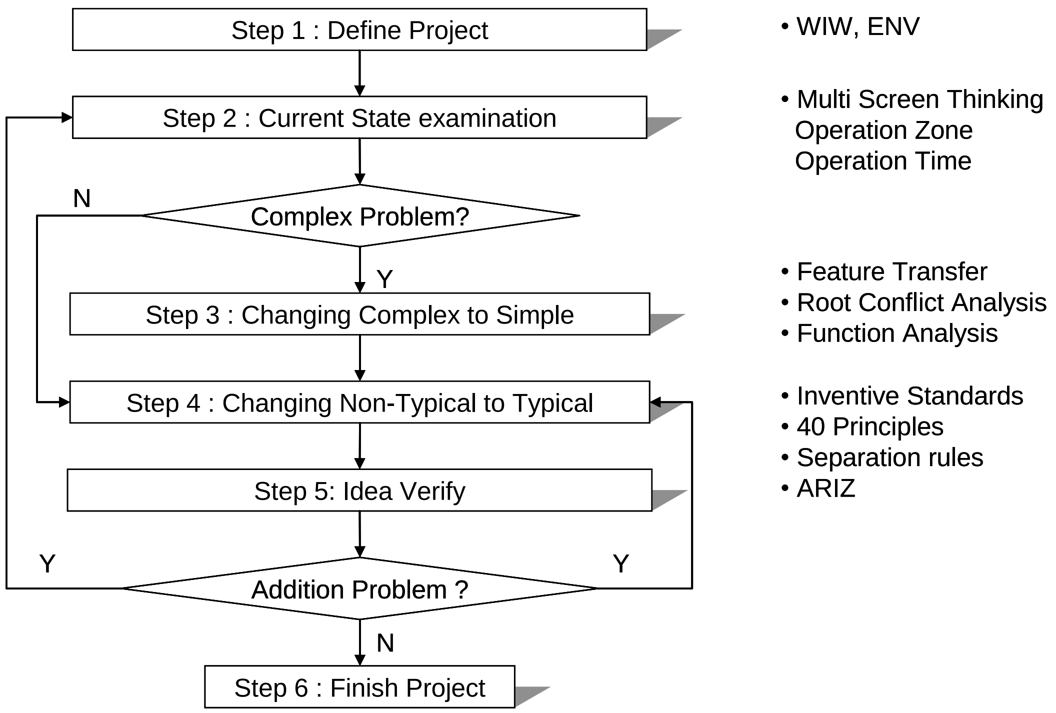

Figure 3. TRIZ Methodology

4.2 TRIZ Tool Analysis

Figure 4 shows that what kind of tool is more useful to solve the problem in SMD. Every project used ENV and MST Tool. That means all projects need to redefine problems and check current state of problems in more detail. In the step of 'Changing Complex to Simple', RCA is the most useful tool in SMD projects. In the case of set maker such as Samsung Electronics, function analysis is generally used. In the step of 'Changing Non-Typical to Typical', inventive standards which are used to generate idea takes the most portion among several tools.

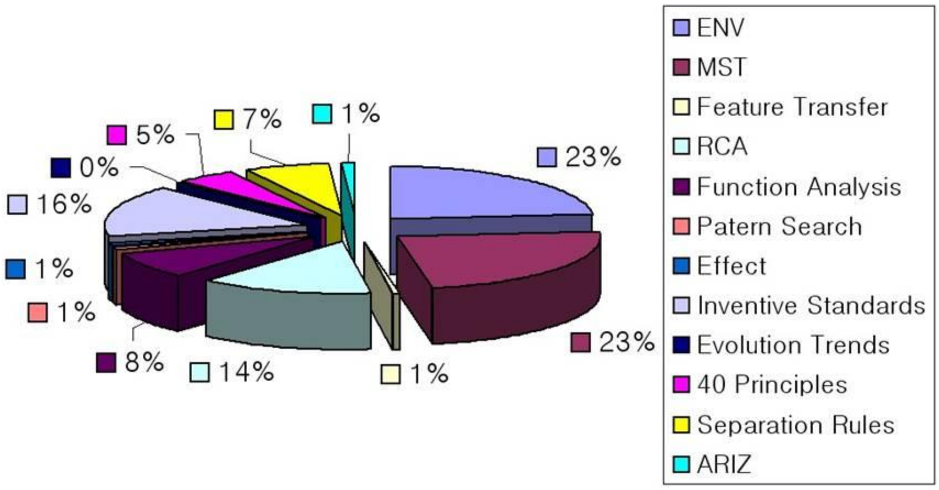

Figure 4. Proportion of each TRIZ tools which are adapted in 2009 projects.

4.3 TRIZ promotion team

TRIZ Promotion Team is very important to propagate TRIZ in our company.
The missions of this team are
- to develop of methodology accorded with feature of R&D and Mass manufacture projects.
- to consult project as visiting the 'scene' and checking the real steps with SEM(Scanning Electron Microscope), TEM(Transmission Electron Microscope) and moving image.
- to train educatee with four step training course (this course will be explained at 4.4).
- to find the future core product and business.

