ISSN (Print): 2077-7973
ISSN (Online): 2077-8767
DOI: 10.6977/IJoSI.201101_1(3)

# International Journal of Systematic Innovation

VOL.01, NO.03
January, 2011

Published by the Society of Systematic Innovation

## *Opportunity Identification & Problem Solving*

ISSN (Print): 2077-7973
ISSN (Online): 2077-8767
10.6977/IJoSI.201101_1(3)

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INTERNATIONAL JOURNAL OF SYSTEMATIC INNOVATION

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# Foreword

Business globalization, complex consumer requirements, and high technology development have led to vigorous business competition and market uncertainty for modern enterprises. It is increasingly important to put more emphasis on innovative concerns than quality and speed of production for products. In the long run, the only sustainable source of competitive advantage is the organization's ability to develop faster than its competitors. Then, innovation has become fundamental to the development of society, business rejuvenation and growth and critical to company survival. Just as we mentioned in last issue, the mission of the International Journal of Systematic Innovation is to gather researchers, industrial practitioners, and students to share theoretical and technological advances in systematic innovation which include TRIZ, non-TRIZ human-originated systematic innovation as well as nature-inspired systematic innovation. While a great deal of detailed information is presented, the journal is user-friendly and allows the reader to quickly find the information most relevant to his or her interests.

Faced with an innovation century, now is the time to take action. This journal provides a unique international platform that can enable research and development of systematic innovation for problem solving and identification of innovative opportunities. It is our sincere hope that you will find it helpful and useful for achieving real innovation.

We are happy that the 1st issue of 2011 (Vol. 1, no. 3) has been published. In this issue, four regularly submitted papers had been carefully reviewed, revised, and selected under the Journal's regular publication guidelines. All the papers were then subject to the usual rigorous peer-review process. And, team efforts contributed the complete publication of this issue. We want to sincerely thank the reviewers, the authors, and the committee for their tremendous help. We are confident that the journal is always bringing concrete benefits to everybody and you will find these papers interesting and useful.

Finally, we would like to cordially invite you to submit your or recommend original papers to IJoSI electronically through the website at http://www.IJoSI.org. Any feedback or question, please send email to editor@systematic-innovation.org.

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July 2011 in Hsinchu, Taiwan

DOI:10.6977/IJoSI.201101_1(3).0001
Tien-Lun Liu, Shao-Ting Kuo / Int. J. Systematic Innovation 2-12 (2011)

# A Study of Applying TRIZ to Technological Patenting Deployment

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**Abstract**

Under the trend of economic globalization, the new survival competitions among enterprises are their patenting capabilities and tactics. The enterprises not merely need patent improvements in "quantity" to protect their researches, but also in "quality" to develop crucial core patents for gaining profits from intellectual property. This research explores various methods in TRIZ and studies how patent activities can be assisted effectively by the right method, then further look into how patenting strategies can be carried out in depth or in breadth. S-curve Analysis and System Operator Analysis should be used for patent trend examination. Evolutionary Trends and Knowledge/Effects may be applied to constructing technological patent roadmaps. In addition, Contradiction Analysis and Function Analysis with Attributes are beneficial for strategic patenting both in depth and in breadth. We also make several observations from the viewpoint of patenting patterns, and compare the similarities between design-around methods and TRIZ inventive principles in order to help construct an integrated patenting strategy.

*Keywords:* TRIZ, Patent Analysis, Patenting Deployment.

## 1. Introduction

Currently Taiwan's technology developments are good enough to compete in the world. The quantity of patent production is stable every year. However, the improvement in patent quality can truly realize the value of intellectual property. For example in Taiwan's electronic industry, lots of enterprises which do not have their own core patents are then suffering huge royalty payment. Therefore how to enhance enterprises' research capabilities and develop significant core patents is a very important issue nowadays. Recent researches in TRIZ applications related to patents are mostly focused on how to design around patents, but not much attention on patenting strategies. By going through patent trends analysis, we may transform the collected results into useful information such as current status and future development, etc.. In this research, we intend to discuss TRIZ methods in the area of patenting strategy and plan to provide several guidelines for enterprises to consider how to patent their researches in depth and in breadth.

## 2. Background and literature review

### 2.1. TRIZ

TRIZ is a Russian acronym, translated in English as Theory of Inventive Problem Solving (TIPS). The TRIZ theory was mainly developed by Russian scientist G. Altshuller in 1946 (Altshuller, 2000). He and his colleagues analyzed hundreds of thousands of patents and classified methodically. They concluded the inventive principles and solving techniques involved in these patents to a systematic innovation approach.

There are various methods and tools in TRIZ, including Problem Formulation, Contradiction Matrix, 40 Inventive Principles, Functional Analysis, Separation Principles, Substance-Field, Ideal Final Result, Effects, ARIZ, etc. The advantages of the TRIZ lie in its broad technical extent. For instance, the thinking direction of a mechanical engineer tends to be confined to his or her specific domain of knowledge. Nevertheless through TRIZ, we are likely to acquire solutions from different fields of knowledge such as electrics, chemistry, biochemistry, etc. The TRIZ theory not only breaks the bottleneck of limited acquaintance but also provides a more systematic search method for technical solutions.

Although a rather complete theoretical system has formed after 60 more years of the TRIZ theory development, relevant researches continue because the innovation is an incessant task. It is especially discussed extensively after the Soviet scholars introduced it to the western countries. The domestic researches of the TRIZ are gradually and systematically developed through the establishment of relevant academies. Chinese transliterations for the TRIZ indicate that the TRIZ spirits lie in the wisdom of collection, extraction, thinking, etc. Currently, relevant developments of TRIZ researches are mainly as follows.

- Revisions and Modifications of the TRIZ theoretical system (Mann, 2002).
- Practical applications of the TRIZ to the technical problem-solving and the innovative products development (Wang, 2002; Domb, 1997; Royzen, 1997).
- TRIZ software developments such as Creax, Goldfire, IWB (I-TRIZ), etc.
- TRIZ-incorporated applications with other design theories (Liu *et al*., 2008; Andrew and Madara, 2005; Yang and Zhang, 2000; Chang and Teng, 2008).
- Extended TRIZ applications other than technical systems, such as in the service, management, software programming, etc. (Mann, 2007; Chen, 2003)

### 2.2. Design around

Designing around (or Inventing around) is a responsive strategy that an enterprise contests with allegations of infringement on patents. Starting from imitating of patents, it requires the sufficient understanding of elements established for the infringement so as to look for creative outcomes with market values rather than patent infringement. The vitalest part of designing around a patent is to judge whether an infringement occurs. There are three judgment principles: All Elements Rule, Doctrine of Equivalents, and File-Wrapper Estoppel. Different methods of design-around are shown in Table 1.

**Table 1.** Design-around methods (Nydegger and Richards, 2000)

| Methods | Original Patent Attributes → Post Design-Around Attributes | Statements |
|---|---|---|
| Elimination | A+B+C+D<br>→A+B+C | Circumvention of the All Elements Rule |

| | | |
|---|---|---|
| Replacement | A+B+C1+D1 →A+B+C2+D3 | Technical Attribute C1≠C2 Technical Attribute D1≠D3 Circumvention of the All Elements Rule & the Doctrine of Equivalents |
| Combination | A+B+C+D →A+B+E | Technical Attribute C+D≠E Circumvention of the All Elements Rule & the Doctrine of Equivalents |
| Decomposition | A+B+C+D1 →A+B+C+D2+D3 | Technical Attribute D1≠D2+D3 Circumvention of the All Elements Rule & the Doctrine of Equivalents |

The relevant researches on the TRIZ methods with the patent-related concerns mostly probe into the design-around issues. For examples, Hsu (2010) and Hung (2007) constructed an integrated design around approach by systematically incorporating patent information, the rules of patent infringement judgment, strategies of designing around patents, and innovative design methodologies. During the design-around process, they mainly used the *contradiction matrix* or *su-field analysis* to generate an engineering solution. Chang and Teng (2008) constructed the patent analysis via indexing the patent information, sifting through the scope of patent rights and evaluating the points of design-around. They then conduct the re-design for a patented safety pushpin through contradiction analysis and the *Independence Axiom* of Axiomatic Design.

Unlike designing around existing patents, our study starts from the viewpoint of patenting strategies for a novel technology or a core patent, and makes direct connections among the concepts of patenting activities and the various TRIZ methods.

### 2.3. Patenting strategies

The so-called patenting strategy means the allocation and deployment for the patent rights, which include patenting in regions, patenting over time, and patenting in technology space. The further explanations are described as follows:

- The strategic patenting in regions is related to the consideration of patents to be registered in different countries, where the enterprises should have plans for their business.
- The strategic patenting over time is related to the life cycle of a patent. Different types of patents have various life spans, and the corresponding products also have their own life spans. Thus, when to apply and whether to continue the claims for the patents are both relevant to this category.
- The strategic patenting in technology space is the deployment that focuses on the core of technical innovations. This category is primarily that TRIZ can play an important role.

This research is focused on the issue of technological patenting strategies, which were first systematically classified by Granstrand (1999) into six patterns as briefly described below. The illustrations of these patent strategies are shown in Fig. 1.

(1) Ad hoc blocking and inventing around: One or a few patents are used in this case to protect an

innovation in a special application. The difficulty of design around in this category is usually low.

(2) Strategic patent searching: A single patent with a large barrier in between R&D isocost curves is called a strategic patent, which may be a key technology and will cause high design-around cost.

(3) Blanketing and flooding：The relative patents are distributed as a minefield or in a less structured form. Some of these patents may be insignificant but a nuisance to slow down competitors.

(4) Fencing： This refers to the situation where a series of patents, ordered in someway, block certain directions of R&D. Fencing is typically used for a range of possibly quite different technical solutions for achieving a similar functional results.

(5) Surrounding：This is the case that a core patent from a competitor is surrounded by other less important patents, which collectively block the effective commercial use of the core patent. Then in turn we would create possibilities for cross-licensing.

(6) Combination into patent networks: This refers to a patent portfolio in which patents of various kinds and configurations are used to strengthen overall protection.

A further research was done by Ikovenko (2006) who proposed five major steps of designing and executing patent strategies from the aspect of business operation. In these steps, he advanced and developed 11 types of patent strategies. For each type of patent strategy, he also suggested several so-called TRIZ*plus* tools, which are based on classical TRIZ and developed by the research group of GEN3 Partners, Inc.. His work is summarized in Table 2.

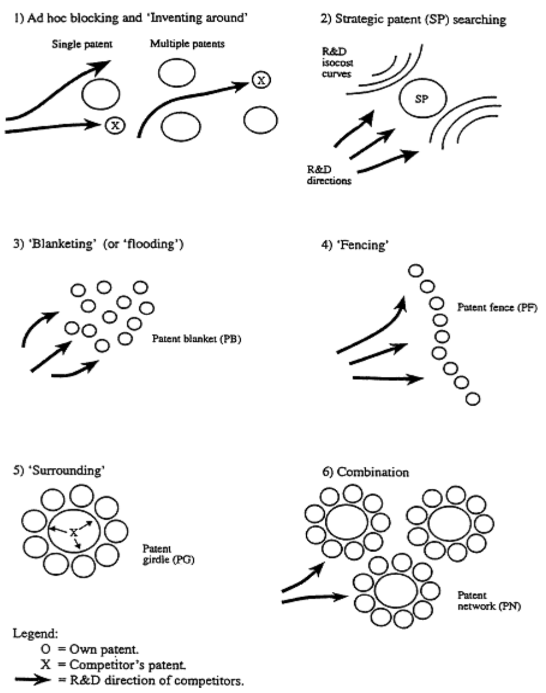


**Fig. 1.** Various patent strategies in technology space (Granstrand, 1999)

**Table 2.** Patent strategies and corresponding TRIZ*plus* tools (Ikovenko, 2006)

| N | Type of Patent Strategy | TRIZ*plus* Tools |
|---|---|---|
| 1 | The Antidote Strategy | Function Analysis, Cause-Effect Chain Analysis, Trimming, Function-Oriented Search |
| 2 | The Picket Fence Strategy | S-Curve Analysis, Trends of Evolution, Function-Oriented Search, Reverse Contradiction Analysis |
| 3 | The Tall Gate Strategy | S-Curve Analysis, Trends of Evolution, MPV Analysis |
| 4 | The Submarine Strategy (old and new) | Trends of Evolution, Function-Oriented Search |
| 5 | The Counter-Attack Strategy | Function-Oriented Search, Reverse Contradiction Analysis, Semantic Tools |
| 6 | The Stealth Counter-Attack | Function-Oriented Search, |

| | | |
|---|---|---|
| | Strategy | Reverse Contradiction Analysis, Semantic Tools |
| 7 | The Patent Busting (through Trimming) | Function Analysis, Cause-Effect Chain Analysis, Trimming |
| 8 | The Patent Busting (about the Doctrine of Equivalents and Prosecution History Estoppel) | Function Analysis, Function-Oriented Search |
| 9 | The Blanketing Strategy | Function-Oriented Search, Trends of Evolution |
| 10 | The Bargaining Chip Strategy | Trends of Evolution |
| 11 | The Cut-Your-Exposure Strategy | Function-Oriented Search |

Ikovenko developed patent strategies more completely according to different practical situations, and his classification was done in a more tactical way. However, his work did not pay much attention on the issue of patenting in-depth or in-breadth with TRIZ tools, which is discussed in this research. In other words, Ikovenko considered patent strategies in a sense of bottom-up manner. Nevertheless we observe patent strategies from a top-down aspect to deploy a core technology.

For a more essential analysis without complicating our intention, this study is primarily focused on the patenting strategies in technology space based on Granstrand's classification. We then probes into the possible applications of the TRIZ, such as how to conduct patent analysis for new techniques within the industry and efficiently transform into useful reference information. Therefore, we start from a general process of patent-related events shown in Fig. 2 and then think from the standpoint of the TRIZ to see what assistance or application it can provide in these patent activities so as to conduct the patent technical deployment in breath and in depth.

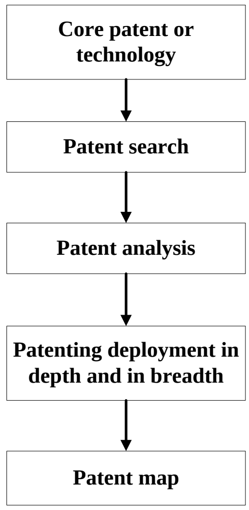


**Fig. 2.** A general process of patent-related activities

## 3. Strategies of patent analysis

After we have done patent search, two useful efforts with TRIZ are performed in the patent analysis as described below.

### 3.1. Patent trend analysis

The purpose that we conduct the patent trend analysis by collecting the information through the patent indexing of keywords for a certain technology is to understand its current status. The patent trend analysis involves the quantity of related patents, what countries the patents register, which company or inventor the patent belongs to, and the citation rate analysis. These pieces of information can be combined with the S-Curve analysis and the System Operator concept that are commonly used for problem definition phase in TRIZ.

(1) The S-curve is shaped as the 4 stages of Birth, Growth, Maturity and Retirement, shown in Fig. 3. The S-curve mainly helps users elaborate on the maturity of techniques or products. Its x-axis is defined as the time unit and the y-axis as the idealism of a technology or a product type. Therefore the concerned entity represented in y axis can then be examined in terms of the patent quantity, the country, the company, or the inventor for different analyses to achieve the patent trend exploration.

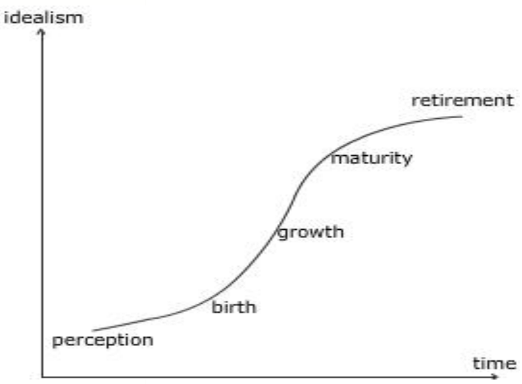


**Fig. 3.** S-curve characteristic

(2) The System Operator concept divides the problem of concerns into nine sections which are expressed as the "system" domain (super-system, system, sub-system) corresponding to the "time" domain (past, present, and future) as shown in Table 3.

