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CONTENTS

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Foreword

"Systematic Innovation (SI)" is a set of knowledge/tools/methods/studies which can enable systematic development of innovative problem solving and/or identification of innovation opportunities. The International Journal of Systematic Innovation (IJoSI) is a journal administered by the Society of systematic Innovation to publish high-quality original work in the areas related to systematic innovation. IJoSI is a peer reviewed, Open Access online journal with lag prints which publishes original research articles, reviews, and case studies in areas related to Systematic Innovation.

The aims of the journal are to publish high-quality scholarly papers with academic rigor in theoretical and practical studies in the SI areas. Although TRIZ (The Theory of Inventive Problem Solving) has been considered one of the most powerful tool set that does systematic innovation, SI goes well beyond TRIZ to include TRIZ and its extensions, non-TRIZ human originated systematic innovation, and Nature-inspired systematic innovations. SI also provides a platform to integrate TRIZ, non-TRIZ, and nature-inspired innovation methods to identify opportunities and solve problems innovatively. This is exactly what IJoSI is established for.

The features of the Journal include:

- Covering broad topics within the field of Systematic Innovation, including TRIZ(Theory of Inventive Problem Solving), Non-TRIZ human-originated systematic innovation, and nature-inspired systematic innovation.
- All published papers are expected to meet academic rigor in its theoretical analysis or practical exercises. The Journal is academically oriented with practical usage.
- Fast response time is a goal for the Journal. The expected average response time for author's submission is within 3 months of last input to the Journal.
- The Journal features double-blind peer review process with fair procedures. Each paper will be reviewed by 2 to 4 referees.

You are cordially invited to submit your original papers to IJoSI electronically through the journal website at http://www.IJoSI.org. For Journal format, please download templates from the web site. Any feedback, please send e-mail to editor@systematic-innovation.org.

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A Proposed Classification and Process of Systematic Innovation

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Abstract

A classification for the field of systematic innovation is proposed. A Systematic Innovation Process (SIP) derived from observations of business practices is proposed and exemplified. Time-wise, the SIP is a series of phases and stages which link the planned business processes from business opportunity identification to technology details to cross-industry application exploitation of newly developed technology/tools/products. Resource-wise, the SIP provides a platform to integrate heterogeneous resources and tools such as TRIZ (Theory of Inventive Problem Solving), non-TRIZ tools, and more opportunity identification and problem solving techniques for systematic innovation. Unlike brain-storming type innovation activities which are often ad-hoc and highly dependent on luck, systematic innovation is regarding the systematic development of innovative problem solving and/or opportunity identification. The proposed SIP is based on authors' observations of industry practices and has not been described elsewhere before. The framework integrated the full phases of systematic innovation processes providing a structured process to enable companies systematically identifying business opportunities and key problems, solving problems, and leveraging developed tools/products/technologies for cross-industry exploitations. This SIP also allows for the integration of various tools and knowledge within the overall systematic and cyclic process to support systematic innovation.

Keywords: systematic innovation, systematic innovation process, TRIZ, non-TRIZ

1. Introduction

1.1 Importance of innovation to the industry and world economy

Science and technologies have been changing rapidly in the last fifty years. In this time of rapid changing and highly competitive world, innovation is a vital source of competitive advantage or even surviving necessity.

Every new product/process/service originates from a new idea. The active functions of executives, for accelerating of innovative ideas to market, shall include developing a means of stimulating the creation of innovative ideas, developing a way of processing these ideas into product/process/service and storing innovative information into a structured knowledge repository, developing a means of analyzing innovative idea viability, and implementing the innovative ideas to product/process/service for maximizing business performance (Stokic et al., 2003).

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1.2 Random innovation versus systematic innovation

In general, there are three types of innovative problem solving approaches:

(1) A flash of genius: It occurs to the innovator with a flash of genius, sometimes accidental. However, only a tiny percentage of people are genii. It is not a primary source of innovative problem solving approach.
(2) Empiric Path: This approach attacks problems by brainstorming or trial-and-error approaches. A great majority of innovation in the world are from this category of source. However, it is highly dependent on luck and fails to take into consideration of all existing/possible solutions for best selection.
(3) Methodical Path: A systematic process is used to reveal the total solution space. It can quickly converge to an optimal solution by systematic analysis. It also provides more comprehensive coverage of the solution space allowing selection of optimal solution. Systematic Innovation belongs to this kind of approach. The differences between systematic innovation and empirical trial-and-error approaches are depicted in Figure 1.