TRIZ promotion team consists of Team Leader, TRIZ expert, Russian expert and prototyper. We achieved best consequence with the organized activity based on the collaboration among Korean engineers, researchers and Russian TRIZ experts. It is well-known that Russia (properly speaking, Soviet Union) is motherland of TRIZ. Therefore we employed and worked with Russian experts because many Russian TRIZ specialists have knowhow, deep understanding and many experience about TRIZ application. The best way of using these unique resources is co-work because high qualified Russian specialists support informal world wide network for information interchange. They are very important resources to make the ability of TRIZ promotion team to enhance.

4.4 Curriculums of TRIZ education in SMD

The special feature of TRIZ education curriculum is that even CEO and inside directors have to pass through a basic training course. Their high understanding to TRIZ leads strong momentum to propagate TRIZ in SMD.

We developed four step of education course (cyber training, basic training, level 2 training and level 3 training) to level up skill of educatees gradually. They have chances to solve a wide range of inventive problems during the instruction period. Table2 is summary of each course.

Table 2. Curriculums of TRIZ education in SMD

Step	Course	Attendance	Type	Time		Main contents
				Training	Project	
1	Cyber	All staff	On-Line	20hrs	-	Fundamental TRIZ
2	Basic	CEO / Director Engineer	Gathering	24hrs	-	Classical TRIZ
3	Level 2	Creative Elite	Camp	60 hrs	50hrs	Modern TRIZ Basic of ARIZ TRIZ Software Practice Project
4	Level 3	Level 2	Gathering	16 hrs	8hrs	Advanced ARIZ Coaching Skill Practice Project

The cyber training program was made by Samsung Electronics and has been used overall Samsung group. This course provides basic overview and understanding about

TRIZ methodology, so participants get ability to design a long-term training program that is most appropriate for their interest and duty. It is a compulsory training course for all employees in SMD and a very useful program for beginner of TRIZ.

Basic training course is enable attendees to apply basic TRIZ principles and tools to their own projects. This course provides a main fundamental TRIZ tools such as RCA, Function Analysis, 40 principles and 76 inventive standards etc. Detailed Korean textbooks are prepared and systematically updated through feedbacks during education period. In this step, we can identify potential students who are interested in more in-depth TRIZ work.

In order to certificate level 2 grade, level 2 training course is provided to educatees who passed through basic training course. This course consists of modern TRIZ, TRIZ S/W and basic ARIZ. Attendances practice application way of TRIZ as carrying out their own project during course with TRIZ expert. The textbook in this course is supplemented by many SMD's execution examples. The main goal of this training course is to help them become more innovative and competitive through the understanding and utilization of proven TRIZ methodology.

Level 3 Training course is also level 3 certification course. This course provides advance ARIZ and coaching skill. The people who attend this program have to make a project which attendees will try to solve with ARIZ tool. The main goal of this training course is to help them get ability to use TRIZ not only for technical problem solving, but also for management problems, to teach other TRIZ users to apply and to develop the new TRIZ tools.

4.5 TRIZ supporting(consulting) program

In Level 2 training course, field researchers firstly meet TRIZ consultant and redefine problem and check current state with TRIZ consultant during training period. After finishing training course, main step to solve SMD's un-solved problem is stared through committee consisted of attendances and TRIZ expert. The period of activity depends on the scope of work and the ability of attendances. Usually for 4 to 6 weeks, several dozens of preliminary concepts are used to be generated by TRIZ. After then, 7 weeks are required to verify concepts and ideas generated by TRIZ. Finally field researchers file up these concepts as patents and write down activity report. TRIZ consultant also retrieves concepts and writes down supporting report. These retrieved concepts by TRIZ consultant will be powerfully used for other TRIZ activity.

4.6 TRIZ supporting System

We develop TRIZ supporting system for effective operation of the TRIZ project and communication between users. This is the first system that is systematized TRIZ activities in Samsung. It has 3 main function; managing TRIZ projects, sharing TRIZ data and publishing activities using TRIZ.

In function of managing TRIZ projects, we can do following; registration, progress, monitoring, assessment and output-document registration of projects. Also, in function of sharing TRIZ data, we can upload and download the document about education materials, seminar materials and good cases of projects. we can also announce TRIZ events and notifications such as festival and communities in function of publishing activities using TRIZ.

4.7 TRIZ Festival

For motivation to performing TRIZ project and booming up TRIZ, we planed special TRIZ festival. For examples, in November 2009, the best 12 projects were presented and 62 projects were posted their results to every employee in SMD. According to decision of jury consisted of CEO and inside directors, seven peoples of them were awarded prizes.

4.8 STA (Samsung TRIZ Association) Webzine

STA was established in 2006. STA has issuing webzine to enhance TRIZ activity and create synergy effect among Samsung relatives through sharing TRIZ information and their issue. Now, Samsung Electronics, Samsung Electro-Mechanics, Samsung SDI, Samsung Corning Precision Glass and Samsung Mobile Display are participated in STA .