**Table 3.** 9- windows representation of the System Operator

| time / system | Past | Present | Future |
|---|---|---|---|
| Super-system | | | |
| System | | Starting point of thinking | |
| Sub-system | | | |

The purpose of the System Operator is to help that we break the psychological inertia to think in terms of time and space to consider all possible factors. Therefore, we can put the collected patents inside the 9 windows, and then trace the relations between the past and present patents of all systems as well as their super-systems or sub-systems. Meanwhile, we can also deliberate on the developments of future patents.

### 3.2. Technical chart analysis

The technical chart analysis is carried on after the patent trend analysis. The main purpose is to understand the technique spreading conditions in the industry to draw up the directions of future technical development, shown as Table 4.

**Table 4.** Technology-Effect matrix

| Technique / Effect | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| E1 | 9 | 5 | 3 | 1 |
| E2 | 7 | 2 | 1 | 2 |
| E3 | 10 | 1 | 6 | |

For example in Table 4, there are 9 patents that technique T1 achieves effect E1 and there are 5 patents that technique T2 achieves effect E1. The technology with more patents means higher competition. On the other hand, the technology with fewer patents may represent opportunities to explore and deploy. Therefore, we can get a hold of the directions of the technical developments. Such survey can be further combined with Evolutionary Trends and the Knowledge/Effects in TRIZ as explained below:

(1) D. Mann (2007) divided the evolutionary patterns into 35 trend lines, such as "geometric

evolution", "smart material", "dynamization", etc., which may be put into three broad categories covering space, time, and interface situations to facilitate their usages. We can analyze the contents of a certain patent through 35 trend lines, find out the correlated trends, define individual evolutionary level, and further construct the radar plot for evolutionary potentials, which helps recognize the possible developments of the next generation techniques. As shown in the Fig. 4, for example, "controllability" and "dynamization" have lower evolutionary levels, thus are more likely to have room for developments. Through the analysis of the trend lines, we may foresee the future trends of the products, predicting the directions of the future patent deployment in advance. There has been some published articles by applying this approach to create new ideas and improve designs (Guan,2008; Zhang,2006). In addition, Shpakovsky (2006) promoted an organized methodology called "Evolution Tree" to structure technical and patent information, and then obtain innovative thoughts or solutions. He also stated that such evolutionary thinking approach provides good opportunities for circumventing others' patents or protecting the patents we own.

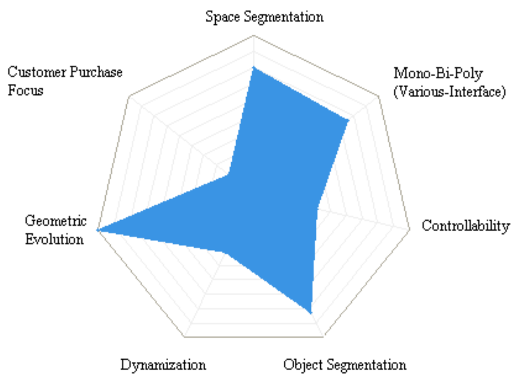


**Fig. 4.** Radar plot of evolutionary potentials

(2) The database of the Knowledge/Effects includes the patents and technical outcomes of physics, chemistry, biology, geometry and so on. If a research staff member needs to realize certain functions, such database may provide more options, i.e., we can search for certain techniques with certain functions. For example, we are to achieve the effects of lower temperature. We can then search the approaches for that function, such as air-cooling, water-cooling, or chemical action, through the Knowledge/Effects. Thus, it is likely to find out solutions that satisfy our needs from multi-disciplinary fields. In this way, we may generate sophisticated patents to deploy. Litvin (2005) developed a newer version of such tool called Function-Oriented Search (FOS) and derived an algorithm to perform FOS step-by-step.

## 4. Technological patenting strategies

As we consider patent strategies from a top-down sense, the technological strategic patenting indicates the patent deployment in depth and in breadth within technology space. The so-called "in-depth patenting" means to derive intensified patents from the fundamental patents within the same category and form a patent chain which achieves the effects of technical monopolization. As for the "in-breath patenting", it refers to discover the possible applicable fields for the fundamental patents and then acquire consequent patents in that fields. In such a way, it will benefit from the technical dominations of application development as well as the market trends. Along with these patenting concepts, we present several tactics of analysis with regard to TRIZ as follows.

### 4.1. Contradiction analysis for patents

For a new developed patent, we can investigate if it can be transformed into a contradiction problem for analysis. By finding what problem this patent is solving, we should identify the improving engineering parameter and the worsening engineering parameter, and then look up the Contradiction Matrix table for inventive principles. These suggested inventive principles could be the possible developments in breadth, which may build the patent strategy of *blanketing and flooding*.

Following the contradiction pattern analysis, we look for the subsequent contradictions possibly caused (i.e. contradiction chain) to intensify the solution or the optimization for this particular type of problem. Thus, we can go deep into the problems with related technical fields, and produce the derived in-depth patents, which may construct the patent strategy of *fencing* or *surrounding*. The analytic flowchart is shown as Fig. 5.

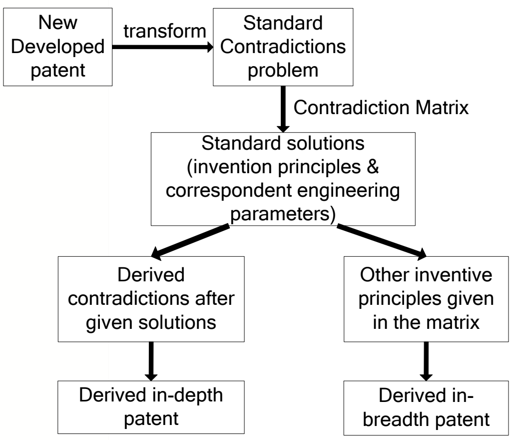


**Fig. 5.** Patent Contradiction Analysis

### 4.2. Functional analysis for patents with attributes

The functional analysis in TRIZ emphasizes on not only the useful functions but also the harmful, ineffective, excessive functional relationships. To additionally present the attributes (or parameters) among these relationships will reveal more information to help capture the critical portion of the problem. We may further observe the variations of functions and attributes from the dimension of time, such as “before the problem” and “after the problem”. We take the engine oil as an example and illustrate the differences in expressions of functional modeling with or without attributes, as shown in Fig. 6.

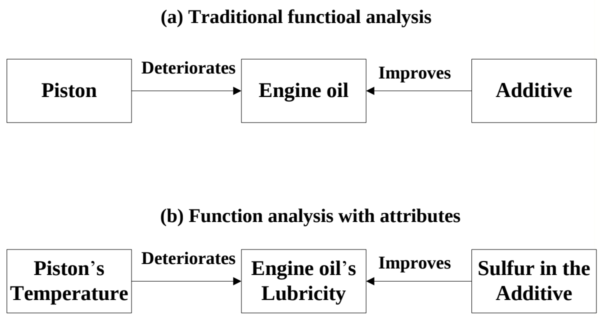


**Fig. 6.** Functional modeling with/without attributes

To express the patent contents in a functional analysis model, it is helpful to recognize the opportunities of derived patents. We perceive two basic indications as follows.

- The “negative” relationship in the functional analysis model may represent improving opportunities for “in-depth” patents.
- The “positive” relationship in the functional analysis model may represent applicable opportunities for “in-breadth” patents.

In the example of engine oil, the temperature variations of the piston worsen the engine oil’s lubricity. Continuous improvements on the poor relations in the model can help us consider the research directions which concern in-depth deployment. On the other hand, Sulfur in the additive can improve on the deterioration of oil lubricity. The good effect can be deemed a promotion of application to other domains, which may bring about in-breadth patents.

### 4.3. Patent strategy applicability

There are diverse innovative methods and tools in TRIZ. According to their characteristics, we probe into the usage occasions from the viewpoints of patenting in breadth or in depth, as well as the deployment patterns. For example, if we intend to conduct a *surrounding* patenting to hinder competitors or in-depth deployment to protect our core patents, what tools in TRIZ are better to make use of? The study concludes some preliminary observation for applicability as follows:

- The patterns of *strategic patent searching* and *fencing* more likely require patenting developments in depth.
- The patterns of *blanketing/flooding* and *surrounding* more likely require patenting developments in breadth..
- The methods of *IFR* and *trends of evolution* are more likely suitable for in-depth patenting developments.
- The methods of *contradiction matrix* and *scientific effects* are more likely suitable for in-breadth patenting developments.
- The methods of *S-Field*, *resources*, *psychological inertia* and *separation principles* are most likely neutral and depend on the situations.

### 4.4. Strategic analysis with design-around：

Well goes the proverb: *know both the enemy and yourself and be ever-victorious*. To protect our own patents, we should also comprehend the design-around techniques adopted by others so as to strengthen the barriers. We bear in mind for the thinking patterns of design-around while conducting the patent deployment by TRIZ. For example, similar concepts can be found among the design-around methods and 40 inventive principles. The analytic results are shown in Table 5.

**Table 5.** Design around vs. inventive principles

| **Design around technique** | **Inventive principle** |
|---|---|
| Elimination | Preliminary Anti-Action、Preliminary Action、Beforehand Cushioning |
| Replacement | Asymmetry、Do it in Reverse、Another Dimension、Blessing in Disquise、Replacement of Mechanical System、Flexible Membranes or Thin Films、Changing the color、Parameter Changes、Phase Transitions、Rejecting and Regenerating Parts |
| Combination | Merging、Universality、Nested Doll、Self-Service、Homogeneity、Composite Materials |
| Decomposition | Segmentation、Separation |

Therefore by means of relating inventive principles, it is of help to increase the design-around difficulties or establish the fencing barriers, and construct an incorporated patenting strategy.

## 5. Conclusion

It has been proven that TRIZ is supportive in many aspects for patent-related applications. However applying TRIZ with suitability and efficiency on the problem is another concern. This study is carried out from a top-down sense to look into the effective usage of TRIZ on the subject of patent analysis and patent deployment in depth or in breadth. We have made several attempts to conceptualize guidelines by clarifying their relations to construct an initial basis. Beard these guidelines in mind, TRIZ users may develop patenting map with ease.

**Acknowledgement**

This research is funded by the National Science Council, Taiwan, R.O.C. under Grant No. NSC 98-2221-E-129-002-MY2. Authors are grateful to its financial support of this work.

**References**

Altshuller, G.S., *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity*, Technical Innovation Center, Inc, 2000.

Andrew, K. and O. Madara , *Improving the Acoustics in a Historic Building Using Axiomatic Design and TRIZ*. The TRIZ Journal, Available on line at: http://www.triz-journal.com/archives/2005/06/05.pdf 2005.

Chang, H.T. and C.S. Teng, *Combining Independence axiom in axiomatic design with TRIZ to conduct design around process*, Proceedings of the 3rd TRIZ Conference, Hsin-Chu, Taiwan, Taiwan TRIZ Association., 2008.

Chen, C.C., Exploring *the TRIZ-based innovative principles for the contradiction phenomena of service attributes in tourism industry*, Master thesis, Department Of Administration, Tamkang University, 2003.

Domb, E., Contradictions*: Air Bag Applications*, The TRIZ Journal, July, Available on line at: http://www.triz-journal.com/ 1997.

Granstrand, O., *The* Economics *and Management of Intellectual Property：towards intellectual capitalism*, Edward Elgar Publishing, Inc., 1999, 218-222.

Guan, X., *A TRIZ-based* Protection *and Promotion Process for Patents*, The 4th International Conference on Wireless Communications, Networking and Mobile Computing, Vols 1-31, 2008, 11311-11315.

Hsu, Y.L., P.E. Hsu, Y.C. Hung and Y.D. Xiao, *Development and Application of a Patent-based Design Around Process*, Proceedings of the 1st International Conference on Systematic Innovation, Hsin-Chu, Taiwan, The Society of Systematic Innovation, 2010.

Hung,Y.C. and Y.L. Hsu, *An Integrated Process for Designing Around Existing Patents Through the Theory of Inventive Problem-solving*, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 221, No.1, 2007, 109-122.

Ikovenko, S., *TRIZ Application for IP Strategies Development*, Boston, Available on line at: www.triz-summit.ru/file.php/id/f4113/name/Яковенко-2006.pdf, 2006.

Litvin, S., *New TRIZ-Based Tool — Function-Oriented Search (FOS)*, The TRIZ Journal, Available on line at: http://www.triz-journal.com/archives/2005/08/04.pdf, August, 2005.

Liu, T.L. and W. L. Jiang and W.L. Lee, *Improvement and Innovation for Product Design- a case study of safety helmet*, Proceedings of the 3rd TRIZ Conference, Hsin-Chu, Taiwan, Taiwan TRIZ Association., 2008.

Mann, D.L., *Assessing the Accuracy of The Contradiction Matrix For Recent Mechanical Inventions*, The TRIZ Journal, February, 2002.

Mann, D.L., *Hands-On Systematic Innovation*, 2nd Ed., IFR Press, 2007.

Mann, D.L., *Hands On Systematic Innovation for Business and Management*, 2nd Ed., IFR Press, 2007.

Nydegger, R. and Richards, J. W., *Design-around techniques, Electronic and Software Patents*, edited by Lundberg, S. W., The Bureau of National Affairs Inc, 2000.

Royzen, Z., *Solving Contradictions in Development of New Generation Products Using TRIZ*, The TRIZ Journal, Available on line at: http://www.triz-journal.com/ archives/1997/02/b/index.html,1997.

Shpakovsky, N., Abstract of book "*Evolution Trees. Analysis of technical information and generation of new ideas*", The TRIZ Journal, Available on line at: http://www.triz-journal.com/archives/2006/12/06.pdf, 2006.

Wang, J.C., The *Improved Study of TRIZ Innovative Design Method*, Master thesis, National Cheng Kung University Department Of Mechanical Engineering , 2002.

Yang, K., Y. and H.W. Zhang., *A Comparison of TRIZ and Axiomatic Design.* Proceedings of ICAD2000, First International Conference on Axiomatic Design, Cambridge, MA, June 21-23, 2000, 235-242.

Zhang, J. and Z. Liu and H. Zhang and J. Dai and R. Tan, *Use of TRIZ in the Process of Intellectual Property Enhancement*, Proceeding of 2006 IEEE International Conference on Management of Innovation and Technology, 2006, 360-364.

## AUTHOR BIOGRAPHIES

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# TRIZ Problem-solving Model for Multiple-to-Multiple Parameter Contradictions Using Case-based Reasoning

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**Abstract**

The engineering parameter and contraction matrix (CM) summarized by Altshuller according to the patents of traditional industries in 1950s can hardly be applied in today's industry due to the following two problems. First, the basic physical and chemical principles of contemporary science and technology industries are totally different from those of the traditional industries. Second, problems faced by the industries are not necessarily one-to-one parameter contradiction correspondence. In view of these problems, this paper used the chemical mechanical polishing (CMP) processing in the semiconductor industry as an example to establish industrial parameters, and employed the case-based reasoning (CBR) method to establish the multiple-to-multiple parameter corresponding case database in order to obtain the correspondence of the inventive principles (IPs) of the contradiction combinations.

This paper first reviews the patent summaries and establishes the multiple-to-multiple parameter correspondence patent case database. Through the operational mode of CBR, the similarity coefficient is employed to compare the similarity between the problems. Similar problems have similar corresponding IP solutions. The weighted integration of solutions to highly similar problem cases can identify the available inventive solutions. The correctly solved cases after validation can be added to the case database to endow it with learning and growing characteristics.

The contributions of this study are as follows. (1) It demonstrates the low applicability of the classical matrix to multiple-to-multiple parameter contradiction problems. (2) It constructs the prototype case database of multiple-to-multiple parameter contradiction of CMP processing problems. (3) It establishes multiple-to-multiple parameter contradiction mathematical solutions, improving the drawbacks of mathematical tools that involve mainly qualitative description but lack logical reasoning, accuracy as well as quantitative analysis, and providing solution sequencing. (4) It provides highly similar cases to problems to be solved as reference to new problems. (5) It can replace the classical matrix to resolve one-to-one parameter contradiction.