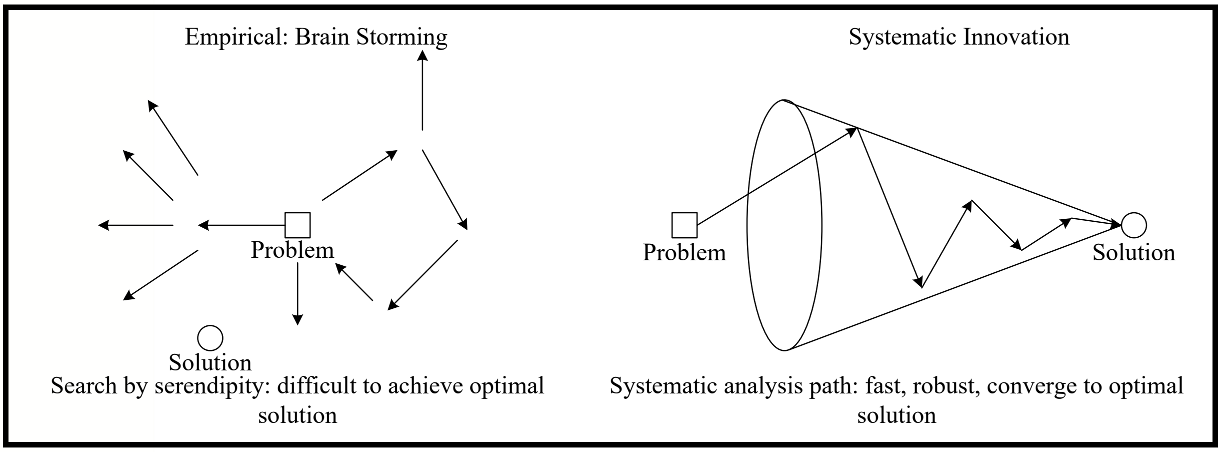

Figure 1. Differences between systematic innovation and try-and-error approach

Systematic Innovation (SI) is a field of studies which aims to enable us systematically identifying opportunities and/or solving problems innovatively. The sources of the SI primarily come from studies of human prior wisdom and/or inspiring problem-solving phenomena in the nature. The author's interpretation of systematic innovation can be described as: "Systematic ways of identifying innovative opportunities and/or problem solving innovatively". The discipline of Systematic Innovation is relatively new. Based on authors' observations of innovative business practices, this article proposes a way to classify the knowledge of systematic innovation and a structured process for systematic innovation which can facilitate innovative product/process/project development.

2. Related Work

2.1 Classification of systematic innovation

The proposed classification of systematic innovation is depicted in Figure 2. It includes Human-originated Systematic Innovation (HSI) and Nature-inspired Systematic Innovation

(NSI). The HSI can be divided into TRIZ (Theory of Inventive Problem Solving) and non-TRIZ systematic innovation systems. The TRIZ tools/knowledge can be divided into Classical TRIZ and TRIZ extension. They are extracted knowledge from patents. The patent-originated TRIZ knowledge/tools include: (1) Classical TRIZ - primarily, developed by Altshuller and his partners; (2) TRIZ-extension – are TRIZ tools/knowledge augments/developed by Altshuller's many disciples. The non-TRIZ systematic innovation knowledge/tools are extracted knowledge from other human studies/activities and knowledge developments such as 6 thinking hat, SCAMPER, etc. In the Nature-inspired SI domain, it consists of biologically inspired SI, known as Bionics/Biomimetics/biomimicry and non-biologically nature-inspired SI.

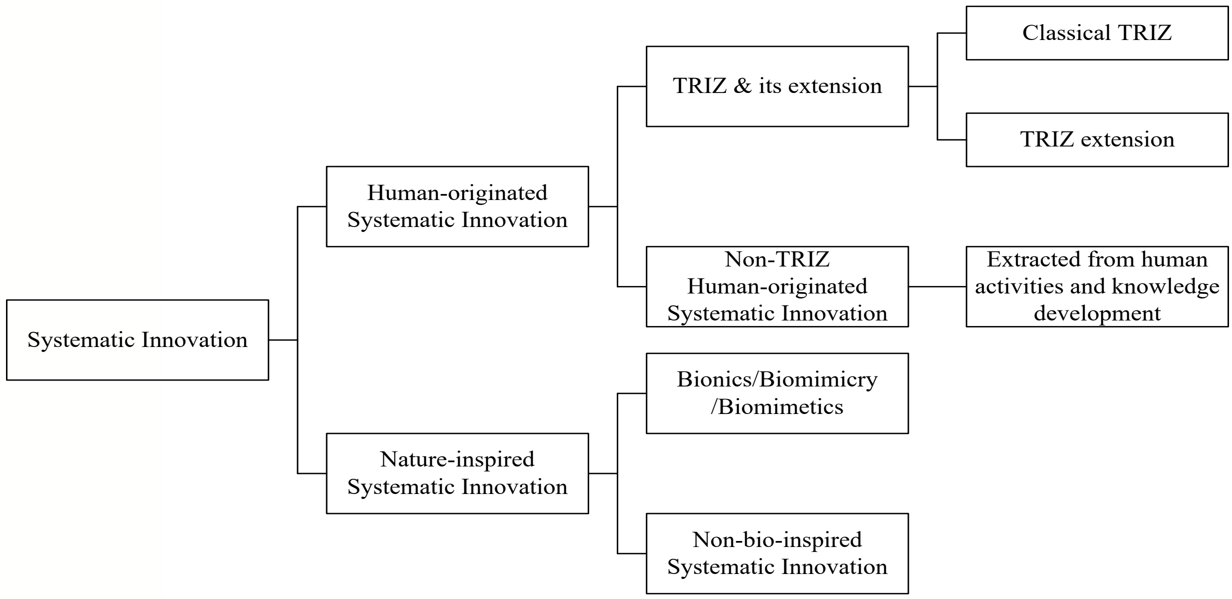

Figure 2. Classification of systematic innovation domain

2.2 TRIZ and non-TRIZ tools

Probably, the set of most important systematic innovation tools is TRIZ. TRIZ is the acronym for the Russian phrase, "Teoriya Resheniya Izobreatatelskikh Zadatch," roughly translated into English as "Theory of Inventive Problem Solving." Genrich Altshuller and his colleagues in the former USSR started TRIZ research in 1946. The three primary findings of TRIZ research are as follows (The TRIZ Journal):

(1) Problems and solutions were repeated across industries and sciences.
(2) Patterns of technical evolution were repeated across industries and sciences.
(3) Innovations used scientific effects outside the field where they were developed.