5. Right Result

In 2009, SMD introduced TRIZ to solve difficult and un-solved problems. SMD achieved remarkable results in short period.

In terms of ‘Right project’, we successfully conducted 48 difficulty projects about AMOLED and LCD products and recognized about 50 patents. Many of the projects have secondly contradiction, but we overcame them. Cooperation with R&D, CAE, analysis and manufacturing technique division made possible these results.

In terms of ‘Right peoples’, we brought up 20 engineers as TRIZ expert. Now we have 28 TRIZ experts in SMD. They should be capable of solving high-level inventive problems, be able to teach trainees to employee, be able to manage a TRIZ Team and coordinate activities.

In terms of ‘Right tools’, we introduced TRIZ methodology which is base on modern TRIZ and analyzed useful tool for SMD. The useful tool in SMD is WIW, ENV, MST, RCA and Inventive standards. On the other hand, Samsung Electro-Mechanics is using RCA most and Samsung Electronics is using Function Analysis most.

In terms of ‘Right support’, we developed TRIZ support program and system and introduced TRIZ software, Gildfire 5.5. In case of Samsung Electronics, they developed TRIZ software which called it I-Spark. It will be powerful TRIZ software in the world. We opened TRIZ festival successfully.

6. Future works

TRIZ is successfully launched in SMD last year. However we need more effort to settle it in SMD.

For next steps, We focus on following : In terms of “Right projects”, We will draw project by not only CEO and leader but also field researcher and reinforce TFT (Task Force Team) project. In terms of ‘Right peoples’, we will bring up TRIZ expert up to 100%. In terms of ‘Right tools’, we will improve TRIZ methodology with continuously modified toolset and develop TRIZ methodology for indirect business such as marketing and human resource division etc. In terms of ‘Right supports’, we will improve quality and effect of TRIZ education and consulting program and open TRIZ festival regularly.

SMD will be more innovative and competitive company through the understanding and utilization of proven TRIZ.

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Paper ID: 277

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. 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.

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

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.

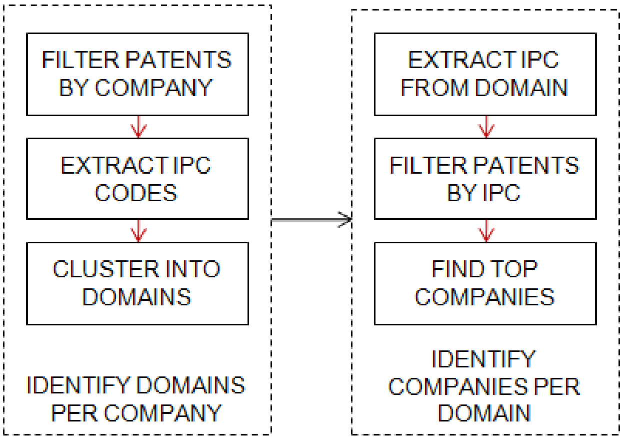

Figure 2: Data flow

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:

1. 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.
2. 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.
3. Finally, we can discover which companies are the top applicants in the subset of documents.

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.

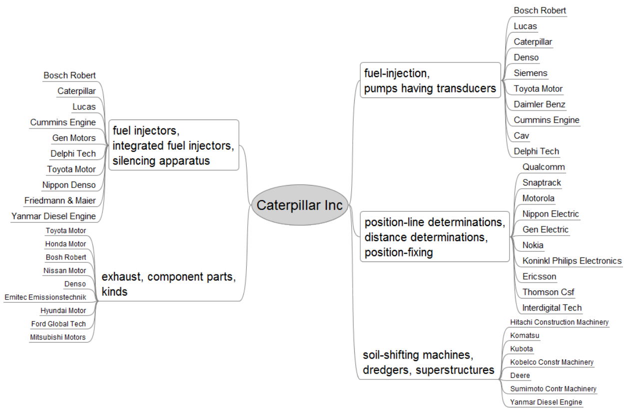

Figure 4: Tree-based visualization of patent domain analysis of Caterpillar Inc.

Figure 5: 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.

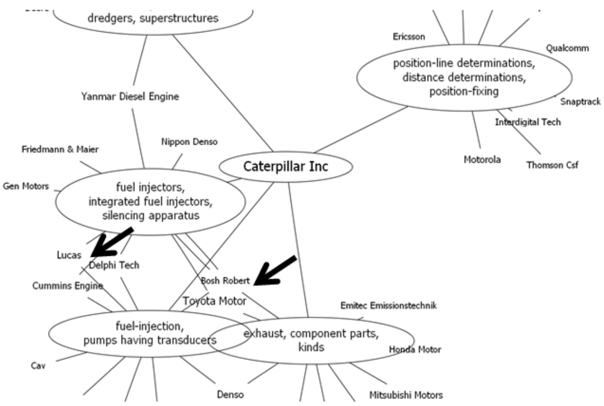

Figure 5: Detecting candidates for Open Innovation opportunities in graph visuzalition