*Keywords:* Contradiction matrix, Chemical Mechanical Polishing Processing, Case-based reasoning, Inventive

principles, TRIZ

## 1. Introduction

TRIZ is a Russian acronym meaning "Theory of Inventive Problem-solving". TRIZ and contraction matrix, after more than a half century of studies and empirical practices, have been proven to be feasible for engineers to correctly define the problems, and propose solutions by referring to previous experiences. They are a set of feasible systematic methods with characteristics of creative thinking and innovative designing. However, the traditional 39 engineering parameters, 40 IPs, and CM are not applicable to all industries. From the perspective of logic judgment, different industries should have different engineering parameters and IPs according to their specific product or equipment characteristics. In particular, the 39 engineering parameters and 40 IPs were developed by Altshuller from developed by Altshuller were based on traditional mechanical products and industries, and preferably for solving mechanical problems. Since the characteristics of mechanical industries differ from those of the semiconductor industry, the CM and IPs are not applicable to both industries. Sheu et al.(2010) established a set of engineering parameters, innovative IPs and CM prototypes for the CMP equipment in the semiconductor industry.

Although all the summarized engineering parameters, IPs and CM use one-to-one parameter correspondence, from the perspective of some industries, the problems are not necessarily of one-to-one parameter correspondence relations. This study took the CMP processing in the semiconductor industry as an example, and found 103 cases of multiple-to-multiple parameter contradiction among a total of 120 cases of parameter contradiction in 90 patents reviewed; the percentage was as high as 86%. The blind use of classical matrix may result in lack of representation of one-to-one corresponding IPs. Hence, this study introduced the multiple-to-multiple parameter contradiction parameter correspondence, and established the case database with multiple pairs of parameters by CBR. By mathematical correspondence, this study aimed to provide more representative innovative solutions.

## 2. Literature Review

### 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 the corresponding "improving" and "worsening" parameter set to Inventive principles to help people solve the problem.

Table 1. The Contradiction Matrix

| | | Worsening Parameter | | | |
|---|---|---|---|---|---|
| Parameter To Be Improved | | 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 | | --- |

**2.2. Suitability of the Contradiction Matrix**

This research evidenced that the interpretability of the classical matrix is only 40% on chemical-mechanical polishing patents. Mann (2002) also reported a mere 48% applicability on mechanical patents. Mann (2006) re-did the matrix for software industry because of the same reason. For the semiconductor industry, the matrix also needs to be re-done if the concept of contradiction matrix and inventive principles are 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.

Mann (2002) chose 130 patents from mechanical systems in both American and European patents to verify the suitability of the classical CM. The principle proposed by the classical CM can interpret only 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 20 years ago, and therefore cannot cater for the more recent advances. The results of this study suggest that, for mechanically oriented problems, the recommendations by the classical matrix will be correct just under half of the time. Therefore, Mann et al. (2003) and his team used the same idea of contradicting parameters and inventive principles to establish Matrix 2003 (Mann and Dewulf 2003a,b) from 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. While the classical matrix has many empty cells, Matrix 2003 has none. 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 to be 40 though the ways to interpret each inventive principle are customized for different types of matrices. The new matrices established were also coded in Matrix+ software [Matrix+] to automate and facilitate the matrix applications.

Sheu (2007) suggested that a major reason why the Classical Matrix is not suitable for the newer industries is that the working principles of the underlying fundamental physics or chemistry for different industries/applications are quite different. Therefore, the matrix solutions developed from certain industries probably will not work well across different industries. For example, a manager from the semiconductor industry in Taiwan described to the author their repeated disappointment in using the classical Altshuller's matrix to solve their problems. Such problem can be solved by developing a specific set of CM and IPs according to 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.

### 2.3 Similarity coefficient

The commonly used similarity coefficient methods can be divided into two types: Machine Similarity Coefficient Method and Part Similarity Coefficient Method. Past studies have proposed various methods for calculating the similarity coefficient. The similarity coefficient method proposed by Jaccard (1991) was the most widely used and well known to general manufacturing designers in earlier times. Table 2 shows an example of the use of Jaccard Similarity Coefficient Method. As seen, the upper part of the matrix indicates Part No. 3 and Part No. 5, and the left part represents Parts numbered 1, 2, 3, 4…7; 0 and 1 of the matrix denote whether the part is processed by the machine. For example, (3, 1) = 1 denotes that Part No. 3 is processed on Machine No. 1. By defining a as all the parts processed on the machine, b and c as one of the parts processed on the machine, and d as none of the parts processed on the machine, the calculation of the similarity coefficient of Part No. 3 and Part No. 5 can be written as:

$$S_{35} = \frac{a}{a+b+c} = \frac{3}{3+1+2} = 0.5$$

Table 2 Part-Machine relational matrix

| | | Part | | |
|---|---|---|---|---|
| | | 3 | 5 | |
| M/C | 1 | 1 | 1 | *a* |
| | 2 | 0 | 1 | *c* |
| | 3 | 1 | 0 | *b* |
| | 4 | 1 | 1 | *a* |
| | 5 | 0 | 1 | *c* |

| | | | | |
|---|---|---|---|---|
| | 6 | 1 | 1 | *a* |
| | 7 | 0 | 0 | *d* |

**2.4 CBR**

**2.4.1 Definition of CBR**

Kolodner (1993) indicated that CBR is a reasoned case that remembers previous situations similar to the current one and uses them to help solve the new problem. Paek et al. (1996) suggested that CBR solves problems by using the knowledge learnt from solving similar problems in the past. Its main actions include the retrieval of past similar cases, adaptation and linking with new problems, and record of failures to prevent recurrence of same mistakes in the future. Montazemi and Gupta (1996) indicated that CBR is developed from the experience of solving same decision-making problems in the past to back up the solution of problems. Its main steps include retrieval, mapping, adaptation and evaluation. The success of CBR depends on the applicability of the retrieved past cases to the new problem. According to the above, CBR is defined as the inference of newly met problems by past experience. The past experience of solving similar cases is applied to solving the new problem.

**2.4.2 Inference process of CBR**

The CBR process proposed by Montazemi and Gupta (1996) is shown in Figure 1, which is a complete reasoning process. Many CBR processes proposed in the past are similar to the one shown in Figure 1. The process involves the following steps: input description of the new problem, retrieve similar cases in the case database to analyze whether the retrieved case requires adaptation, adapt the case if necessary to suit the new problem, evaluate the feasibility and effectiveness of the case, and input the case in the database if the evaluation results are positive. These steps are described in detail below.

(1) Case retrieval

It includes the retrieval of past similar cases and selection of the best case. The purpose of retrieving past similar cases is to obtain the good cases. The process of retrieval involves using the characteristics of the new case as the case index of the case database. The selection of the best case is to obtain the closest or most representative candidate case among a number of similar cases.

(2) Case adaptation

This step analyzes items that require adaptation and implements the adaptation process. Some adaptation strategies can be set out or some heuristic solutions may be used for adaptation in this step.

(3) Case evaluation

This step tests whether the inferred results are correct, and it includes evaluation of simulations before and after the actual application.

(4) Case database

Owing to the case database, CBR can function and learn. Past cases and solutions are stored in the case database. As in other databases, case index retrieval and storage are employed to store and obtain cases with better results in case of a large database.

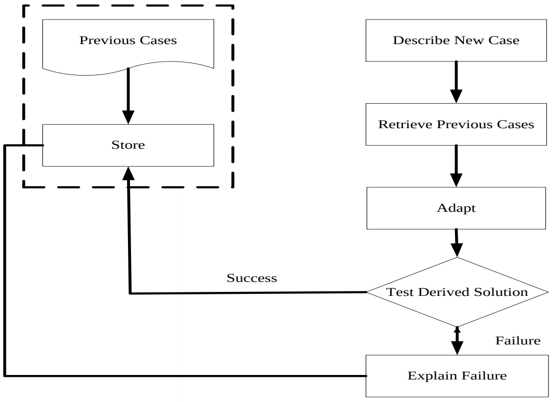


Figure 1 CBR process (Montazemi and Gupta, 1996)

## 3. Research Method

This study focused on the key processing of semiconductor manufacturing — CMP. It first reviewed patent summaries and established a patent case database. The new problem identified was compared with the cases in the case database by CBR, and the similarity coefficient was calculated to retrieve one or more than one similar cases of the past, in order to provide solutions accordingly. Then, the solutions were revised according to actual needs, and useful new and innovative solutions were stored in the case database. In this way, a new problem solved could serve as a new case in the database. After continuous accumulation, multiple-to-multiple CM and IPs better suited for specific industries could be developed.

### 3.1 Problem Solution Characteristics Array (PSCA)

The Problem Solution Characteristics Array (PSCA) determines the core characteristics of the problem. When presenting the problem core characteristics in a PCA, two parts: Problem characteristics Array (PCA) and Solution Array (SA) are included. The structure is shown in Figure 2.

| PCA | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section 1 | | | | Section 2 | | | | Section 3 | | | | …… | | | SA | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |

Figure 2 PSCA

***<u>Problem characteristics Array (PCA)</u>***

In this study, the PCA is divided into the Engineering Parameter Contradiction-Based PCA, the Function and Attribute-Based PCA, the Su-Field-Based PCA and others. The Engineering Parameter Contradiction-Based PCA describes the problem of parameter contradiction; that is, improvement of some parameters may worsen some other parameters. The format of Engineering Parameter Contradiction-Based PCA is as follows.

| Case | Problem Characteristics Array | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Improve Array | | | | | | Worsen Array | | | | | |
| | 1(+) | 2 (+) | …. | …. | …. | m (+) | 1 (-) | 2 (-) | … | … | … | m(-) |
| i | | | | | | | | | | | | |

Figure 3 Engineering Parameter Contradiction-Based PCA

The Function and Attribute-Based PCA describes the problem's Initial Attribute Array, the Target Attribute Array for improving the problem, and the functions involved in the change attribute. Hence, the Function and Attribute-Based PCA comprises the Attribute Array and the Function Array, with the Attribute Array further divided into Initial Attribute Array and Target Attribute Array.

| Case | Problem | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Attribute Array | | | | Function Array | | | | | | | |
| | Initial Attribute Array | | | | Change Attribute | | | | Function | | | |
| | $a_1$ | $a_2$ | …. | $a_p$ | $a_1$ | $a_2$ | …. | $a_p$ | $f_1$ | $f_2$ | … | $f_q$ |
| i | | | | | | | | | | | | |

Figure 4 Function and Attribute-Based PCA

The Su-Field-Based PCA uses the Su-Field relationship to describe the problem. It includes the Su-Field Array and Constraint Array, with structure shown below:

| Case | Problem | | | | |
|---|---|---|---|---|---|
| | Su-field Array | | | | Constraint Array |
| | Substance | Tool | Field | Interaction between substances | |
| i | | | | | |

Figure 5 Su-Field Based PCA

If there are other classification methods, arrays can be added to describe the problem.

***Solution Array (SA)***

This array is the expression array of the problem's trigger solution. The solution tools of TRIZ can be employed to present the solution in the following types of expressions.

(1) 40 IPs; (2) 37 trends; (3) 76 standard solutions.

According to the above PSCA definition, the PCA used in this study uses the Engineering Parameter Contradiction-Based PCA only; while the Solution Array (SA) uses IPs only with structure as below.

| Case | Problem Characteristics Array | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Improve Array | | | | | | Worsen Array | | | | | |
| | 1(+) | 2 (+) | …. | j | …. | m (+) | 1 (-) | 2 (-) | … | k | … | m(-) |
| i | $x_{i1}^{+}$ | $x_{i2}^{+}$ | | $x_{ij}^{+}$ | | $x_{im}^{+}$ | $x_{i1}^{-}$ | $x_{i2}^{-}$ | | $x_{ik}^{-}$ | | $x_{im}^{-}$ |

Figure 6 PSCA of this study

where:

$$1.x_{ij}^{+} \in \begin{cases} 0 & \text{The i - th case does not use the j - th improvement parameter} \\ 1 & \text{The i - th case uses the j - th improvement parameter} \end{cases}$$

$$2.x_{ik}^{-} \in \begin{cases} 0 & \text{The i - th case does not use the k - th worsen parameter} \\ 1 & \text{The i - th case uses the j - th worsen parameter} \end{cases}$$

$$i = 1,2,\ldots,q,\ j = 1^{+},2^{+},\ldots.,m^{+},\ k = 1^{-},2^{-},\ldots.,m^{-}$$

### 3.2 Multiple-to-multiple parameter contradiction case database

#### 3.2.1 Establish specific CMP engineering parameters and IPs

According to the "Invention Principles and Contradiction Matrix for Semiconductor Manufacturing Industry: Chemical Mechanical Polishing" established by Sheu et al. (2010), this paper refines engineering parameters to suit the CMP processing and equipment, and adds seven new engineering parameters as well as three new and two modified IPs.

#### 3.2.2 Review patent summary

The multiple-to-multiple parameter correspondence is used as the basis for reviewing patent summaries to retrieve and read patent data. The sources of patents are R.O.C Patent Database, Patent Full-Text and Full-Page Image Databases, and the U.S. Patent Database. Each patent is formatted as a PSCA after the review of patent summary.

#### 3.2.3 Establish multiple-to-multiple parameter contradiction and IP database

According to the results of Section 3.2.2, multiple-to-multiple parameter contradiction and IP database are established, as shown in Table 3.

Table 3 Multiple-to-multiple contradiction and IP database

| Case | Improving Parameter | | | | Worsening Parameter | | | | IP | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1(+) | 2 (+) | …. | m (+) | 1 (-) | 2 (-) | … | m(-) | 1 | 2 | 3 | …. | $l$ | …. | $v$ |
| Case 1 | $x_{11}^{+}$ | $x_{12}^{+}$ | …. | $x_{1m}^{+}$ | $x_{11}^{-}$ | $x_{12}^{-}$ | …. | $x_{1m}^{-}$ | $y_{11}$ | $y_{12}$ | $y_{13}$ | …. | $y_{1l}$ | …. | $y_{1v}$ |
| Case 2 | $x_{21}^{+}$ | $x_{22}^{+}$ | …. | $x_{2m}^{+}$ | $x_{21}^{-}$ | $x_{22}^{-}$ | …. | $x_{2m}^{-}$ | $y_{21}$ | $y_{22}$ | $y_{23}$ | …. | $y_{2l}$ | …. | $y_{2v}$ |
| Case 3 | $x_{31}^{+}$ | $x_{32}^{+}$ | …. | $x_{3m}^{+}$ | $x_{31}^{-}$ | $x_{32}^{-}$ | …. | $x_{3m}^{-}$ | $y_{31}$ | $y_{32}$ | $y_{33}$ | …. | $y_{3l}$ | …. | $y_{3v}$ |
| . | . | . | …. | . | . | . | …. | . | . | . | . | …. | . | …. | . |
| Case i | $x_{i1}^{+}$ | $x_{i2}^{+}$ | | $x_{im}^{+}$ | $x_{i1}^{-}$ | $x_{i2}^{-}$ | …. | $x_{im}^{-}$ | $y_{i1}$ | $y_{i2}$ | $y_{i3}$ | …. | $y_{il}$ | …. | $y_{iv}$ |
| . | . | . | …. | . | . | . | …. | . | . | . | . | …. | . | …. | . |
| Case q | $x_{q1}^{+}$ | $x_{q2}^{+}$ | …. | $x_{qm}^{+}$ | $x_{q1}^{-}$ | $x_{q2}^{-}$ | …. | $x_{qm}^{-}$ | $y_{q1}$ | $y_{q2}$ | $y_{q3}$ | …. | $y_{ql}$ | …. | $y_{qv}$ |

Where:

$$1. x_{ij}^{+} \in \begin{cases} 0 & \text{The i - th case does not use the j - th improvement parameter} \\ 1 & \text{The i - th case uses the j - th improvement parameter} \end{cases}$$

$$2. x_{ik}^{-} \in \begin{cases} 0 & \text{The i - th case does not use the k - th worsen parameter} \\ 1 & \text{The i - th case uses the k - th worsen parameter} \end{cases}$$

$$3. y_{il} \in \begin{cases} 0 & \text{The i - th case does not use the k - th IP} \\ 1 & \text{The i - th case uses the k - th IP} \end{cases}$$

$$i = 1,2,3,\ldots,q,\ j = 1^{+},2^{+},\ldots,m^{+},\ k = 1^{-},2^{-},\ldots,m^{-},\ l = 1,2,3,\ldots,v$$

### 3.3 New problem-solving process

#### 3.3.1 Describe the New Problem

When a new problem arises, it is described by the PCA using the description array, as shown in the table below:

Table 4 New PCA

| | Problem Array | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Improving Parameter | | | | Worsening Parameter | | | |
| | 1(+) | 2(+) | … | m(+) | 1 (-) | 2 (-) | … | m(-) |
| New Prob.(r) | $x_{r,1}^{+}$ | $x_{r,2}^{+}$ | … | $x_{r,m}^{+}$ | $x_{r,1}^{-}$ | $x_{r,2}^{-}$ | …. | $x_{r,m}^{-}$ |

#### 3.3.2 Retrieval of similar cases

After describing the new problem, the user should input the characteristic array of the new problem. According to the calculation of similarity, some past cases that are most similar to the description of the new case are selected from the case database.