At the heart of the TRIZ theory, there are five key concepts which make TRIZ very valuable for innovative problem solving:

(1) Ideality, which defines the goodness of any product or system.
(2) Resources, which inspires us to use existing resources and to turn harm into help.
(3) Functionality, which helps us focus on the primary function and inspires us to create simplicity design.
(4) Contradiction, which profoundly indicated that:
 a. The underlying factor that blocks human advancement is contradiction.
 b. Innovation is, in essence, out of solving at least one contradiction.
(5) Space/time/interface, which facilitates us to see problems from various space/time/interface allowing us to solve problem easier and more innovatively.

There are many TRIZ publications which describe the TRIZ theories and provide numerous successful applications. (Altshuller 1984, 1997, 1999; Kaplan, 1996; Fey and Rivin 1997; Terninko et al. 1998; Zlotin et al., 1999; Savransky, 2000; Rantanen and Domb, 2002; Mann, 2002; Clausing and Fey 2004, 2005)

Hua et al. (2006) surveys TRIZ integration into other creativity tools, methods and philosophies using a literature review of publications, most of them are from proceedings and the TRIZ Journal, from 1995 to 2006. In their review, there are many problem-solving tools, techniques and philosophies that have been integrated or compared with TRIZ, such as Quality Function Deployment, Six Sigma, Design For Manufacture and Assembly, Robust Design, Axiomatic Design, Theory of Constraints, etc. Rantanen and Domb (2002) used TRIZ to enhance Six Sigma, Constraints Management, Supply Chain Management, QFD, and Taguchi methods to gain innovative and technological competitive advantages. To link the OTSM-TRIZ theory with concurrent engineering, Eltzer et al. (2004) proposed guidelines to analyze and synthesize the resulting complex contradiction network in a single inventive redesign task for the parametric design model and cause-effect relationships. Akay et al. (2008) presented the applications of the adaptation of TRIZ into human factors problems and revealed the benefits. Many TRIZ success cases can be found in the articles published in the TRIZ Journal. However, non-TRIZ systematic innovation tools are also useful and can be integrated with TRIZ tools for the process of systematic innovation. Yamashina et al. (2002) presented an innovative product development process by integrating non-TRIZ tool, Quality Function Deployment, and TRIZ and enables the effective and systematic creation of technical innovation for new products.

This article proposes a classification of the knowledge/tools of systematic innovation and a Systematic Process which can provide a framework to guide the integration of various innovation tools to facilitate the full life cycle of systematic innovation.

2.3 Related Work on Systematic Innovation Processes

Since the late 1990s, knowledge management has been the core of contemporary R&D management. The keyword is intellectual property, and the essence is innovation.

In the past, innovation ideas are mostly from brainstorming or trial-and-error. This is largely dependent on luck. There is a need to bring structure and systematic processes to innovation. As quoted by Strategos' Directors Loewe and Chen (2008): "an innovation process is critical to bringing structure to a fundamentally unstructured activity" - anonymous. One attempt at describing the latest development within the systematic innovation field is shown in Figure 3.

Refer to Figure 3. Mann (2002) proposed a four-step Systematic Creativity Process (SCP), namely, Define, Select Tool, Generate Solutions and Evaluate. The process starts with a perceived need for something to happen, followed by a clear definition of the right problem (conflicts), selecting the most appropriate tools to help people to solve it, solving by the TRIZ tool-kit, and finally identify the best solution (ideality) from the ones generated during the preceding 'solve' part. This process emphasizes the adaptation of the concepts and tools of TRIZ to carry out design activities. The conflict-based model and tools are applied to support the decision-making. Mann also proposed a 4-phase process to solve problems which covers Problem Identification Phase, Problem Selection Phase, Solution Generation Phase, and Solution Selection Stage. Mann's models did not cover the early stage of opportunity definition, and subsequent stages of implementation and further exploitation of newly developed technologies/products.