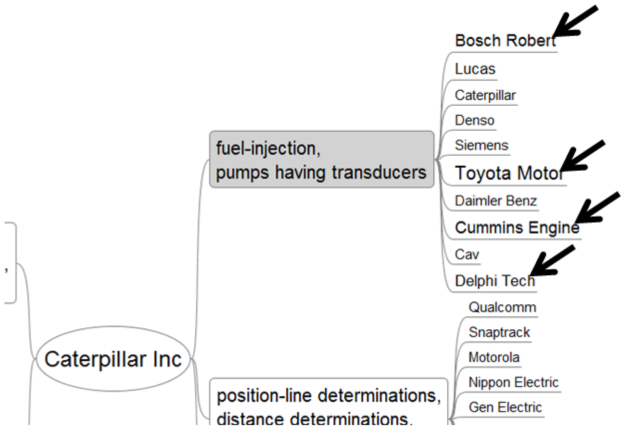

Figure 5: Detecting candidates for Open Innovation opportunities in graph visualisation

In this case, Caterpillar can identify that in the area of fuel-injection Delphi systems has competing knowledge. This means a listing of this 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.

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Paper ID: 278

Why Lean and Six Sigma Thinking is Unlikely to Solely Help Beat the Recession

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Abstract

Previous research by the author has tried to identify the 'break-through' thinking tools and creative processes that are employed by engineers and their managers when using Lean or Six Sigma. Separately the break-through thinking tools and approaches used by TRIZ practitioners have been explored. What has been found is that TRIZ has a wealth of tools available compared to Lean/ Six Sigma. Looking at the underlying motivation between these two area using a well known approach such as Myers-Briggs, suggests that the TRIZ approach leads to practitioners looking for new opportunities and being comfortable with change etc, whereas the Lean/ Six Sigma users and managers may more likely follow the safe/ no risk path, In a recession (or being faced with an innovative competitor), the ground rules are altered and new opportunities are present. This is precisely the time when TRIZ practitioners should be utilised and in particular when managers should encourage TRIZ thinking into their teams.

Keywords: Lean, Myers-Briggs, Six Sigma, TRIZ.

1. Introduction

In a very recent article in the Harvard Business Review, Dyer, Gregersen, and Christensen (2009) ask what separates the real innovators from the rest of us. From a six year study, they propose five 'discovery skills' of which four are classified as 'doing' skills': questioning, observing, experimenting and networking, and one: associate, is classified as a 'thinking skill'. The article looks at what many classify as psychological and creative thinking skills and also at the area that the author classifies as 'mindsets'.

This paper focuses on the 'innovative skills' of engineers and their management. It will become apparent, that TRIZ practitioners have many skill set equivalences to those mentioned for the very top innovative entrepreneurs in the Harvard paper. In previous papers (Filmore 2007a, 2008a, 2008b), key attributes ('skills') of 'highly effective engineers' were identified and then linked to the creativity/ problem solving potential of TRIZ practitioners. Subsequently (Filmore 2008b) the problem solving and creativity potential of engineers using TRIZ and those using Lean/ Six Sigma was compared. What was found was that TRIZ had a much wider innovative toolset than Lean/ Six Sigma. This paper takes the work further by asking what limits the innovative entrepreneurial potential of engineering organisations and in particular, is it the training/ focus on particular 'tools' such as Lean and Six Sigma? The paper starts by looking at a few of the psychological areas and the concepts of mindsets (Filmore 2007b). It then ties in work utilising Myers-Briggs type indicator (Filmore & Crust 2009) and then reviews the background of the 'highly effective engineers' work mentioned above.

2. The Human Condition

Have you ever found a book on psychology for engineers? It seems that engineers and scientists do not need to be aware of themselves until they become managers! The management literature has though many direct references to the 'human condition' i.e., how to: communicate better, learn effectively, reduce psychological blocks, be more creative, effective, innovative etc. Most engineers move into becoming managers with little training. They may have had a leadership module at university or perhaps more recently an entrepreneurship module which are of little help here. So, what could be called the 'human condition', is some how supposed to be learnt by a process of osmosis i.e., being picked up as one goes along. Rather than list psychological areas etc, this paper will just pick up a few areas to make the point that these area are important and affect the innovative potential of engineers and engineering mangers.

2.1 Creativity is limited by emotional and habitual ways of thinking

Some barriers to creativity (source unknown) are:-

- 'Tramline Thinking: i.e., the problem of precedence (the way things have always been done is the only way).
- Fear of Looking Foolish: limits our contributions to those safe and conventional (from experience at school).
- Evaluating Instantaneously: not giving ideas a chance (because at first they appear impractical, impossible or simply crazy.

- One Right Answer (a commonly held view which tends to drive people into an analytical thinking mode and to look for the single obvious answer).'