The method for calculating the similarity coefficient follows that proposed by Jaccard (1991), and it is modified in this study according to the actual situation. The calculation is as follows.

Table 5 Case relational matrix

| | | Number of parameters used in case *i* | |
|---|---|---|---|
| | | 1 | 0 |
| Number of parameters used in new case *r* | 1 | *a* | *b* |
| | 0 | *c* | *d* |

$$S_{ri} = \frac{a + 0.5 \times d}{a + b + c + 0.5d} \quad (3-1)$$

Notes to symbols

1. $S_{ri}$ : Similarity of New Case and Case i.

i=1,2,3,….,q

2. $a$ : Number of parameters used by New Case and Case i.

3. $b$ and $c$ : Number of parameters used by New Case and Case i, respectively

4. $d$ : Number of parameters that were not used by New Case and Case i.

where, d is the number of parameters that are not used by New Case and Case i.. In this case, the two situations may not be related to the engineering parameters, or the two cases do not use the engineering parameters, hence, the weight value is

0.5.

### 3.3.3 Calculation of similarity coefficient value

In the IC manufacturing industries with complex processing, there were often interactions between parameters. Hence, by quantified classification methods, we expected to find out the multiple-to-multiple contradiction relations as there might be improvement or worsening of more than one group of parameters rather than one-to-one parameters. This study searched for the IPs using the Similarity Coefficient Methods with steps as shown below.

**Step 1: Compare the new problem with the case database established in Table 3.**

**Step 2: Obtain the similarity coefficient between the new problem and the case database established in Table 3.**

The calculation of the similarity coefficient involves the following

(1) To improve the engineering parameter similarity coefficient

If a new problem and Case i of the case database have relevant data as below:

Table 6 New problem and case of the case database to improve parameter relational matrix

| | Improving Parameter | | | | | |
|---|---|---|---|---|---|---|
| | 1(+) | 2 (+) | …. | j(+) | …. | m (+) |
| New Prob.($r$) | $x^{+}_{r,1}$ | $x^{+}_{r,2}$ | …. | $x^{+}_{rj}$ | …. | $x^{+}_{r,m}$ |
| Case i | $x^{+}_{i1}$ | $x^{+}_{i2}$ | ….. | $x^{+}_{ij}$ | ….. | $x^{+}_{im}$ |

The relational coefficient of the two is as illustrated as below

$$S^{+}_{r,i} = \frac{a^{+} + 0.5 \times d}{a^{+} + b^{+} + c^{+} + 0.5 \times d} \qquad (3\text{-}2)$$

$S^{+}_{r,i}$: New problem and Case i of the case database that improve the parameter similarity coefficient.

$a^{+}$: Number of improving parameters of the new problem and Case i of the case database.

$b^{+}$ and $c^{+}$: Number of improving parameters used by the new problem and Case i of the case database, respectively.

$d^{+}$: Number of improving parameters not used by the new problem and Case i of the case database.

Hence, we have the following equation:

$$a^{+} = \sum_{j=1}^{m} x^{+}_{r,j} \times x^{+}_{ij} \qquad (3\text{-}3)$$

$$b^{+} + c^{+} = \sum_{j=1}^{m} \left| x^{+}_{r,j} - x^{+}_{ij} \right| \qquad (3\text{-}4)$$

$$d^{+} = m - a^{+} - b^{+} - c^{+} \qquad (3\text{-}5)$$

(2) To worse the engineering parameter similarity coefficient

If a new problem and Case i of the case database have relevant data as below:

Table 7 New problem and case of the Case i of the case database to avoid the worsening of parameter relational matrix

| | Worsening Parameter | | | | | |
|---|---|---|---|---|---|---|
| | 1(-) | 2 (-) | ….. | k(-) | …. | m (-) |
| New Prob.(*r*) | $x_{r,1}^-$ | $x_{r,2}^-$ | ….. | $x_{rk}^-$ | …. | $x_{r,m}^-$ |
| Case i | $x_{i1}^-$ | $x_{i2}^-$ | ….. | $x_{ik}^-$ | ….. | $x_{im}^-$ |

The relational coefficient of the two is as shown below:

$$S_{r,i}^- = \frac{a^- + 0.5\times d^-}{a^- + b^- + c^- + 0.5\times d^-} \qquad (3\text{-}6)$$

$S_{r,i}^-$ : New problem and Case i of the case database to avoid the worsening of parameter similarity coefficient.

$a^-$: Number of worsening parameters of the new problem and Case i of the case database.

$b^-$ and $c^-$ : Number of worsening parameters used by the new problem and Case i of the case database.

$d^-$: Number of worsening parameters not used individually by the new problem and Case i of the case database.

Hence, the following equation:

$$a^- = \sum_{k=1}^{m} x_{r,k}^- \times x_{ik}^- \qquad (3\text{-}7)$$

$$b^- + c^- = \sum_{k=1}^{m} \left| x_{r,k}^- - x_{ik}^- \right| \qquad (3\text{-}8)$$

$$d^- = m - a^- - b^- - c^- \qquad (3\text{-}9)$$

(3) Calculation of similarity coefficient between new problem and Case i of the case database

$$S_{r,i} = \sqrt{S_{r,i}^+ \times S_{r,i}^-} \qquad (3\text{-}10)$$

$S_{r,i}$ : Similarity coefficient between the new problem and Case i of the case database.

By the above calculation, the similarity coefficient of each case of the case database and the new problem can be represented as below:

Table 8 New problem and case similarity coefficient

| | | IP | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Similarity coefficient | Case | 1 | 2 | 3 | …. | *k* | …. | *v* |
| $S_{r,1}$ | 1 | $y_{11}$ | $y_{12}$ | $y_{13}$ | …. | $y_{1k}$ | …. | $y_{1v}$ |
| $S_{r,2}$ | 2 | $y_{21}$ | $y_{22}$ | $y_{23}$ | …. | $y_{2k}$ | …. | $y_{2v}$ |
| $S_{r,3}$ | 3 | $y_{31}$ | $y_{32}$ | $y_{33}$ | …. | $y_{3k}$ | …. | $y_{3v}$ |
| | . | . | . | . | …. | . | …. | . |
| | . | . | . | . | …. | . | …. | . |
| $S_{r,q}$ | q | $y_{q,1}$ | $y_{q,2}$ | $y_{q,3}$ | …. | $y_{rk}$ | …. | $y_{qv}$ |

where:

$$y_{il} \in \begin{cases} 0 & \text{The i-th case does not use the k-th IP} \\ 1 & \text{The i-th case uses the k-th IP} \end{cases}$$

**Step 3: Set threshold value ( $L$ ) for Similarity Coefficient of each retrieved case**

This threshold value is set because the retrieved case in the case database should have certain degree of similarity with the new problem. The setting method is as follows.

$$Sign(S_{r,i}) = \begin{cases} 0 & if\ S_{r,i} < L \\ 1 & if\ S_{r,i} \ge L \end{cases} \quad (3\text{-}11)$$

Table 9 Similarity coefficient of each case

| Case | Similarity coefficient | $Sign(S_{r,i})$ |
|---|---|---|
| 1 | $S_{r,1}$ | $Sign(S_{r,1})$ |
| 2 | $S_{r,2}$ | $Sign(S_{r,2})$ |
| 3 | $S_{r,3}$ | $Sign(S_{r,3})$ |
| . | . | . |
| . | . | . |
| Q | $S_{r,q}$ | $Sign(S_{r,q})$ |

### 3.3.4 New problem solution array

By the calculation of the similarity coefficient, the calculation of the weights of the IPs used by the new problem is as follows:

$$z_{r,l} = \sum_{i=1}^{p} S_{r,i} \times Sign(S_{r,i}) \times y_{il} \quad (3\text{-}12)$$

where:

where $z_{r,l}$ is the weight value of $l$–th IP used by the new problem in the case database.

Table 10 New Problem Solution Array

| IP | 1 | 2 | 3 | …. | n |
|---|---|---|---|---|---|
| New Problem Solution | $z_{r1}$ | $z_{r2}$ | $z_{r3}$ | …. | $z_{rn}$ |

### 3.3.5 Weight value normalization

As the new problem may be related to many cases in the case database (low similarity with very small similarity coefficient value) and the total similarity coefficient value would be very large due to too many samples, the user may misjudge the IP as important. Hence, the weight should be normalized by the method below:

$$W_{r,l} = \frac{z_{r,l}}{\sum_{i=1}^{q} Sign(S_{r,i})} \quad (3\text{-}13)$$

where,

where $W_{r,l}$ is the normalized value of the $l$–th IP of the new problem.

#### 3.3.6 Search for the trigger solution

After obtaining the IPs suggested by the previous step (Solution Array), the IPs are arranged in sequence according to their weight values. The one with the highest weight value represents the highest frequency of solving problems according to the accumulation of past experience and knowledge. The trigger solution can be obtained according to this IP; if not, search for the one with lower weight value until the trigger solution was found; or search directly for the most similar case and use the IP of that case as the trigger solution of the new problem.

#### 3.3.7 Verification of the new case

The final step is to obtain the new case. As the new problem has a new solution, the new problem can be changed into a case of the case database. In addition, besides adding the new case, the void or mistaken cases of the case database should be deleted because obsolete cases are no longer representative as time progresses or innovations of equipment and manufacturing technologies emerge. Otherwise, there will be redundant cases or the need for the merger or reorganization of key cases. The purpose is to make sure that the size of the case database would not increase continuously, which would affect the retrieval speed. In addition, keeping a database of optimal size would make each patent more correct with higher accuracy.

## 4. Research Results

### 4.1 Multiple-to-multiple parameter contradiction case

This study reviews the CMP processing patents of the semiconductor industry, and finds that there are 103 out of 120 cases (about 86%) in the 90 patents are of multiple-to-multiple parameter contradiction correspondence. Hence, using the classical matrix may result in a lack of representation of the IPs. The following shows an example case of the multiple-to-multiple parameter contradiction correspondence.

**Patent description (Chinese/English): GROOVED ROLLERS FOR A LINEAR CHEMICAL MECHANICAL PLANARIZATION**

**Patent number:** U. S. Patent /US, 10/040,501

**Patent content:**

(Notes to the past situations)

1. Figure 7 shows a linear polishing device. Grinding belt 12 is a continuous belt around roller 20 driven by the motor. The grinding belt is in a linear motion against wafer 16.
2. Pressure-supported platform 24 supports parts of the polishing belt under wafer 16.
3. In CMP processing, liquid substances such as grinding fluids or deionized water are used; hence, there would be liquid in between roller 20 and polishing belt 12. As a result, sliding may occur between the polishing belt and the roller, resulting in imprecise and heterogeneous polishing.
4. In the past, there were even number of parallel grooves 30 on the surface of the roller to remove the liquid from the contact area between the roller and the polishing belt.
5. As each groove 30 forms separate rings along the

roller, some parts of the polishing belt are not supported in rotation. Figure 8 shows the distribution of polishing pressure.

6. Hence, in the past, there are even numbers of parallel grooves 30 on the surface of the roller to remove the liquid from the contact area between the roller and the polishing belt.

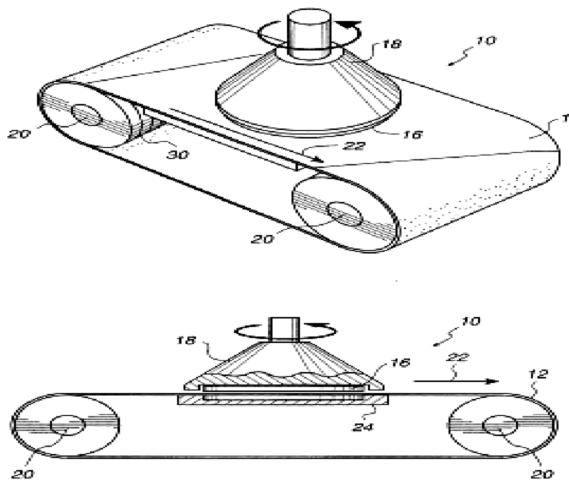

Figure 7 Linear polishing device

7. As each groove 30 forms separate rings along the roller, therefore, some parts of the polishing belt are not supported in rotation:

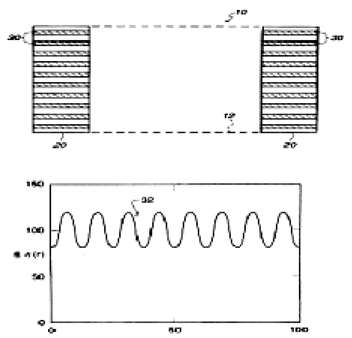
Figure 8 Distribution of polishing pressure

(The problematic issues)

1. Liquid substances, such as the grinding liquid or deionized water, may exist between the roller and the polishing belt, resulting in sliding. Even having parallel grooves may not achieve the best result, and there are still parts without grooves.

2. Owing to the parallel patterns on the roller, there will be uneven distribution of polishing pressure across the polishing belt. A group of concentric circles may be found on the surface of the polished wafer and different parts of the polishing belt may have different tensile forces, resulting in different polishing speeds.

3. Patent invention content

The parallel grooves of the roller are replaced with rotating grooves having angled side channels.

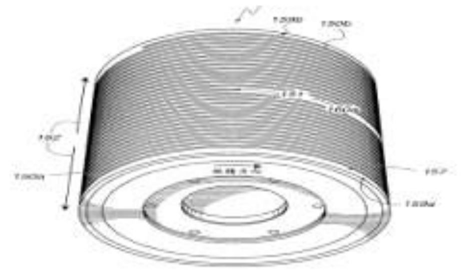
Figure 9 Patent Solution

4. Relevant engineering parameters

According to the above patent content, it is a case of multiple-to-multiple contradiction parameter correspondence. The improving parameters are (1) cleanliness between the polishing belt and the roller, and (2) uniformity of polishing surface; while the worsening parameters are (1) device complexity with extra devices needed, (2) time waste due to longer washing required, and (3) material waste.

Improving Parameters:

31.b Cleanness (Particle count); 31. d Uniformity

Worsening Parameters:

36. Device complexity—extra device; 25. Time waste—washing longer ; 23. Material waste.

**4.2 Validity verification of multiple-to-multiple parameter contradiction case database**

To verify whether the multiple-to-multiple parameter contradiction case database can help solve future CMP-related problems, this study uses 25 cases in 2007 and 30 cases in 2008 of the U. S. and Taiwan patents to verify the validity of the classical matrix and CBR case database. Classical matrix is employed to deal with the multiple-to-multiple parameter contradiction correspondence by dividing each group of multiple-to-multiple parameter correspondences into a number of one-to-one parameter correspondences.