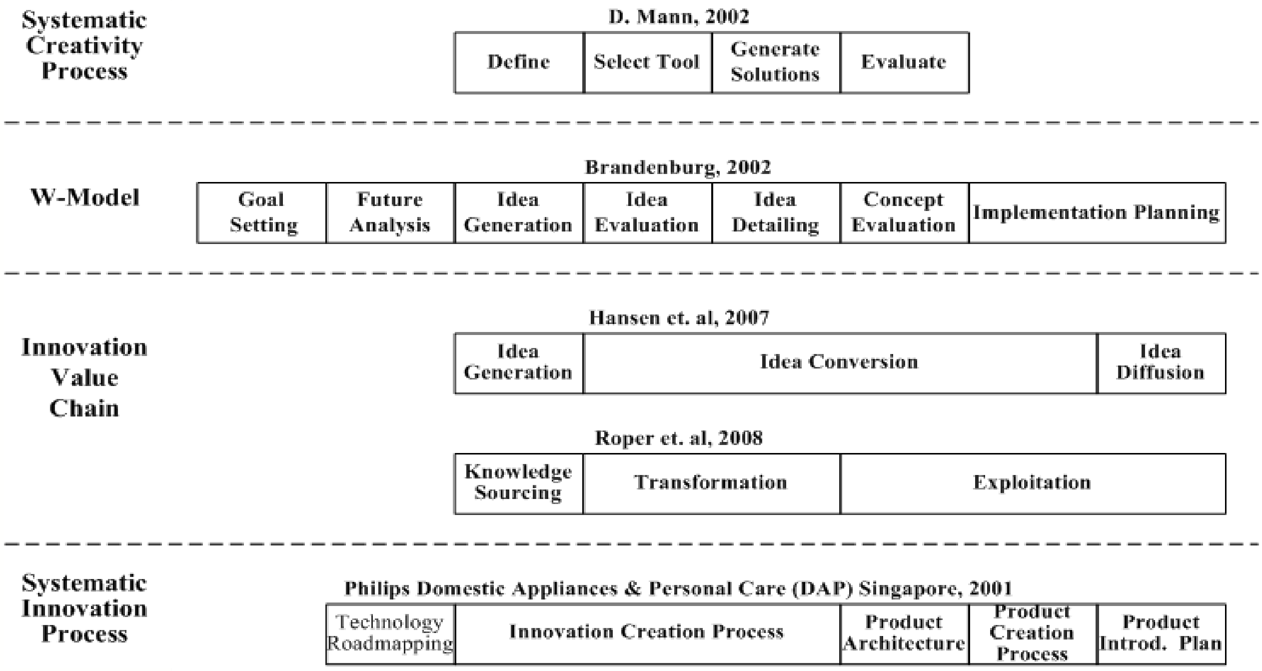

Figure 3. Literature review of systematic innovation process

Brandenburg (2002) proposed a seven-stage W-Model which forms a continuous circle that brings about recurring innovation activities on a strategic level. The final output of the W-Model is an Innovation Roadmap, which identifies future innovations and immediate innovations with a lot of potential for success, as well as innovations that should be investigated in more detail or at a later stage. The W-Model thus builds in strategic planning for immediate and future innovation projects, and creates a further input for the W-Model. The W-model did not cover the actual implementation and further exploitation of developed new products/technologies.

Hansen and Birkinshaw (2007) recommended viewing innovation as a value chain comprising three phases, namely, Idea Generation, Idea Conversion and Idea Diffusion. The aim of Idea Generation phase is to generate ideas from various sources: internal, external and cross-unit collaboration. During Idea Conversion phase, the major tasks are screening and funding of ideas and developing ideas into viable products, services, or businesses. In the Idea Diffusion phase, the developed ideas are spread within and outside the company to receive buy in.

Roper et al. (2008) modeled the innovation value chain for manufacturing firms highlighting the drivers of innovation, productivity and firm growth. This process includes

Knowledge Sourcing, Transforming, and Exploitation phases. Their model highlights the structure and complexity of the process of translating knowledge into business value and emphasizes the role of skills, capital investment and firms' other resources in the value creation process.

The innovation value chain models proposed by Hansen and Robert, et al., provide conceptual interpretational links between the upstream and downstream stages. Yet, no actionable methods were provided to facilitate the innovation processes.

Philips Domestic Appliances and Personal Care unit of Singapore (2001) presented a Systematic Innovation Process as indicated at the bottom of Figure 2. The first stage of its Systematic Innovation Process is Technology Road Mapping (TRM), which defines the needs and technological directions required for future R&D. The result of TRM is a series of innovation projects, which ranges from breakthrough product concepts to developing new technologies. Following the TRM is the Innovation Creation Process (ICP) where consumer needs and technological opportunities are developed into working prototypes to test the feasibility of concepts. Project teams are assigned to carry out the innovation projects arising from the TRM. Once innovation projects are proven to be feasible with functional prototypes, new concepts are further developed into standard technical modules. This structure is implemented in product design and process design for flexible manufacturing. The introduction of new products is managed via a Product Creation Process (PCP). The progress of this process is marked by milestones at which management reviews the results and decides on whether the project should continue. Multi-disciplinary project teams are formed to undertake PCP projects in a concurrent engineering environment. The SIP proposed provides good guidelines for company's current product development process. However, there is no mention on technology exploitation and no development tools were provided or linked for the proposed SIP.

The authors' proposed process of systematic innovation was based on the observations of innovative product and process development. Time-wise, it provides a logical framework to cover the systematic innovation processes from initial problem to opportunity and problem identification, to problem solving and to technology/product exploitation and forms a full cyclic life cycle of the innovation processes. Resource-wise, the proposed SIP provides a framework upon which various tools and knowledge can be integrated to facilitate the innovation processes. The tools/knowledge which can be used to fulfil the process of innovation include TRIZ tools and non-TRIZ tools.