2.2 Thinking Preferences dominate thinking

In their book on 'Creative Problem Solving' (1995), Lumsdaine & Lumsdaine report the work of Ned Herrmann on brain dominance (Herrmann, 2007). Dominance, or 'cognitive (thinking) processes', or 'preferred modes of knowing', have advantages in quick response time and higher skills level, which is why people default to a particular thinking process. Herrmann developed a questionnaire (the Herrmann Brain Dominance Instrument: HBDI) and from the results of now over a half million people, concludes that there are four identifiably separate dominances. Herrmann has found that 7% of the population have single dominance, 60% have double, 30% have triple and 3% have a quadruple dominance. The preferences (see Figure 1) 'A' and 'B' relate (metaphorically) to the left brain hemisphere (i.e., the logical, structured areas) and the 'C' and 'D' relate to the right hemisphere (i.e., the creative and holistic thinking areas). Herrmann relates these preference dominances to creative problem solving mindsets (see Figure 1: right) e.g., 'engineer' (A & D), 'detective' (B, A & D), 'explorer' (A, D & C), 'artist' (D & C) etc. A key point is that our preferences have been influenced by our (school and college) teaching and that individuals can strengthen non-dominate preferences by the careful choice and practice of specific activities (e.g., daydreaming and sketching etc. for developing quadrant 4).

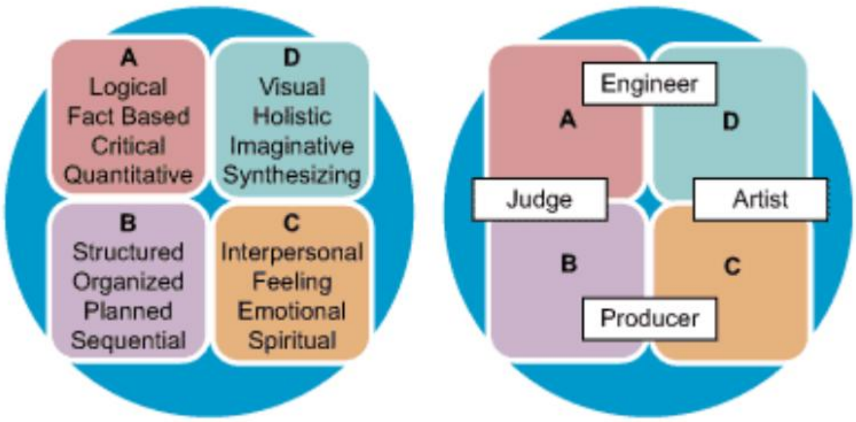


Figure 1: The Four Quadrant Herrmann model of Thinking Preferences.

Adapted from: Lumsdaine & Lumsdaine (1995)

2.3 Myers-Briggs and personality preferences

The Herrmann model shows that we have thinking preferences. What would be interesting is to see if anyone has taken this further to include 'subject' thinking preferences. By this is meant that an e.g., engineer will always first look for a solution in their subject area e.g., in a particular area of mechanical engineering (if that was from their training) rather than from e.g., electrical engineering. If there are organisational pressures, which includes competition between departments/ work colleagues, then this may be more pronounced.

The Myers Briggs type Indicator (MBTI) describes personality using a framework initially suggested by Carl Jung (Jung 1923). Katharine Cook Briggs and Isabel Briggs Myers developed the framework (adding the J/P preference) and a questionnaire which is now available in 19 languages (OPP 2009). A vigorous business has grown up around this instrument; each year 3.5 million questionnaires are completed across the globe, with a broad range of supporting literature. MBTI describes four "**Preferences**", broadly speaking:

1) the **Extraversion / Introversion** (E/I) Preference scale describes whether a person prefers to receive and direct their energy towards the outer world or their inner world
2) the **Sensing / iNtuition** (S/N) Preference scale describes whether a person prefers to perceive the detail or the patterns amongst the detail
3) the **Thinking / Feeling** (T/F) Preference scale describes whether a person prefers to make judgements based on facts or human values
4) the **Judging / Perceiving** (J/P) Preference scale describes whether a person prefers to plan and structure or keep their options open.

Each of these four scales indicates one of two possible Preferences. Thus sixteen different combinations of Preference are possible. MBTI defines the 16 combinations as 16 different **Types**, as 16 distinct descriptions of personality.

Jung describes one's innate Preferences as one's personal preferences without the influence and constraints of work and family; your "shoes off" self. Engineers' shoes may be particularly difficult to remove because engineers enjoy being engineers. The sixteen distinct personality Types identified by Myers & Briggs are shown in Figure 2. These 16 Types can be simplified into four quadrants of similar characteristics. For each of the four quadrants one can specify characteristics associated with different areas of activity (Figures 4 to 7) (Hirsh & Kummerow 2000). Looking at Figures 4 to 7 it would seem that there are two distinct overall areas; those quadrants associated with careful & incremental thinking and those quadrants associated with the creative and breakthrough thinking process (see Figure 8). Can we relate these to engineering categories of people? Filmore (2009) identified that Lean and Six Sigma document few innovation practices associated with breakthrough thinking, where as TRIZ indicates a plethora. Referring back again to MBTI and Figure 8, it was thus suggest that there is a link between the Types and the engineering practice preference.