The results of applying the classical matrix and CBR case database to the recent CMP-related patents in the case of 30 patents are shown in Table 11. The success rate of the classical matrix is only 43.33% while that of the CBR case database proposed in this study is as high as 83.33%. This study reviews 120 out of 40000 patents with success rate of correspondence 40% higher than that achieved by the classical matrix. In addition, the CBR case database proposed in this study can provide cases very similar to the new problem as references to the trigger solution of the new problem to improve the inability of the classical matrix to provide such IPs.

Table 11 Comparison between classical matrix and CBR-based matrix for CMP cases

| Case | Patent No. | Source | Patent Solution | Classical Matrix | | CBR-Based Matrix | |
|---|---|---|---|---|---|---|---|
| | | | | Classical Matrix Solution | Success | CBR-Based Matrix Solution | Success |
| 1 | 7,210,981 | USA | 1,3,15 | 19,**1**,31 | ✓ | **3[0.94]**,35[0.94],40[0.94],41[0.94],24[0.94],**1[0.93]**,**15[0.93]**,28[0.93],29[0.93],17[0.93],23[0.92] | ✓ |
| 2 | I270128 | ROC | 10,24 | **10(3)**,18(3),35(2),28(2),39,**24**,26, 23,32 | ✓ | **10[0.95]**,3[0.93],1[0.93],15[0.93],41[0.93] | ✓ |
| 3 | I272998-1 | ROC | 5,6,15 | 15,29,37,28 | × | 24[0.94],1[0.93],**15[0.93]**,17[0.92],13[0.92],23[0.91],10[0.91],9[0.91],35[0.91] | ✓ |
| 4 | I272998-2 | | 5,6 | 35(2),10,28,29,13,1 | × | 29[0.95],41[0.93],17[0.91],**15[0.91]**,14[0.91],10[0.91],23[0.91],35[0.91] | ✓ |
| 5 | 20070989-1 | ROC | 29,7,10 | 32(2),1(2),**10(2)**,25 | ✓ | 41[0.93],17[0.92],1[0.92],10[0.92],**15[0.91]**,3[0.91],24[0.91],35[0.91],29[0.91] | ✓ |
| 6 | 200709893 | | 29,33 | 35(3),1(3),34(3),22(2),10(2), 28(2),18,39, 4,15,33 | × | 14[0.95],1[0.94],35[0.93],3[0.93],40[0.93],15[0.93],17[0.93],**29[0.92]**,9[0.92] | ✓ |
| 7 | 09/057704 | USA | 9,31 | 1(4),10(2),19 ,**31**,22,28,20,16,13,35,27,17,40,30,4 | ✓ | 34[0.95],3[0.93],35[0.93],15[0.93],24[0.93],41[0.93],29[0.93],17[0.92],**9[0.91]**,40[0.91],**31[0.91]** | ✓ |
| 8 | | | 1,3 | **1(2)**,28(2),19,31,22,15,10,37, | ✓ | 10[0.94],**3[0.92]**,17[0.92],24[0.92],40[0.92],**1[0.91]**,15[0.91],35[0.91],29[0. | ✓ |

| Case | Patent No. | Source | Patent Solution | Classical Matrix | | CBR-Based Matrix | |
|---|---|---|---|---|---|---|---|
| | | | | Classical Matrix Solution | Success | CBR-Based Matrix Solution | Success |
| | | | | 2,5,18,32,9 | | 91],9[0.91] | |
| 9 | 200709895-1 | ROC | 7 | 10(2),1,34,35,29,39 | × | 24[0.93],17[0.93],35[0.92],15[0.92],29[0.92],41[0.92],1[0.91],3[0.91],40[0.91],23[0.91],10[0.91] | × |
| 10 | 200709895-2 | | 31 | 1,22,28,20,10,16 | × | 1[0.94],3[0.93],17[0.93],15[0.93],24[0.93],40[0.93],15[0.91] | × |
| 11 | 200713548-1 | ROC | 24,40 | 27,17,**40** | ✓ | 18[0.94],**24[0.93]**,17[0.92],1[0.92],35[0.92],29[0.92],15[0.91],**40[0.91]** | ✓ |
| 12 | 200713548-2 | ROC | 24,40 | 35(2),27,23,**40**,3 | ✓ | 1[0.93],**40[0.93]**,29[0.93],3[0.92],15[0.93],17[0.92],35[0.92],**24[0.91]** | ✓ |
| 13 | I278062 | ROC | 31 | 22(2),1, 35,18,39 | × | 17[0.95],3[0.94],1[0.94],15[0.94],29[0.94],24[0.94],35[0.93],40[0.93] | × |
| 14 | 11/168579 | USA | 1 | 19,**1**,31 | ✓ | 3[0.93],**1[0.93]**,24[0.93],35[0.93],40[0.93],17[0.92],15[0.92],29[0.92] | ✓ |
| 15 | 60/670466 | USA | 40 | 1,22 | × | 41[0.94],3[0.93],17[0.93],15[0.93],35[0.93],29[0.93],1[0.93],24[0.92],**40[0.92]** | ✓ |
| 16 | I278033-2 | ROC | 40 | 19,1,31 | × | 3[0.93],17[0.93],35[0.93],**40[0.93]**,24[0.93],29[0.93],15[0.92],1[0.92] | ✓ |
| 17 | I278929 | ROC | 28,17 | 1,22 | × | **17[0.93]**,15[0.93],1[0.93],3[0.92],35[0.92],24[0.92],41[0.92],29[0.92],40[0.91] | ✓ |
| 18 | I278377 | | 29 | 18(3),1(2),22(2),35(2),39(2),10(2),30,4,29,38,32,26,28,32 | × | 3[0.95],15[0.94],23[0.94],1[0.94],35[0.93],24[0.93],**29[0.93]**,17[0.93],40[0.92],41[0.92] | ✓ |
| 19 | I280175 | ROC | 40,42 | 10(2),20,16,18,38,32,39 | × | 17[0.93],15[0.92],29[0.92],3[0.91],35[0.91],1[0.91] | × |
| 20 | I280175-2 | ROC | 28,23 | **28(4)**,10(3), 32(3), 18(3), 24(2),34(2),16,31 , 1, 9,35 | ✓ | 10[0.95],**23[0.95]**,41[0.93],15[0.92],35[0.92],17[0.91],29[0.91] | ✓ |
| 21 | I287655 | ROC | 40 | 22,35,18,39 | × | 35[0.94],29[0.94],41[0.94],17[0.93],15[0.93],3[0.93],1[0.93],**40[0.92]**,10[0. | ✓ |

| Case | Patent No. | Source | Patent Solution | Classical Matrix | | CBR-Based Matrix | |
|---|---|---|---|---|---|---|---|
| | | | | Classical Matrix Solution | Success | CBR-Based Matrix Solution | Success |
| | | | | | | 92],24[0.92] | |
| 22 | 60/706971 | USA | 35,36 | **35(2)**, 1(2),22, 18,39, 29,38,27,17,40,10,34,28,32,13,17,34 | ✓ | 41[0.93],24[0.92],3[0.91],**35[0.91]**,29[0.91],9[0.91] | ✓ |
| 23 | 60/670466 | USA | 31,35,42 | 1(2),13,35, 26,2,18,19,**31** | ✓ | 10[0.96],23[0.94],17[0.93],24[0.93],29[0.93],**35[0.93]**,41[0.93],3[0.92],15[0.92],40[0.92],1[0.92] | ✓ |
| 24 | I269381 | ROC | 9,24,40, 35 | 10(4),**24(2)**,**35(2)**,34(2) ,6,3, 31,1,28,23,33,15 | ✓ | 41[0.93],**40[0.91]** | ✓ |
| 25 | 11/226979 | USA | 1,19 | -- | × | 10[0.95],41[0.94],23[0.94],35[0.93],29[0.93],3[0.92],17[0.92],**1[0.92]**,24[0.92],15[0.92],9[0.92] | ✓ |
| 26 | 11/168579 | USA | 10,9,24, 39 | 3(3),35(3),1(3),31(2),**10**,21,28,40,13, 24,39,19 | ✓ | 17[0.92],35[0.92],41[0.92],3[0.91],**24[0.91]**,40[0.91],29[0.91] | ✓ |
| 27 | 11/221375 | USA | 31,42,9 | 11,28,3,27,15,35,22, 2 | × | 10[0.95],23[0.94],29[0.92],41[0.91],3[0.91],35[0.91],17[0.91],15[0.91],1[0.91],24[0.91],**9[0.91]** | ✓ |
| 28 | I279898 | ROC | 30,42 | 13,35(2),1(2),19(2), 2,24,22, 29,40,31 | × | 35[0.93],**42[0.93]**,3[0.92],17[0.92],24[0.92],29[0.92],15[0.91],1[0.91] | ✓ |
| 29 | 10-2005-034-119.5 | Europe | 40,42 | 35(4),28(2),21,11,1, 29,38,3,23,22,18,39 | × | **35[0.93]**,24[0.93],29[0.93],9[0.93],17[0.92],41[0.92],15[0.91],3[0.91],1[0.91],**40[0.91]**,10[0.91] | ✓ |
| 30 | 11/127718 | USA | 11 | 35(3),1, 29,38,19,23,40,3 | × | **11[0.97]**,29[0.94],41[0.94],24[0.93],35[0.93],17[0.92],**3[0.91]**,15[0.91],1[0.91] | ✓ |
| Success rate | | | | | 43.33% | | 83.33% |

( ) number of occurrences for IPs

[ ] the Similarity Coefficient values of IPs

## 5. Conclusions

This study took the CMP process and equipment of the semiconductor manufacturing industry as the target. It then reviewed relevant patents, established

CBR case database and found cases similar to the new problem by the similarity coefficient numerical method as the trigger solution to the new problem. A total of 30 patent cases in 2007-2008 were employed to verify the applicability of the classical matrix and CBR case database to CMP problems. Results showed that the applicability of the classical matrix is only 43.33%, while the CBR case database has an applicability rate as high as 83.33% in the case of 120 patents. The main contributions of this study are as summarized below.

(1) It explained why the traditional Altshuller CM does not have high applicability in cases of one-to-one parameter correspondence.

(2) It constructed the prototype case database of multiple-to-multiple parameter contradiction of CMP processing problems.

(3) It established multiple-to-multiple parameter contradiction numerical solutions, improved the drawbacks of the classical matrix that uses mainly qualitative numerical tools that lack logical reasoning and accuracy and quantitative analysis, and provided the solution sequence.

(4) It provided cases very similar to the problem to be solved as the direct reference cases to the new problem.

In the future, more cases can be added to the CBR case database, and the case database can be updated with latest patents to ensure applicability. In addition, CMP is a very precise technology with various parts of the problems having different characteristics. With enough relevant knowledge, it may further be divided into CMs for specific grinding pad problems, grinding liquid problems, or equipment design problems to address more accurately the practical issues of the industry.

**REFERENCES**

Altshuller, G., 1997. 40 PRINCIPLES: TRIZ Keys to Technical Innovation. Translated by Lev Shulyak and Steven Rodman. Worchester, Massachusetts: Technical Innovation Center.

Jaccard P., 1991. Etude Comparative de Distribution Florale Dans une Portion Des. Alpes et des Jura, Bulletin de la Society Voudoise des Sciences Naturelles, Vol. 37, 547-579.

Kolodner J., 1993. Case-Based Reasoning, Morgan Kaufmann, California.

Mann, D., 2007. Hands-On Systematic Innovation. IFR Press. ISBN 90-77071-02-4.

Mann, D., 2002. Assessing the Accuracy of the Contradiction Matrix for Recent Mechanical Inventions. The TRIZ Journal, Available from http://www.triz-journal.com/, February.

Mann, D., 2006. Re-Structuring TRIZ to Meet the Needs of Software Engineers. Proceedings of the 2nd TRIZ Symposium in Japan, Osaka, 31 August - 2 September.

Mann, D., Dewulf, S., Zlotin, B. and Zusman, A., 2003. Matrix 2003 – Updating the TRIZ Contradiction Matrix. CREAX, Belgium.

Mann, D. and Dewulf, S., 2003b. Updating TRIZ 1985-2002 Patent Research Findings. The TRIZ Journal, Available from http://www.triz-journal.com/, May.

Mann, D. and Dewulf, S., 2003a. Updating the Contradiction Matrix. TRIZCON12003, Philadelphia, March.

Montazemi A.R. and Gupta K.M., 1996. An Adaptive Agent for Case Description in Diagnostic CBR Systems, Computers in Industry, Vol. 29, 209-224.

Paek, Y.K., Seo, J.Y. and Kimm G.C., 1996. An Expert System with Case-Based Reasoning for

Database Schema Design, Decision Support Systems, Vol. 18, 83-95.

Patent database, The Republic of China: Available from http://www.twpat.com/webpat/

Patent database, The United States: Available from http://www.uspto.gov/patft/index.html

Patent database, The World Intellectual Property Organization (WIPO): Available from http://www.wipo.int/portal/index.html.en.gov/patft/index.html

Sheu, D. and Lee, H.K., 2010. A Proposed Process for Systematic Innovation. International Journal of Production Research, DOI: 10.1080/00207540903280549.

Sheu, D., 2007. Body of Knowledge of Classical TRIZ & Relationships Among its tools. The TRIZ Journal, Available from http://www.triz-journal.com/, Oct.

Sheu, D. and Chen, C.H., 2010. Invention Principles and Contradiction Matrix for Semiconductor Manufacturing Industry: Chemical Mechanical Polishing. Journal of Intelligent Manufacturing, DOI 10.1007/s10845-010-0466-4.

Shirwaiker, R. and Okudan (2008). Triz and axiomatic design: a review of case-studies and a proposed synergistic use. Journal of Intelligent Manufacturing, DOI 10.1007/s10845-007-0044-6.

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# Systematic Method for Roadmapping Disruptive Innovation on the Fuzzy Front End of New Product Development

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**Abstract**

As an effective innovation method, disruptive innovation (DI) can be applied in a new firm to achieve leaping-over development. Based on technology evolution theory, the necessary conditions for DI are put forward. 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 for the fuzzy front end (FFE) stage of new product development (NPD). The method highlights effective disruptive technologies in the end mostly relies on disruptive innovation and presents it as the final high quality idea of FFE. The adoption of this method makes the objectives of the initial stage of product development clearer, which improves the effectiveness of innovation and success rate of product development. It is particularly fitting for new product development process of new enterprises entering a mature market.

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

## 1. Introduction

Disruptive Innovation (DI) is a technological innovation theory put forward by Christensen (1997) in 1997 and also consummated by him (Christensen, 1996, 2000, 2003). DI has several characteristics used for attracting unimportant consumers or new users. When these products are gradually becoming stable not only in the low-end market and the new market, but they can also take the place of the products which finalized the design in the mainstream market, enterprises that have these products, in other words, radical enterprises will replace current ones so as to achieve DI.

The development of DI product requires brand-new values to be brought into the existing market. Therefore, the development process of DI product involves an integration of a series of procedures. The integration contains various contents which include field selection of initial products consumer demand analysis, forecast of disruptive technologies opportunity, realization of disruptive technologies, the research and development production plan, design administration that can ensure each plan is carried out effectively. Sometimes the integration even includes the selling channel for preparing the new product and other promotion arrangements etc. Product design is included in the process of product development and is made up of each technical activity in accord with market development and commercial operation. It contains the development that conforms with the technical manual requirements for conceiving of the product, the development of new thinking and blending technological factors in the new product.

The initial stage of product innovation is called fuzzy front end (FFE). Recently, the products lifecycle has been shortened because of fierce market competition with new products coming out continuously to replace existing products. The success rate of product design must be greatly improved for adapting to this situation. Reliable and effective design constraints must be implemented from the front end of the conceptual design of product and the FFE stage, to achieve an effective innovation process. To improve the success rate of the DI process, the FFE stage of the DI process should be studied.