3. The Proposed Process for Systematic Innovation

Refer to Figure 4. The proposed process of systematic innovation consists of five linked phases and eight stages. The proposed five phases are Opportunity Definition, Problem Definition, Solution Definition, Project Execution, and Application Exploration in that order. For each of the three definition phases, there is a diverging stage followed by a converging stage as shown in the Figure. The corresponding tools identified so far for the various phases and stages are listed in Figure 5. Acronyms in the figure are explained in Appendix. It is noted that the tools listed are the ones identified so far. There may be other tools which are yet to be explored under the umbrella of the proposed systematic innovation process. Because the interfacing inputs into and outputs from the connecting stages are well defined regardless of whatever tools/resources used in each stage, this framework allows integration of heterogeneous tools/resources in each stage for the process of systematic innovation. The brief functional descriptions for the listed tools in Figure 5 are in Appendix for cross reference.

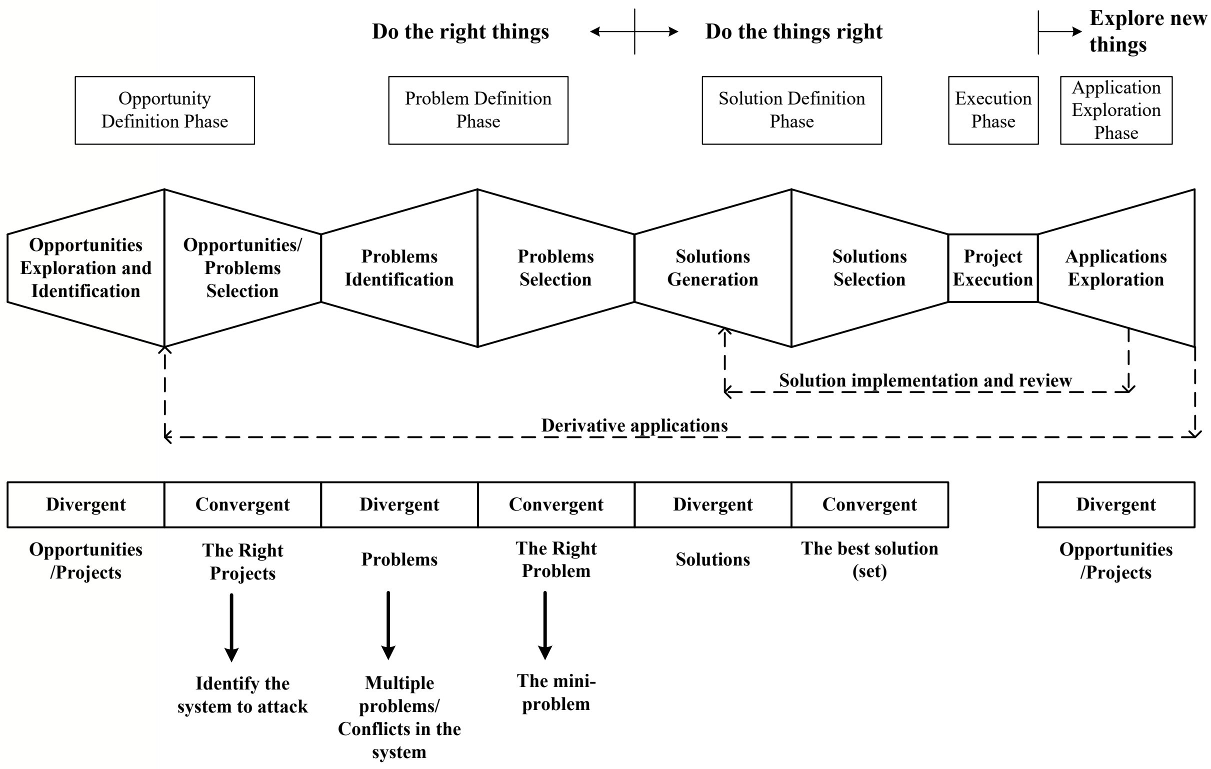

Figure 4. Systematic Innovation Process

Refer to stage designations in Figure 5 for descriptions below.

<u>Stage (1) and (2):</u>

The Opportunity Definition Phase consists of a divergent Project/opportunity Identification Stage followed by a convergent Project/opportunity Selection Stage. An input to the beginning stage is a current problem spotted. This initial stage enables wide-open opportunity explorations which may lead to solving the current problem without actually dealing with the current problem or locating other business opportunities/projects to work on.

In this stage, the initial problem is analyzed using the TRIZ and/or Non-TRIZ tools as listed in the lower part of Figure 4 to find out all possible business opportunities or projects/products to work on. Refer to Appendix, the tools for this Opportunity Definition Stage can be further divided into two classes:

a. **Wide-open opportunity exploration tools:** These tools include Problem Hierarchy, Ideal Final Result, and 9/12 Windows analysis. These tools allow the users to go beyond the space/time/interface of the current problem and identify relevant possible opportunities in other space/time/interface. Often times, a problem is difficult to solve at the current space/time/interface and can be better and easier solved in a different and maybe non-obvious space/time/interface. This is liken to the essence of Fourier Transform. Instead of solving a difficult time-domain differential/integral problem, the Fourier Transform is able to convert the original time domain problem to frequency domain (Wikipedia on Fourier Transform). Then, solving the difficult differential/integral problem in time domain becomes solving a much easier minus/plus problem in frequency domain. The three tools listed in this paragraph can systematically take the users to analyze the current problem from different perspectives and hopefully identify better position to solve the current problem and locate many opportunities for innovation.

b. **Tools for opportunity exploration within a given product/service direction:** These tools include Ideal Final Attribute (IFA), Omega Life View (OLV), Perception mapping, Voice of Customer Table (VOC), and Quality Function Deployment (QFD), etc. The IFA can systematically help us identify conflicts between customers and providers or among features/functions/attributes of the product/service we provide. Since conflicts are opportunities for innovative product or service, these tools can help us identify innovation ideas systematically within the direction of our given products or services.