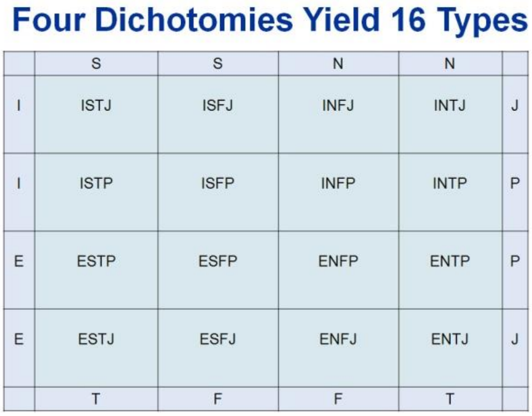


Figure 1: The 16 Types

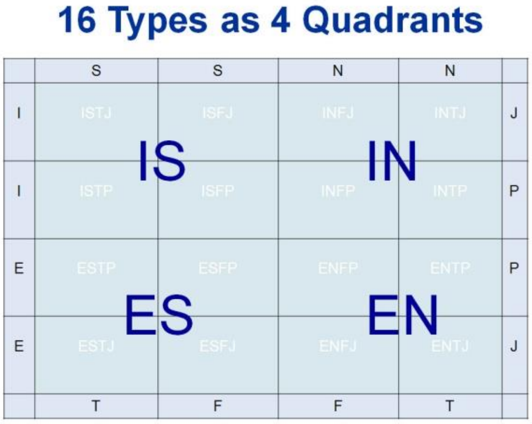


Figure 3: The Four Quadrants

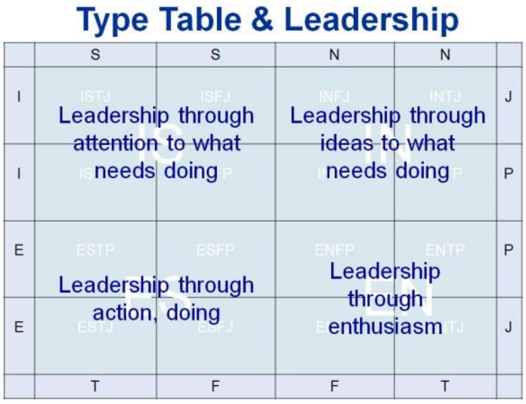


Figure 2: Leadership

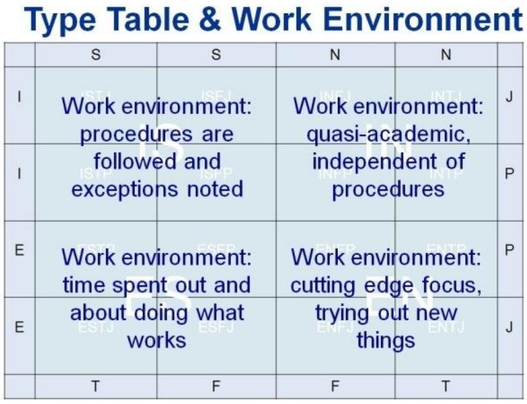
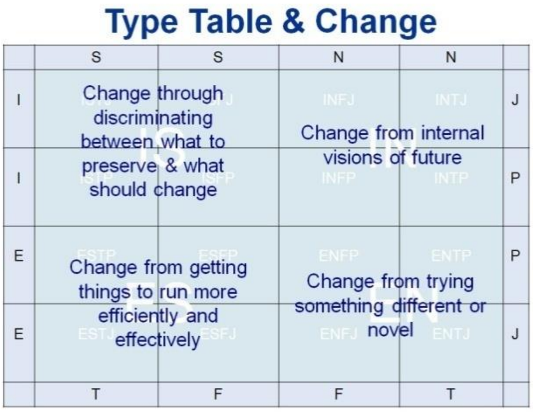