## 2. Literature Review

Disruptive Technology (DT) is the technology used in the process of the realization of DI. DT is technology which doesn't match the typical needs of mainstream consumers of enterprises and the improvement of it doesn't take place on the continuous evolutionary track of mainstream capability. DT might be the innovation technology that could not fulfill the needs of mainstream consumers of enterprises. The performance of DT is usually lower than that of the mainstream in the initial stage. It will surpass the mainstream technology before long and replace the mainstream technology. Successful DT can offer extra product characteristics for existing market consumers to meet their uncovered needs. The extra characteristics of these products are usually in the improvement directions of being small, light, cheap, function, ease of use, high reliability, high efficiency and energy saving (Kostoff and Boylanb, 2004). To some extent, the process of DI is just the process of forecasting and searching of DT. Therefore, the forecasting and searching method of DT has been a focus of studies, many scholars have their own definition of DT.

Abernathy and Utterback (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 (1995) believed that the kind of technology can be regarded as having the characteristics of being disruptive, when the service or entity commodity produced by this technology has 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. The consumers then took no account of the size attribute. We can define that the technology for 8-inch drive is a DT then.

Walsh and Linton (2000) regarded 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 (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.

Walsh, Kirchhoff and Newbert (2002) thought DT was the technology which didn't support the fundamental manufacturing operation of existing enterprises. In other words, DT is the technology that isn't consistent with the fundamental manufacturing technology of existing enterprises.

Kassicieh, Walsh and Cummings etc. (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 technologies. 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 the 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 product commercialization. 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 estimation 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 are 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 (Tan, Yang and Zhang, 2008).

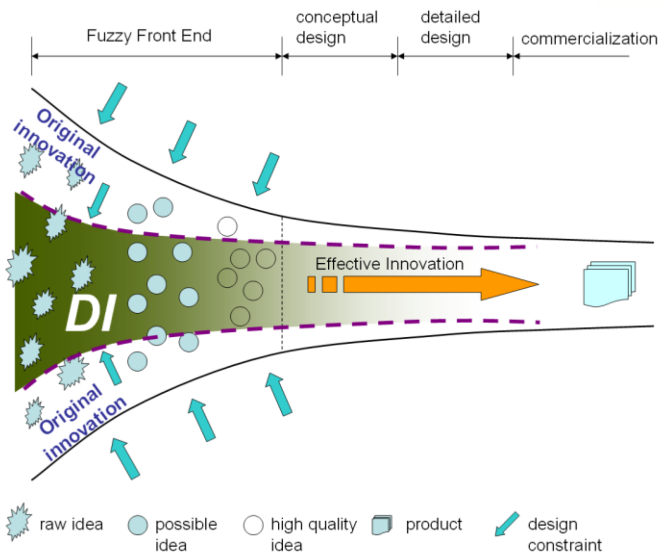


**Fig. 1.** The process of product innovation

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 framework. “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 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. Millions of 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 evolutionary insufficiency of main function of the product. Technology evolution law and technology evolution route and method in TRIZ are needed in searching for DT opportunities then ensuring possible evolutionary direction of technical subsystem which is waited to be improved, the state of technology that is on certain evolutionary 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 (Tan, 2007) to fix on innovative idea for the settlement of field problems as the product 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. CAIs contains all kinds of TRIZ tools and the corresponding repository, so it can support the generation of product innovative idea expediently.

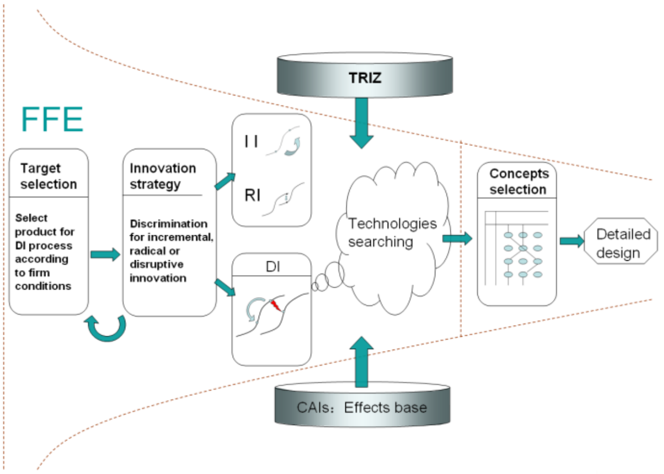


**Fig. 2.** The model of disruptive product development

### 3.3 Disruptive technologies forecasting based on technological system evolution theory

Product is a kind of complicated entity 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 shown in figure 3 is usually used in foregone decomposition of system. To avoid over complication of the technical system decomposition hierarchy, each outsourced unit can be limped as one unit. Moreover, design constraints (volume, price, operative accessibility, energy consumption etc.) can be listed in all subsystems.

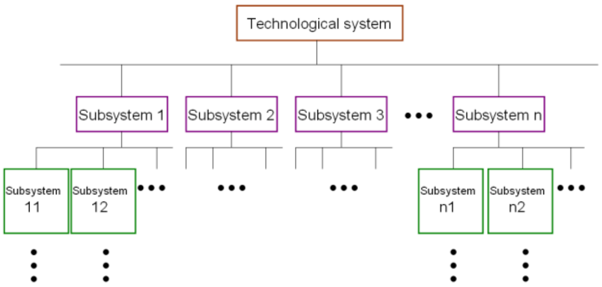


**Fig. 3.** Hierarchies of technological system

Refers to Figure 4, the evolution of product technology is not a single technical evolvable process. The product evolution appears as evolution of various aspects such as needs, overall technical system and the constituent technical subsystems. Evolution of needs is made up of different demands of user groups. The needs 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 the technology in another field that affects some technological level of the product.

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

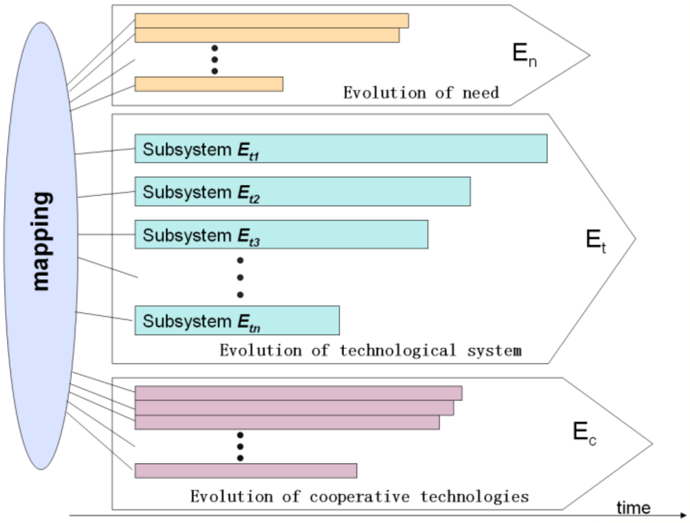


**Fig. 4.** Technologies system evolution model

Part 2:

Before technologies forecasting, there are two judgment 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 sustaining innovation. 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 an ideal robust evaluation is contained. Then, the following 4 steps proceed:

1. Technical design
2. Detailed design
3. Blueprint
4. Put into production

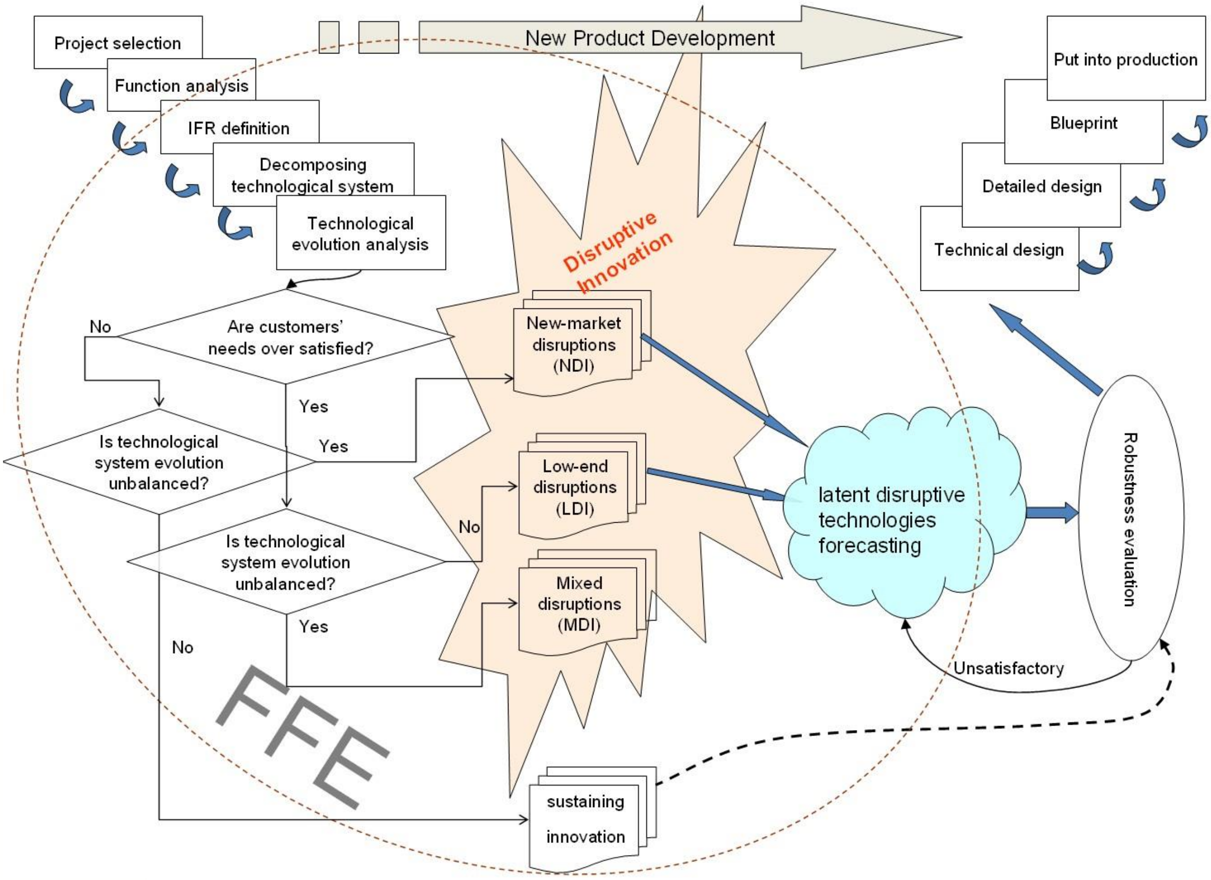


**Fig. 5.** Model of disruptive technologies roadmapping

## 4. Results

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

Product design starts from 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 opportunities. 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 evolutionary state of product technology system is acquired through technical system decomposition of chosen object product. And then making the decision, which one to choose, Low-end DI, New-market DI or Mixed DI by the method 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.

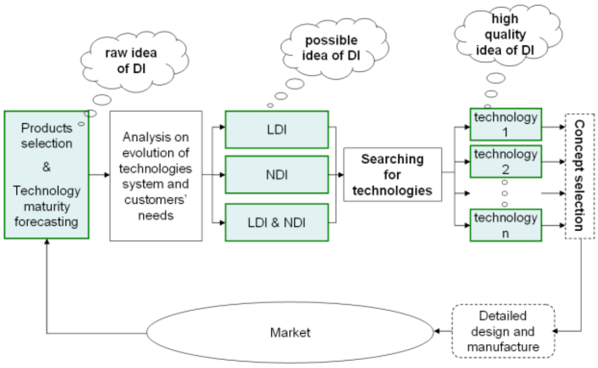


**Fig. 6.** Raw, possible and high quality ideas during DI

## 5. Case study-mobile phone for pupils and elderly

With the development of modern science and technology, mobile phones have been used in many fields as a convenient means of communication. Mobile phone has developed from the initial stage of doing telephony only to a transportable and multimedia unit that collects communication, entertainment and business in one. It is doubtless that the mobile phone market has been taken by several mainstream enterprises, such as Nokia, Samsung, Apple, Motorola and so forth. Low-end market has also been taken by a lot of ‘imitating’ enterprises. Hence, it will be quite difficult for new enterprises to enter mobile phone market, develop mainstream mobile phone product and compete with mainstream enterprises in the market directly. Therefore, DI policy has to be adopted and we should do DT searching in the FFE of product developing.

Mobile phones become more and more advanced and will be more abundant in functions. For instance, the functions include: listening to music, watching movies, playing games, browsing the webs and so forth. Meanwhile, the prices of them are quite high, such as iPhone. But not all of the customers need these functions. To some customers, certain advanced functions are unwanted. On the contrary, some unimportant functions which may be easily ignored are always of interests to them. DI got the opportunity to develop.

As the manufacturing technology of mobile phones becomes more and more mature, the prices get cheaper and cheaper too. And this situation makes more customers join in. According to the survey, we may find out that: the mobile phone market of the young pupils and the elderly enlarged gradually. Aiming at this market, DI can be adapted and disruptive technology will be searched according to the analyzing result.

As displayed in figure 5, the phases of the DI process are:

Phase 1: Products selection and technology maturity forecasting

In December of 1947, Douglas H. Ring and W. Rae Young, Bell Labs engineers, proposed hexagonal cells for mobile phones in vehicles (Tom, 2007). By the end of 2007 there were 295 Million subscribers on 3G networks worldwide, which indicated that mobile phone are popular worldwide. According to the market

DOI:10.6977/IJoSI.201101_1(3).0003
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investigation, the conclusions can be drawn that mobile phone is at its maturity stage. The evolutionary timing of mobile phone is suitable for DI process.

Phase 2: Technology system decomposition

As shown in figure 7, the technology system of mobile phone is decomposed into several units, including more than 3 sub-function technologies and 4 constraints. Through data collection, processing and analyzing, 2 circular radar diagrams are shown in Figure7.

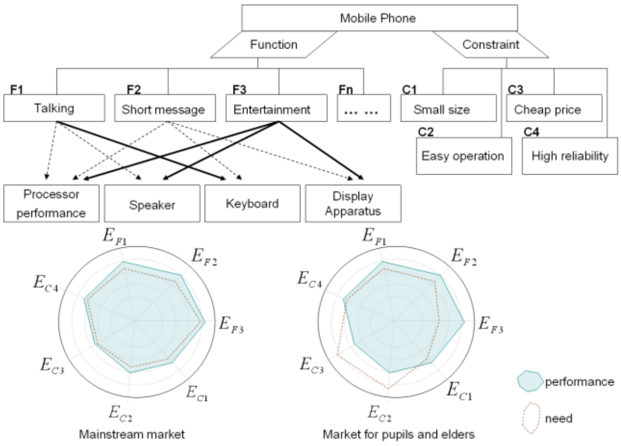


**Fig. 7.** Decomposition and analysis of mobile phone technology system

Phase 3: Technology sub-systems analysis

From the radar diagrams, we can draw a conclusion as shown in the table of Figure 8. For pupil and elder customer, the complex entertainment functions of mobile phone are unnecessary, and even harmful to pupils, but it is demanded that mobile phone is cheaper and ease to use.

| Sub-technology | Evolution state | Disruptive technologies |
|---|---|---|
| $E_{F1}$ | Optimal Performance state, OPS | |
| $E_{F2}$ | Optimal Performance state, OPS | |
| $E_{F3}$ | Over-satisfied need state, ONS | Reduce entertainment functions |
| $E_{C1}$ | Optimal Performance state, OPS | |
| $E_{C2}$ | Dissatisfied need state, DNS | Simplify operation |
| $E_{C3}$ | Dissatisfied need state, DNS | Cost reduction |
| $E_{C4}$ | Optimal Performance state, OPS | |

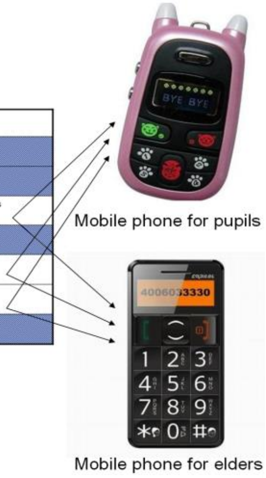


**Fig. 8.** Disruptive technologies face to the market of pupils and elders

The display panel of mobile phone for kids has only seven key-presses as the figure shows, which doesn't have digital input key-press and can just dial five pre-stored phone numbers. The five pre-set phone numbers can be set as the phone numbers of most conversant guardians such as parents and grandparents to avoid inappropriate usage of mobile phone for kids. It has simplified the usage of mobile phone too. The display screen takes up with simple alphanumeric display so as to prevent kids using mobile phone for entertainment. Mobile phone for the elderly has bigger key-pad which is good for dialing and its cost has been reduced owing to the simplified display design and the deletion of other entertainment functions.