The outputs of the Opportunity Exploration Stage are the multiple projects/opportunities which can be explored to solve the current problem or create new business opportunities. These outputs then feed into the convergent Project Selection Stage of the Opportunity Definition Phase to select the best opportunity/project to attack using the corresponding tools listed in the Opportunity Selection Stage as indicated in Figure 4. Though not listed here, many more tools such as project selection methods are available to screen the identified opportunity and converge the wide-open opportunities into a best project for further studies.

	Opportunities Exploration and Identification (1)	Opportunities/ Problems Selection (2)	Problems Identification (3)	Problems Selection (4)	Solutions Generation (5)	Solutions Selection (6)	Project Execution (7)	Applications Exploration (8)
TRIZ tools	▪ Problem Hierarchy ▪ 9/12 Windows ▪ Ideal Final Results (IFR) ▪ Ideal Final Attributes (IFA) ▪ Evolution Potential Anal	▪ S-curve Analysis)	▪ F(A)A ▪ CECA ▪ Root Contra. Analysis (RCoA) ▪ Func. Rel Anal ▪ Size-Time-Interface-Cost (STIC) ▪ Problem Hierarchy ▪ 9/12 Windows ▪ Flow Analysis ▪ IFA ▪ SFA		▪ Inventive Principles ▪ Inventive Standards ▪ Trends ▪ Patent DB ▪ FOS ▪ Func / Attr. DB ▪ Patent Circum. ▪ Trimming ▪ Smart Little People ▪ Feature Transfer ▪ Resources			
Non-TRIZ tools	▪ Omega Life Views (OLV) ▪ VOC ▪ QFD ▪ Perception Mapping ▪ 6 Thinking Hats	▪ Benefit Analysis ▪ Constraint Analysis ▪ Resource Analysis ▪ Pugh Matrix ▪ Feasibility Study	▪ Red Team Analysis ▪ Kepner Tregoe method ▪ 6 Thinking Hats	▪ Root Cause Anal. (RCaA) ▪ Red Team Analysis ▪ Pugh Matrix ▪ Kepner Tregoe method	▪ Anticipatory Failure Anal. ▪ Lateral Thinking ▪ SCAMPER ▪ Oblique Strategy	▪ Multi-Criteria Decision Analysis ▪ Axiomatic Design ▪ Pugh Matrix	▪ Proj. mgmt tools ▪ Six Sigma ▪ Lean Prod-uction	▪ VOC/QFD ▪ Product Platform Analysis (PPA) ▪ Product/ Technology Roadmap

Figure 5. TRIZ vs non-TRIZ Tools in SIP

Stage (3) and (4):

The selected best project is then fed into the divergent Problem Identification / Selection Stage of the Problem Definition Phase to identify all possible problems/conflicts in the project/product to attack. Again, the corresponding problem identification tools listed in Figure 4 can be used to identify conflicts. Each conflict constitutes a problem to attack, as described in the TRIZ concept. The identified problems are then fed into the convergent Problem Selection Stage of the Problem Definition Phase to select the right problem for attack. The selected problem is a “mini-problem” in the TRIZ problem solving term as we now focus on a minimal critical area to attack one at a time.

Stage (5) and (6):

The right problem is then fed into the Solution Generation Stage of the Solution Definition Phase for generation of all possible solutions. Classical TRIZ tools as listed in Figure 4 are very powerful means to generate innovative solutions. Non-TRIZ tools can also be used to solve problems.

The resultant multiple solutions are then fed into the Solution Selection Stage of the Solution Definition Phase for the best set of solution(s) to use. Few TRIZ tool is available for this stage. However, non-TRIZ tools such as those listed in Figure 4 are available for solution selections.

Stage (7):

The selected best set of solution(s) is then executed at the Project Execution Stage to solve the target problem and to review the results. No TRIZ tools are available for this stage of the SIP. Abundant typical project management tools are available for this stage.

Stage (8):

After product launched, one should balance the introduction of revolutionary products with incremental improvements in others so as to maintain a steady flow. The product models evolve from a core product. The core product system will express the generic technology system, and higher- or lower-priced versions will differ in the subsidiary technologies of features. The product family planning is especially important to deal with competitive conditions of shortened product life cycles, which can decrease profits. By having a comprehensive view of one’s initiatives over time, one can avoid either overwhelming or underwhelming the marketplace.

Upon completion of the project, it is likely that new technologies, tools, and/or products may be created. However, the innovation process should not stop here. These newly produced technologies/tools/products can be further exploited in the Application Exploration Stage to extend their applications across different industries for innovations. No TRIZ tool is available to help the application exploration stage. However, some non-TRIZ tools are available to help systematically explore new opportunities for exploitations within and across industries as indicated in Figure 5 and explained in Appendix. There are rooms to develop tools for this stage to aid the systematic exploitation of new technologies/tools/products.