Figure 5: Work Environment



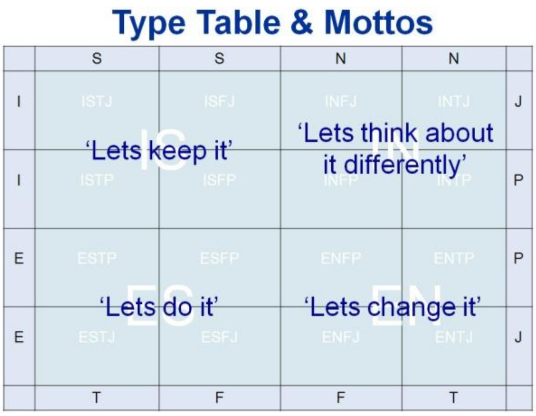


Figure 3: Change **Figure 7: Mottos**

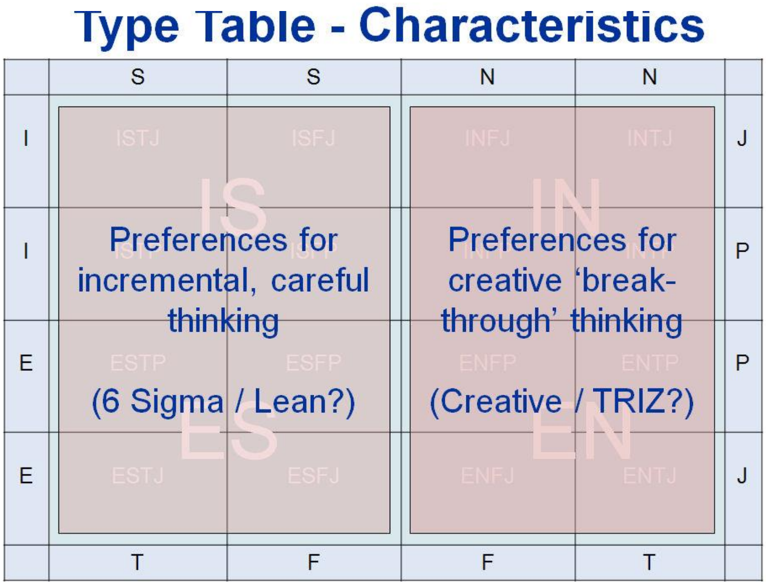


Figure 8: Engineering practice preference

2.4 The potential to make a creative leap/ paradigm shift

There are many definitions of creativity. A useful collection is given by Dewulf & Baillie (1999), e.g., 'conceptual combination – merging of two or more concepts resulting in a novel entity' (Ward et al 1997). Dewulf & Baillie also develop a definition: 'Creativity is shared imagination'. They also say, 'creativity becomes innovative when a commercial application becomes apparent' and 'if the creativity is not domain specific, it becomes an invention'. A different approach to the definition of creativity is illustrated visualually from technological forecasting (Meredith & Mantel 1995) or TRIZ trends of evolution (Mann 2002). This shows breakthrough innovation as the jumps between 's-curves' (see Figure 9). NB Lumsdaine and Lumsdaine (1995) call this jump a 'paradigm shift'. This identifies a key attribute for innovative engineers, namely looking for 'breakthrough' c.f. incremental innovation. NB It should be noted that breakthrough thinking is central to TRIZ and not practiced with Six Sigma.

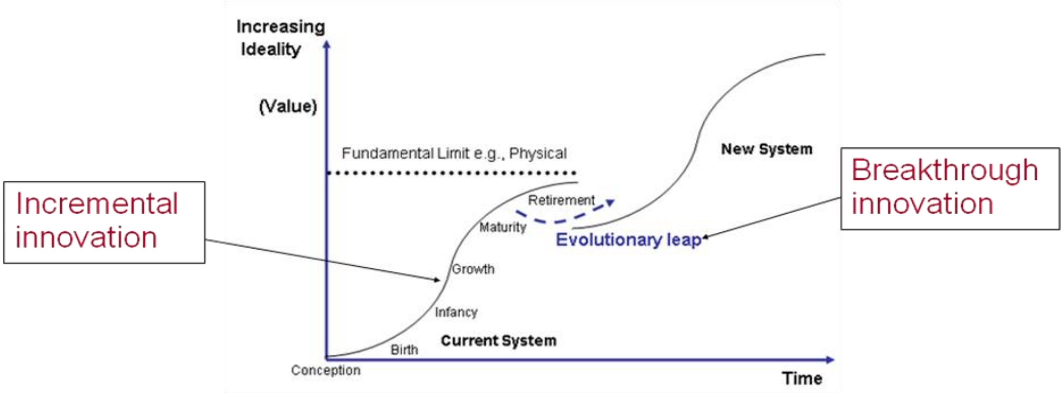


Figure 9: Showing the jump ('creativity leap') between s-curves.

3. TRIZ and Lean/ Six Sigma

In previous papers (Filmore 2007a, 2008a, 2008b), key attributes ('skills') of 'highly effective engineers' were identified and then linked to the creativity/ problem solving potential of TRIZ practitioners. Subsequently (Filmore 2008b) the problem solving and creativity potential of engineers using TRIZ and those using Lean/ Six Sigma was compared. Table 1 shows the result from TRIZ tools/ approaches related to key characteristics/ approaches demonstrated by highly effective people. Filmore (2009) also shows similar tables related to Six Sigma and Lean. This paper shows that TRIZ apparently has a more focused toolsets for creative and breakthrough thinking type problems; i.e., those that have been associated with highly effective engineers previously. The results also show that Lean Six Sigma has the next closest tool set/ approach with that relevant for 'highly effective engineers', with Lean and then finally Six Sigma of lesser potential.