Phase 4: DI strategy formation

At this phase, technologies of sub-functions are adjusted according to the results of technology system decomposition (Sun, 2011). All of the over-satisfied need state (ONS) technologies will be reduced and the dissatisfied need state(DNS) items will be increased. As shown in Figure7, to simplify the operation process of telephone number input, instead of the full keyboard , only 4 shortcut keys in that 4 relative's telephone numbers preset are designed on the panel of mobile phone for pupils and a special keyboard with extra large key is designed for elders. Meanwhile, the display designs of the two mobile phones are simplified for reduced cost.

## 6. 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 an 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.

## 7. Acknowledgment

This research is supported in part by the Natural Science Foundation of China under Grant Numbers 70972050, the Natural Science Foundation of Hebei under Grant Numbers E2009000070 and Foundation of the Construction of Innovation Engineer Training Base for the China Association for Science and Technology (CAST). Any opinions or findings of this work are the responsibility of the authors, and do not necessarily reflect the views of the sponsors or collaborators.

**References**

Abernathy, W. J. and J. M. Utterback, *Patterns of industrial innovation*, in Readings in the Management of Innovation, 2nd ed., M. L. Tushman and W. Moore, Eds. Ballinger, 1988: 25-36

Bower J. L. and C. M. Christensen, *Disruptive technologies: Catching the wave*, Harvard Business Review, 1995

Christensen, Clayton M. and Bower, Joseph L. *Customer Power, Strategic Investment, and the Failure of Leading Firms.* Strategic Management Journal, vol.17, no.3, pp. 197-218, 1996.

Christensen, Clayton M. *The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail.* Boston, MA: Harvard Business School Press, 1997.

Christensen, Clayton M. and Overdorf, Michael. *Meeting the Challenge of Disruptive Change.* Harvard Business Review vol.78, no.1, pp.67-76, March, 2000.

Christensen, Clayton M. and Raynor, Michael E. *Innovator's Solution.* Harvard Business School Press, Boston, 2003.

Lewis, A. V., G. Cosier and P. M. Hughes, *Dimensions of Change-a better picture of disruption*, BT Technology Journal, 2001, 19(4): 15-23

Ronald N. Kostoff, Robert Boylanb, Gene R. Simons, *Disruptive technology roadmaps*, Technological Forecasting and Social Change, 2004, 71: 141-159

Sun Jianguang, Tan Runhua. *Product innovative design* *methodology based on disruptive technologies.* Journal of Engineering Design, 2011, 18(1):1-11.(in Chinese)

Kassicieh, S. K., S. T. Walsh, J. C. Cummings, *Factors differentiating the commercialization of disruptive and sustaining technologies*, IEEE Transactions on Engineering Management, 2002, 49(4): 375-387

Tan Runhua. Process of Two Stages *Analogy-based Design Employing TRIZ.* International Journal of Product development, 2007, 4(1/2): 109-121

Tan Runhua, Yang Bojun, Zhang Jianhui. *Study on Patterns of Idea Generation For Fuzzy Front End Using TRIZ.* China Mechanical Engineering, 2008, 19(16): 1990-1995

Farley, Tom. *The Cell-Phone Revolution*. American heritage of invention & technology New York, 22 (3): 8–19, 2007

S. Walsh and J. Linton, *Infrastructure for emerging markets based on discontinuous innovations*, Eng. Manag. J., 2000, 12 (2): 23-31

Walsh, S. T., B. A. Kirchhoff and S. Newbert, *Differentiating marketstrategies for disruptive technologies*, IEEE Transactions on EngineeringManagement, 2002,49(4): 341-351

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IJoSI

DOI:10.6977/IJoSI.201101_1(3).0004

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# Development of Eco-Innovative Framework and Methodology for Product Design

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**Abstract**

"Design for X" has been an important design philosophy for product engineers. In recent years, many eco-design methods have been proposed. At the same time, many TRIZ tools have been adopted to assist the process. However, issues concerning how to utilize an integrated method to analyze the product design problem and how to evaluate the improved design are seldom investigated. In this paper, we propose an eco-innovative framework and methodology for product design. The framework includes three design modules— problem analysis, problem solving and solution evaluation, along with two auxiliary modules to assist the design process with collaborative coordination and information recording. The related design methodology adopts some popular tools, such as the TRIZ tools, system analysis tools, as well as criteria-evaluation tools. An example was used to illustrate the feasibility of this framework and methodology.

*Keywords:* TRIZ, Eco-Design, Eco-Innovation, Function Attribute Analysis Diagram.

## 1. Introduction

In the past, products were designed without considering environmental impacts. Often, traditional factors considered in the product design stage are function, quality, cost, ergonomics and safety. Now, it is imperative to consider the environmental influences of a product throughout its entire life cycle. Traditional end-of-pipe directives or regulations only focused on the emissions from the manufacturing processes of a product. However, adverse impacts on the environment may occur in any one of the life cycle stages such as use, recycle, distribution, and material acquisition. Therefore, enterprises need to analyze and evaluate the environmental impacts of the entire life cycle of a product, and thus target the core of the problem and effectively resolve the problem.

In the early design stage, decisions made during the preliminary design stage greatly affect the eco-effectiveness of a product. Therefore, it is very important to consider the environmental impact during the design stage. "Design for X" has been an important design philosophy for product engineers (Kuo et al., 2001; Huang and Mak, 1999). The "X" may be reliability, safety, quality, manufacturability, assembly, logistics, ergonomics, serviceability, maintainability, environment, etc. In recent years, many eco-design methods have been proposed (Tukker and Eder, 1999; Gottberg et al., 2006). Furthermore, many innovative ideas and tools are integrated into eco-design tasks, which then evolve into many eco-innovative methods (Pujari, 2006; Smith, 1999). However, issues concerning how to analyze the design problem and how to evaluate the design result were seldom investigated in previous researches. Therefore, it is worthwhile to discuss how one can develop an integrated method that can be used to solve design problems, as opposed to solving problems with piecewise tools. In this paper, some popular tools such as the TRIZ tools, system analysis tools, as well as criteria-evaluation tools are adopted to form an integrated eco-innovative design methodology for the analysis and evaluation of a product design and development. A practical example with Function Attribute Analysis (FAA) diagram (Mann, 2007), IDEF0 (Integration Definition for Function Modeling) system analysis (Colguhoun and Baines, 1989), TRIZ-Eco-innovation matrix (Chen and Liu, 2002) and 40 Inventive Principles as well as Eco-Compass diagram (Fussler and James, 1996) was demonstrated to illustrate the feasibility of this method.

## 2. Literature Review

### 2.1 TRIZ

The TRIZ method was developed by Altshuller, who had analyzed over 400,000 patents to build the contradiction matrix and 40 inventive principles. TRIZ shows the feasibility of the problem solving by extracting generic principles from patents (Terninko et al., 1998). Mann (2007) proposed a hierarchical view of TRIZ that is shown in Fig. 1. In this figure, TRIZ is an integrative system that includes a set of tools, a method, a way of thinking and a philosophy. At its highest level, TRIZ may be seen as the systematic study of excellence. At the philosophy level, there are five key elements in TRIZ— Ideality, Resources, Space/Time/Interface, Functionality, and Contradiction. The method level, located between the philosophy level and the tool level, is the main research interest of many scholars. In this paper, the research also focuses on this level. At the bottom of the TRIZ hierarchy, there are many tools in the tool level; these tools include: Inventive Principles, Contradiction Matrix, Ideal Final Result (IFR), S-Fields, Function Analysis, Separation Principles, Subversion Analysis, Trimming, etc. Among these tools, the contradiction matrix and the 40 inventive principles are the most famous tools. When adopting the contradiction matrix method to solve a specific problem, the designer needs to find the contradiction that contains a pair of improving and worsening parameters. Consequently, the designer can find around 3~4 recommended inventive principles in the contradiction matrix. With consideration to the specific situations and scenario in different disciplines, many scholars have recently proposed some new contradiction matrices in their researches.

### 2.2 Eco-design

Product design concerning environmental impact has many forms of expressions such as ecological design, environmental design, environmentally conscious design, environmentally responsible design, sustainable design, green design, etc. In this paper, we adopt eco-design as a term of choice. There are many definitions and interpretations for "eco-design." In this paper, we adopt the statement of Lee and Park (2005)— eco-design is an activity that integrates environmental aspects into product design and development.

The aim of eco-design is to reduce the environmental impact during the product life cycle through the following: raw materials, preliminary design, detailed design, manufacturing, assembly, packaging and transportation, use, and disposal (Jones and Harrison, 2000). Fleischer and Schmidt (1997) proposed a top-down 3-layered eco-design tool for the selection of materials. Michelini and Razzoli (2004) developed a knowledge-based infrastructure for product-service eco-design. They proposed a framework that included three types of innovations—product-innovation, function-innovation and method-innovation. Horváth (2004) suggested that the eco-design research should investigate the concepts of corrective products, reduce the environmental degradation, and ameliorative products and cope with the environmental effects. Dewulf and Duflou (2005) discussed how one could integrate different levels into business operations, and they proposed a concept of the 3-layered framework for eco-design. Ritchie (2005) considered that virtual technologies and applications might provide product design with many feasible tools and result in an eco-friendly approach. He also suggested the use of virtual prototypes and virtual concurrent engineering practices would reduce the need for physical prototypes and allow for evaluation and checking of product life cycle costs. Trappey et al. (2008) proposed an integrated green product design

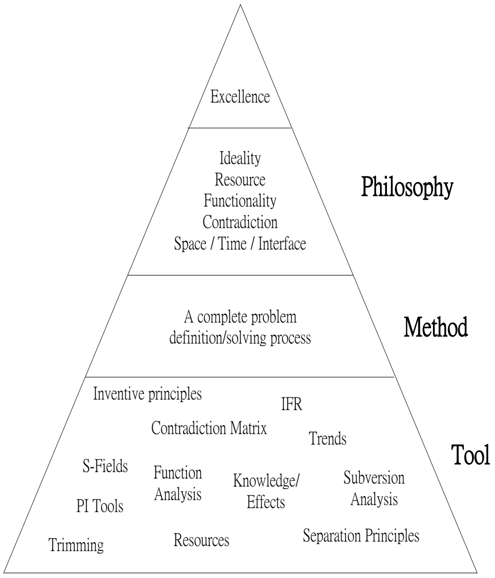

**Fig. 1.** Hierarchical view of TRIZ (Mann, 2007)

methodology and system. Though there have been many researches done on eco-design, it is necessary to develop a systematic method in order to design products that comply with ecological and economic requirements.

### 2.3 Eco-innovation

Facing the growing societal concerns with the global environment, enterprises are responsible for many directives and regulations such as Restriction of Hazardous Substances Directive (RoHS), Waste Electrical and Electronic Equipment Directive (WEEE), the Registration, Evaluation and Authorization of Chemicals (REACH) Regulation, and the Eco-Design for Energy Using Products (EuP). In order to comply with these directives and regulations, the cost of products involving entire life cycle stages inevitably increases. Although these costs are considerable, the costs of non-compliance are even more significant. Enterprises might face the risk of exclusion from key markets, stopped shipments, product recalls, etc. Non-compliance would result in not only loss of revenue, but also damage done to brand image and corporate reputation**.**

Although enterprises inevitably must cope with the cost pressure, this trend has also brought new opportunities for enterprises. For example, the trend has brought in financial institutions or individual shareholders looking to invest in and to support "greener" and "environmentally sustainable" companies (Butler and McGovern, 2009). Moreover, economic principles offer useful insights here. These principles suggest that the incentive to avoid costs associated with extended producer responsibility gives firms an economic inducement to undertake innovatory activities that may be conceptualized as eco-design (Gottberg et al., 2006).

Eco-innovation is a process that develops new products, processes or services that provide customer and business value but significantly decrease environmental impact (James, 1997). The simplest way to integrate TRIZ into eco-innovation is to use the TRIZ classical method to identify the contradiction parameters and to find suitable principles from the contradiction matrix. Chen and Liu (2002) linked seven major eco-efficiency elements from World Business Council for Sustainable Development (WBCSD) with classical TRIZ engineering parameters and developed an inventive design method to solve eco-design problems. Proposed by WBCSD, the seven major elements used to consider the eco-efficiency of developing environmental friendly products or processes are:

*A. Reduce the material intensity of its goods and services*

*B. Reduce the energy intensity of its goods and services*

*C. Reduce the dispersion of any toxic materials*

*D. Enhance the recyclability of its materials*

*E. Maximize the sustainable use of renewable resources*

*F. Extend the durability of its products*

*G. Increase the service intensity of its goods and service*

The eco-TRIZ matrix (Chen and Liu, 2003) was adopted as a tool in the problem solving stage and it is shown in Appendix.

## 3. Framework and methodology

In this paper, a framework and its related methodology for eco-innovative product design are proposed and shown in Fig. 2 and Fig. 3.

In Fig. 2, the framework includes three design modules— problem analysis module, problem solving module and solution evaluation module, along with two auxiliary modules, database & information recording module and computer-supported cooperative work (CSCW) (Santos, 1995) module. The two auxiliary modules are used to assist the design process with collaborative coordination and information recording. The problem analysis module is the most important stage in product design and development, since the wrong direction of a problem will result in incorrect solutions and will waste resources (time, money, etc.). The essence of problem analysis is problem definition, in which one should simultaneously note the requirements of members in the supply chain and green directives and regulation. The database & information recording module includes STEP (STandard for Exchange of Product model data) based data (Lee et al., 2003), TRIZ-based data, eco-based data and patent resources. The CSCW module can support the collaborative tools and method for members located in different places.

The corresponding methodology for the framework is shown on the left side of Fig. 3, which is a 3-stage design process. In the first stage, the problem analysis, there are two analytical tools adopted to analyze the scenario and the focus of the problem. The second stage focuses on problem solving, and it may adopt many TRIZ-based tools such as Technical

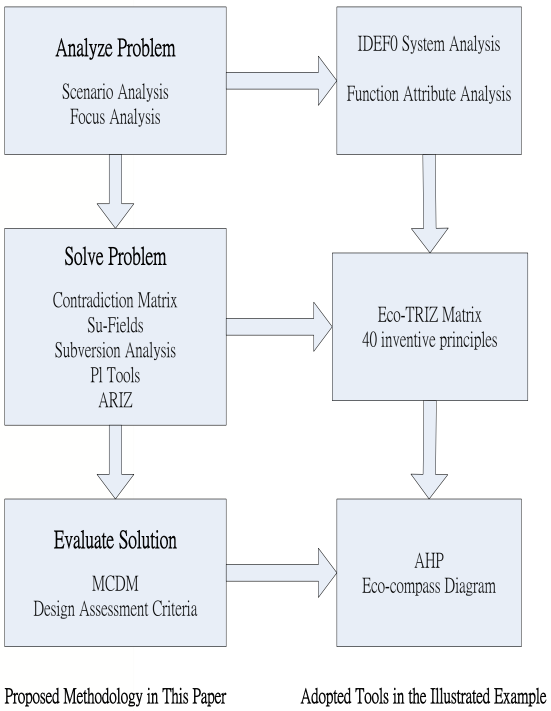


**Fig. 2.** The proposed framework of eco-innovative product design system

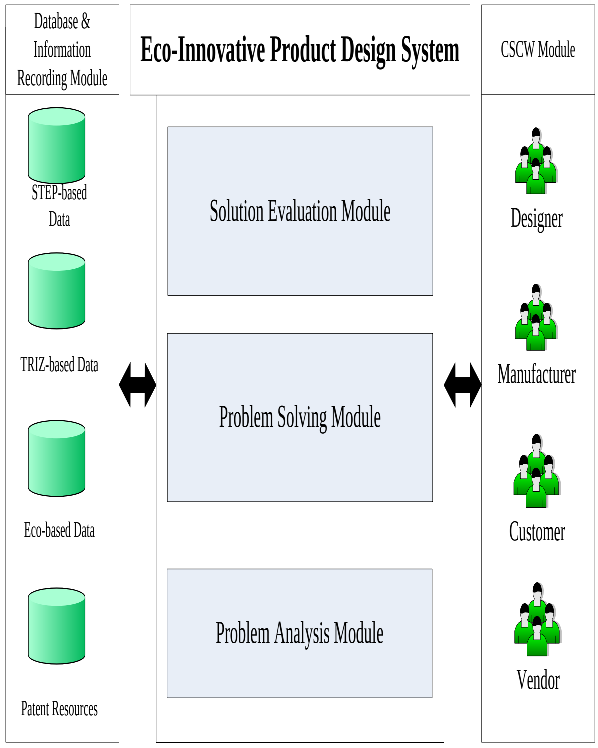


**Fig. 3.** Proposed design methodology and adopted tools

Contradictions/Inventive Principles, Physical Contradictions, S-Field Analysis/Inventive Standards, Trends of Technical Evolution, and ARIZ. For the last stage, the solution evaluation, Multiple Criteria Decision Making (MCDM) method (Tsai et al, 2010) and other design assessment methods can be adopted.