Refer to Figure 4. The identified opportunities for application exploitation can be further fed back into the entry point of the Opportunity Selection Stage of Opportunity Definition Phase for further studies and analysis. This forms a cyclic life cycle of the Systematic Innovation Process. In addition, while in the Solution Generation Stage of Solution Definition Phase, it is helpful to obtain ideas from across industry by utilizing new technologies/products/tools available in the Application Exploration Phase of other projects possibly from a heterogeneous industry. This is indicated by a dashed line linking from Application Exploration Phase to the Solution Generation Stage in Figure 4.

The proposed SI framework provides a full-stage SI roadmap to enable companies systematically identifying business opportunities/key problems, solving problems, and leveraging developed tools/products/technologies for cross-industry exploitations.

Time-wise, along the horizontal track, the proposed SIP provides visibility that allows a firm to pace the introduction of new products and services and exploitation of developed technologies/tools. It provides a logical roadmap in series of connected stages w/ clear purposes for each stage to guide the full life cycle of the systematic innovation processes.

Resource-wise, as listed in Figure 5, the proposed SIP provides pointers to the library of tools/knowledge in each stage and a platform to integrate heterogeneous tools for opportunity identification and problem solving. This framework allows integration of heterogeneous resources such as TRIZ tools and non-TRIZ tools to support continuous and cyclic systematic innovation process. This framework also allows for integration of TRIZ & non-TRIZ tools under a unified umbrella. The results from any TRIZ or non-TRIZ tools can be integrated at the end of that stage and feed to relevant tools in the ensuing stage. The individual results developed by any tools in the previous stage can be further “operated” by any TRIZ or non-TRIZ tools in the ensuing stage. By the logical nature of the proposed SIP, it can be used to guide the development of comprehensive computer-aided systematic innovation tools.

The proposed SIP covers not only the problem solving part but also connecting from the abundant business opportunity exploration/identification and tying to applications explorations of developed technologies/products/tools. The bases for this new set of innovation process are a broader systematic view for business opportunities and problem solving and a feedback system structure. This SIP is a platform for integrating heterogeneous resources, from marketing research to technology details. The broader view of SIP brings more business opportunities, more tools, TRIZ and non-TRIZ tools, more solution techniques and even more research opportunities.

The proposed model of systematic innovation process hopefully can:

(1) Guide the full life cycle of innovation process effectively and efficiently;
(2) Provide a platform to integrate TRIZ and non-TRIZ SI tools allowing complementary supports between tools.

Although innovation may often be accidental in practice, the proposed SIP can facilitate systematic processes for destined innovations in a full cyclic life cycle.

4. Case Study: Simulator I/O System Update

This case study illustrates an application of the Systematic Innovation Process on energy supply issues. The overall journey of this case is illustrated in Figure 5.

(0) Initial problem: The typical operating license period of nuclear power plant is forty years. The training simulator system's computer system for nuclear power plant operator is gradually obsolete. Simulator is an essential system not only for new operator training and qualification, but also for operator on-the-job training. One key part of simulator computer update project is the input/output system, which interconnects simulator computer and simulator control panels.

4.1 Opportunity Definition Phase

(1) Opportunity Identification Stage (TRIZ Tools – 9/12-window analysis and Ideal Final Results): Refer to Figure 6, the present system relevant to the Simulator I/O system is RTP system which provides data communication function. The 9/12-window analysis indicated the problems/issues on the super-system/system/sub-system and alternative system levels covering time frame from past/present/future.

The analysis indicated alternative opportunities for improvements or problem handling. We can improve system, sub-system or super system. While considering any system to attack, the 9/12-window helps us to consider the life cycle situations of each system we will attack. The tools in the first stage help us analyze one initial problem and diverge to alternatives, virtual reality, as indicated in the opportunity identification stage of Figure 5. The Structured Thinking Questionnaires (Table 1), a technique of IFR, provides a step by step questionnaire to elicit the right opportunity direction.

(2) Opportunity Selection Stage (Non-TRIZ Tool – Constraint Analysis): Taking the multiple opportunities into consideration, one should consider cost-benefit analysis, resource availability, design capability/flexibility, etc. Obviously, from the 9/12-window analysis, there are two basic requirements, the necessity of continuous improvement and the license renewal shall be met. While virtual reality is attractive this may cause incompatible with real nuclear power plant operating environment. Considering systems cost, design engineering, development cost and maintenance issues, the preferable candidate is a mature industrial I/O communication system.

Table 1. Structured Thinking Questionnaires

Questions	Answer
1. What is the final aim of the system?	To keep the simulator system working.
2. What is the Ideal Final Result outcome?	Simulator can work without I/O system.
3. What is stopping you from achieving this IFR?	The I/O system has to match the current simulator hardware system.
4. Why is it stopping you?	The cost is too high to get a new simulator system.
5. How could you make the thing stopping you disappear?	Change the I/O system. Function desired: keep I/O working and provide spare capacity Attribute desired: low cost I/O system
6. Has anyone else been able to solve this problem?	PC-based industrial I/O system
7. What resources are available to help create these circumstances?	PC, Industrial I/O bus system.