Recent unpublished work (Frobisha 2010) has also confirmed the potential of TRIZ over FMEA (Failure mode and effects analysis) practitioner engineers (NB often used by Lean and Six Sigma). After TRIZ workshops were run it was found from feedback from 17 workshop participants 'that TRIZ tools were on balance easier to learn and understand than the commonly used methodology FMEA, and useful in their daily work. This view is supported through the ability of several workshop participants to solve a seemingly intractable problem that had thwarted several attempts at solution using the company's incumbent tools and approaches to problem solving and creativity' (Frobisha 2010).

Table 1: TRIZ tools etc. related to key characteristics/ approaches demonstrated by highly effective people (Filmore 2009).

Key characteristics/ approaches	TRIZ tool/ approach
Seeing the whole rather than the parts	IFR (Ideal Final Result) tool, Functional Analysis
Valuing difference	Being a creative TRIZ practitioner can make one have this awareness as one is always looking for difference.
Aspire above conformity	IFR tool. NB Being a TRIZ practitioner by definition, in the present climate, means aspiring to seek/ learn better tools
Being aware of our assumption	9 Windows, Trends, Resources tool
Using all resources available	Resources & Constraints tool
'Thinking outside the box'	Trends, 9 Windows, Functional Analysis, Smart Little People, Space-time-interface-cost
Looking for 'breakthrough' c.f. incremental innovation	IFR tool, Trends
Developing win-win solutions	Contradictions, Matrix, IFR, Trends
Risk taking	IFR, trends. NB TRIZ practitioners are looking for highly 'unusual' solutions, if using all the tools. Risk in the solution space is thus a common occurrence in practice.

In the recent article in the Harvard Business Review, Dyer, Gregersen, and Christensen (2009) ask what separates the real innovators from the rest of us. The innovators identified are the people, which one is lead to believe, with the skill set to get companies out of a recession and compete very effectively. What is interesting here is to compare the skill sets with those found in the TRIZ practitioners. Some connections are shown in Table 2.

In the Harvard paper the authors say 'Innovative entrepreneurs have something called creative intelligence, which enables discovery yet differs from other types of intelligence (as suggested by Howard Gardner's theory of multiple intelligences). It is more than the cognitive skill of being right-brained. Innovators engage both sides of the brain as they leverage the five discovery skills to create new ideas'. Referring to section 2.2 on Thinking Preferences, it would be interesting to measure the profile of TRIZ practitioners. It would be expected that TRIZ practitioners have at least three dominances (A, B & D) as the TRIZ tools can be seen to be active in these three areas. In comparison, Six Sigma and perhaps to a lesser extent Lean practitioners, would be expected to have two dominances (A & B).

Table 2: Making connections between the Harvard paper and the TRIZ results

Harvard 'Discovery Skills'	**Descriptions** from Dyer, Gregersen, and Christensen (2009)	**TRIZ connection in this paper**
Associating	successfully connect seemingly unrelated questions, problems, or ideas from different fields	Key approach/ tools from TRIZ to force people out of current thinking e.g., look at what has been done in other industries. See Table 1: 'seeing the whole'
Questioning	allows innovators to break out of the status quo and consider new possibilities.	Also key approach/ tools from TRIZ e.g., IFR, Trends, M-B Preference (Figure 8). See Table 1: 'thinking outside the box'
Observing	detect small behavioural details – in the activities of customers, suppliers, and other companies – that suggest new ways of doing things.	See Table 1: 'Aspire above conformity'
Experimenting	they relentlessly try on new experiences and explore the world.	E.g., Smart Little People, Space-Time-Interface-Cost tools, M-B Preference (Figure 8). See Figure 5: '…. Trying out new things'
Networking	through *networking* with individuals from diverse backgrounds, they gain radically different perspectives.	See Table 1: 'Valuing difference'. NB TRIZ is 'based' on 'someone else has solved this problem before', forcing one to look to other industries etc.

4. Conclusion

In the Harvard paper the authors 'found that innovative entrepreneurs (who are also CEOs) spend 50% more time on these discovery activities' (i.e., five "discovery skills: associating, questioning, observing, experimenting, and networking") 'than do CEOs with no track record for innovation.' This paper has tried to show that TRIZ practitioners have these 'activities' as part of their tool set and perhaps more importantly, part of their psychological make up in terms of creativity, thinking preferences and personality preferences (section 2). The Harvard paper also suggests that real innovator skills can be strengthened through practice: ‘Though innovative thinking may be innate to some, it can also be developed and strengthened through practice. We cannot emphasize enough the importance of rehearsing over and over the behaviours described above, to the point that they become automatic. This requires putting aside time for you and your team to actively cultivate more creative ideas.’ This paper again has shown (e.g., Tables 1 and 2) that TRIZ practitioners, through utilising such a diverse tool set and approach, constantly are likely to be strengthening their innovation potential compared to Lean/ Six Sigma practitioners.

For any organisation wishing to respond to change or champion change, having TRIZ practitioners (who utilise the full tool set and thinking approaches), is essential in their project teams and management thinking. Also essential is incorporating a training and reward focus that promotes TRIZ and realises that it has a complementary position to the established Lean/ Six Sigma culture, in any innovative organisation.

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