## 4. Case Study

In this section, an improved design of a fire-extinguishing system is used as an example to illustrate how one can implement the method. The tools chosen in this example are shown in the right side of Fig. 3. In the first stage, we use IDEF0 system analysis (Shen et al., 2004) and Function Attribute Analysis (Mann, 2007) to find the focus and the key point of the problem. In the middle stage, Eco-TRIZ matrix (Chen and Liu, 2003), along with 40 inventive principles, are adopted as the tools of problem solving. In the last stage, analytic hierarchy process (AHP) method (Tsai et al., 2010) and Eco-Compass diagram (Fussler and James, 1996) are used to evaluate the improved effect of the new design. In this paper, a traditional dry-powder fire extinguishing device is chosen to be the original design that needs to be improved. This fire extinguisher has exhibited flaws when used in a household kitchen. Fig. 4 shows the IDEF0 analysis diagram used as a tool to analyze the entire product life cycle of a product so that we can know what constraints and resources can be utilized. From this figure, we find the focus of the problem located in the stages of product use and product recycling.

To explore the product problem in depth, we adopt the FAA diagram (Mann, 2007) to find the problematic components and the interactive functions in the traditional, dry-powder extinguisher. The analysis result of the FAA diagram is shown in Fig. 5, and these results identify the causes of the problem that occur in three harmful relations: between nozzle and chemical powder, between chemical powder and kitchen equipment, and between kitchen equipment and fire. And thus, the key functions and the related components are discovered. From the FAA diagram, the dry powder may block the nozzle. Thus, the problem is solved by the Eco-TRIZ matrix as shown in the Appendix along with inventive principles. Fig. 6 shows a photograph of the improved design of the fire-extinguishing system for household kitchens. The Eco-compass for comparison of the improved design with original product is shown in Fig. 7.

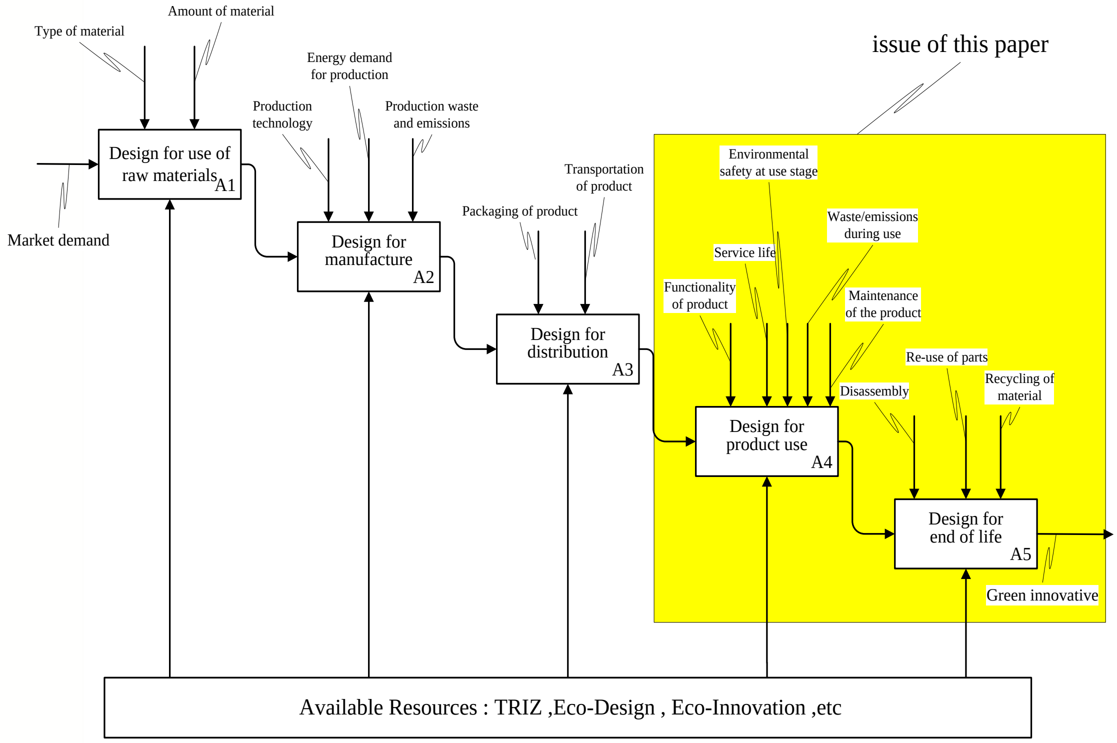


**Fig. 4.** IDEF0 system analysis diagram of green innovative product design

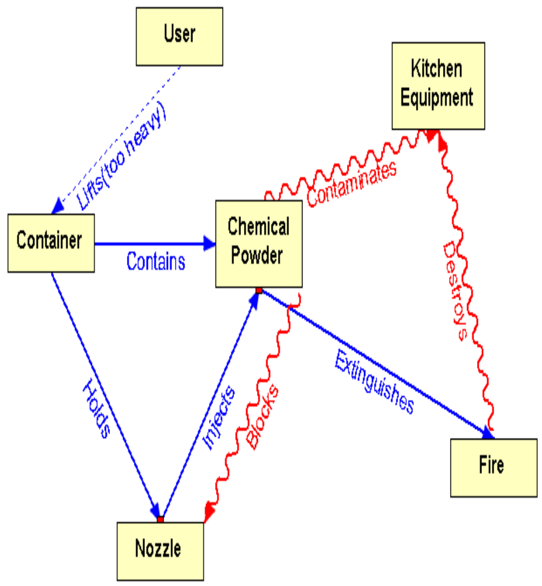


**Fig. 5.** Function attribute analysis diagram of dry-powder fire extinguisher

**Fig. 6.** Photograph of the improved design of fire-extinguishing system for household kitchen

## 5. Conclusions

As consumer demand and environmental consciousness increases, TRIZ and eco-design have attracted more attention from the academy and industries in recent years. The main contribution of this paper is to propose an integrated eco-innovative framework and its related methodology as a reference for product design that complies with both economical and ecological needs. Moreover, an example was used to illustrate the design process in order to prove the feasibility of this framework and methodology.

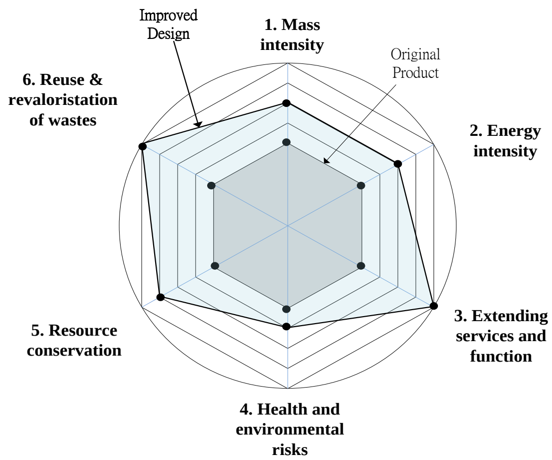


**Fig. 7.** Eco-compass for comparison of improved design with original product

## 6. Acknowledgement

This work was supported by the National Science Council, Taiwan, under grant numbers: NSC 95-2745-H-269 -002–HPU, and the fruit of this research (Fire Extinguishing System of Kitchen Equipment) has acquired the gold medal in 2007 Taipei International Invention Show and Technomart.

References

Butler T. and D. McGovern, *A Conceptual Model and IS Framework for the Design and Adoption of Environmental Compliance Management Systems*, Information Systems Frontiers, 2009, DOI: 10.1007/s10796-009-9197-5.

Chen J.L. and Liu C.C., *An eco-innovative design* *approach incorporating the TRIZ method without contradiction analysis*, The Journal of Sustainable Product Design, 2003, 1, 262–72.

Colquhoun G.J., J.D. Gamble, and R.W. Baines, *The Use of IDEF0 to Link Design and Manufacture in a CIM Environment*, International Journal of Operations & Production Management, 1989, 9, 48-65.

Colquhoun, G.J. and R.W. Baines, 1991. *A generic IDEF0 model of process planning*, International Journal of Production Research. **29**, 2239-2257

Dewulf W. and J.R. Duflou, 2005. Product Engineering. Springer. ISBN 1-4020-2932-2.

Fleischer G. and W.P. Schmidt, *Iterative Screening LCA in an Eco-Design Tool*, International Journal of Life Cycle Assessment, 1997, 2, 20-24.

Fussler C. and P. James, 1996. Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability, Pitman Publishing. ISBN **0273622072**

Gottberg A., J. Morris, S. Pollard, C. Mark-Herbert, and M. Cook, *Producer Responsibility, Waste Minimisation and the WEEE Directive: Case Studies in Eco-Design from The European Lighting Sector*, Science of the Total Environment, 2006, 359, 38-56.

Horváth I., A Treatise on Order in Engineering Design Research, Research in Engineering Design, 2004, 15, 155-181.

Huang G.Q. and K.L. Mak, *Design for Manufacture and Assembly on the Internet*, Computers in Industry, 1999, 38, 17-30.

James P., *The Sustainability Circle: A New Tool for Product Development and Design*, Journal of Sustainable Product Design, 1997, 2, 52-57.

Jones E. and D. Harrison, *Investigating the use of TRIZ in Eco- innovation*, The TRIZ Journal, Available from http://www.triz-journal.com/, September, 2000.

Kuo T.C., S.H. Huang, and H.C. Zhang, *Design for Manufacture and Design for 'X': Concepts, Applications, and Perspectives*, Computers & Industrial Engineering, 2001, 43, 214-260.

Lee, K.M. and P.J. Park, 2005. Ecodesign: Best Practice of ISO/TR 14062. Eco-product Research Institute, Ajou University. ISBN 981053115X.

Lee R.S., J.P. Tsai, Y.C. Kao, Grier C.I. Lin and K.C. Fan, *STEP-based product modeling system for remote collaborative reverse engineering*, Robotics and Computer-Integrated Manufacturing, 2003, 19, 543-553.

Mann, D., 2007. Hands-On Systematic Innovation. IFR Press. ISBN 90-77071-02-4.

Michelini R.C. and R.P. Razzoli, *Product-Service Eco-design: Knowledge-based Infrastructures*, Journal of Cleaner Production, 2004, 12, 415-428.

Pujari D., *Eco-Innovation and New Product Development: Understanding the Influences on Market Performance*, Technovation, 2006, 26, 76-85.

Ritchie J., 2005. Virtual Environments - the Eco-Friendly Approach to Product Design?. Springer. DOI: 10.1007/1-4020-2933-0_5.

Santos A., 1995. Multimedia and Groupware for Editing. Springer-Verlag. ISBN 3-540-60001-9.

Shen H., B. Wall, M. Zaremba, Y. Chen, and J. Browne, *Integration of business modelling methods for enterprise information system analysis and user requirements gathering*, Computers in Industry, 2004, 54, 307-323.

Smith M.T., *Eco-Innovation and Market Transformation*, The Journal of Sustainable Product Design, 1999, 1, 147-161.

Tukker A. and P. Eder, *Eco-design: The State of Implementation in Europe - Conclusions of a State of the Art Study for IPTS*, The Journal of Sustainable Product Design, 1999, 1, 147-161.

Terninko J., A. Zusman, and B. Zlotin, 1998. Systematic innovation, CRC Press, ISBN 1574441116.

Trappey A.J.C., M.Y. Chen, D.W. Hsiao, and G.Y P. Lin, 2008. The Green Product Eco-design Approach and System Complying with Energy Using Products (EuP) Directive, Global Perspective for Competitive Enterprise, Economy and Ecology, Springer, 243-254. DOI: 10.1007/978-1-84882-762-2

Tsai J.P., S.Y. Wang , and H.Y. Cheng, *Multi-Criteria Decision Making Method for Selection of Machine Tool*, 2010 International Symposium on Computer, Communication, Control and Automation, Tainan, Taiwan, 2010.

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**Appendix:**

Table A. The relationship of engineering parameters and eco-efficiency elements [Chen & Liu, 2003]

| TRIZ parameters engineering parameters | | Eco-efficiency elements | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| 1 | Weight of moving object | ◎ | ◎ | | | | | |
| 2 | Weight of non-moving object | ◎ | | | | | | |
| 3 | Length of moving object | ◎ | ◎ | | | | | |
| 4 | Length of non-moving object | ◎ | | | | | | |
| 5 | Area of moving object | ◎ | ◎ | | | | | |
| 6 | Area of non-moving object | ◎ | | | | | | |
| 7 | Volume of moving object | ◎ | ◎ | | | | | |
| 8 | Volume of non-moving object | ◎ | | | | | | |
| 9 | Speed | | | | ◎ | | | ◎ |
| 10 | Force | | | | ◎ | | | |
| 11 | Tension/pressure | | | | ◎ | | | |
| 12 | Shape | ◎ | | | | | | |
| 13 | Stability of object | | | ◎ | | | ◎ | |
| 14 | Strength | ◎ | | | | ◎ | ◎ | |
| 15 | Durability of moving object | | | | | | ◎ | |
| 16 | Durability of non-moving object | | | | | | ◎ | |
| 17 | Temperature | | ◎ | | | | | |
| 18 | Brightness | | ◎ | | | | | |
| 19 | Energy spent by moving object | | ◎ | | | | | |
| 20 | Energy spent by non-moving | | ◎ | | | | | |
| 21 | Power | | ◎ | | | | | |
| 22 | Waste of energy | | ◎ | | | | | |
| 23 | Waste of substance | ◎ | | ◎ | | | | |
| 24 | Loss of information | | | | | | | ◎ |
| 25 | Waste of time | | | | | | | ◎ |
| 26 | Amount of substance | ◎ | | ◎ | | | | |
| 27 | Reliability | | | | | | | ◎ |
| 28 | Accuracy of measurement | | | ◎ | ◎ | | | |
| 29 | Accuracy of manufacture | | | | ◎ | | | |
| 30 | Harmful factors acting on object | | | | | ◎ | ◎ | |
| 31 | Harmful side effects | | | ◎ | | | | |
| 32 | Manufacturability | ◎ | ◎ | | ◎ | | | |
| 33 | Convenience of use | | | | | | | ◎ |
| 34 | Repair ability | | | | | ◎ | ◎ | |
| 35 | Adaptability | | | | | | | ◎ |
| 36 | Complexity of device | | | | ◎ | | | |
| 37 | Complexity of control | | | | | | | ◎ |
| 38 | Level of automation | | | | | | | ◎ |
| 39 | Productivity | ◎ | ◎ | | | | | ◎ |

Note: A, reduce the material intensity of its goods and services; B, reduce the energy intensity of its goods and services; C, reduce the dispersion of any toxic materials; D, enhance the recyclability of its materials; E, maximize the sustainable use of renewable resources; F, increase the service intensity of its goods and services; G, extend the durability of its products.

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