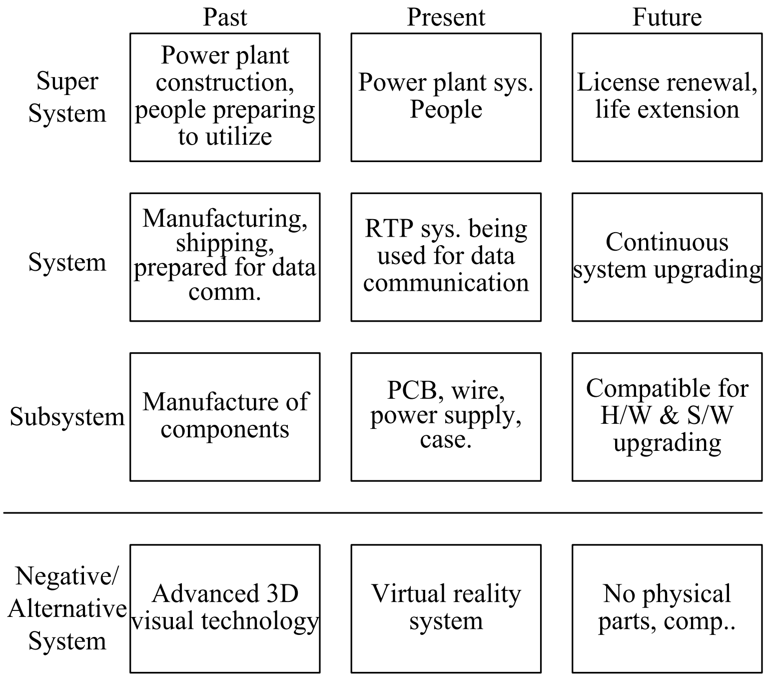

Figure 6. 9/12-window analysis of Simulator I/O system problem

4.2 Problem Definition Phase

(3) Problem Identification Stage (TRIZ Tool – Root Contradiction Analysis): The next question is what kind of problems behind this potential opportunity? How do we define them and focusing the right problem? For any industrial application system, the basic design philosophy is to maximize the system performance at lowest cost. Simulator I/O system also follows this philosophy.

The Root Contradiction Analysis tool can help us search for conflicts in a system, i.e., the right problem. By Root Contradiction Analysis (Table 2), for meeting communication performance, we need more I/O modules, but more I/O modules mean higher cost, consequently, we have conflict. The conflict identified by the analysis is between data communication capability and materials, or data communication capability and space, or data communication capability and cost. Other tools can also help us identify other conflicts. For the sake of brevity, they are omitted.

Table 2. Root Contradiction Analysis

Subject: To achieve high performance at low cost, what is stopping us?

Why	Answer	Parameter involved	Improve (desirable)	Worsen (undesirable)
What is our problem/sore point for I/O system?	We want to increase I/O system data communication capability.	Data communication band.	Data communication band.	
Why? What stopping us?	To increase I/O capability we need more I/O systems. To get more I/O systems, we need more I/O modules to increase data communication capability.	materials		Materials
Why? What stopping us?	To put more modules we need more I/O systems to place it.	I/O systems		spaces
Why? What stopping us (to get more space)?	More I/O systems cost more	cost		cost
Conclusion: We have conflicts: Between data communication band and materials; or data communication band and space; or data communication band and cost.				

(4) Problem Selection Stage (Non-TRIZ Tool – Feasibility Study): How do we deal with the conflicts from the above Root Contradiction Analysis? A Feasibility Study can provide analysis to the problem and recommendation for the best alternative (Wikipedia on Feasibility Study). A comparison of technical feasibility for the conflicts in "data communication capability and materials", "data communication capability and space", and "data communication capability and cost" is given in Table 3. It appears that the modern data communication technology can solve the above mentioned conflicts.

Table 3. Feasibility Study

	Data communication band and Material	Data communication band and Space	Data communication band and Cost
Technology	Data communication efficiency depends on industrial communication protocol, and there are feasible technologies in firmware form.	Current technology is more advanced than the existing old system. Current technology can solve data communication band and space conflict.	Current technology can solve data communication band and cost conflict.

4.3 Solution Definition Phase

(5) Solution Generation Stage (TRIZ Tools – Inventive Principles and Patent Database): The next question is how do we resolve the contradiction? A number of tools maybe available as listed in Figure 4. In this case, the 40 Inventive Principles are appropriate TRIZ tools to generate solutions.

The number 5 inventive principle, Consolidation/Merging can reduce material usage while providing needed functions, and the number 20 inventive principles, Continuity of useful action, can provide most efficient work for all elements at all time. For improving the data communication efficiency, from space view, we can utilize new communication technology by advanced materials, e.g. firmware. By internet search and/or more specific domain literature review, there are many options available, for instance, RS-485、RS-422、IEEE-488，token ring、token bus, …etc.

For time effectiveness, we can utilize time division or frequency division technology to promote data communication performance in a fixed time frame and reduce the quantity of material. The switching technology, by switching between host system and backup system, can provide continuity of useful action, and also reduce the quantity of material.

(6) Solution Selection Stage (Non-TRIZ Tool – Multi-Criteria Decision Analysis): Considering the multiple decision criteria, including maturity of technology, cost, physics, engineering feasibility and compatibility of existing simulator system, maintainability, etc., the final solution is a RS-4xx switching data communication system. The new system will interconnect the existing control panel RTP interface and the new PC server host computer system, to replace the obsolete ENCORE host computer interface I/O system.

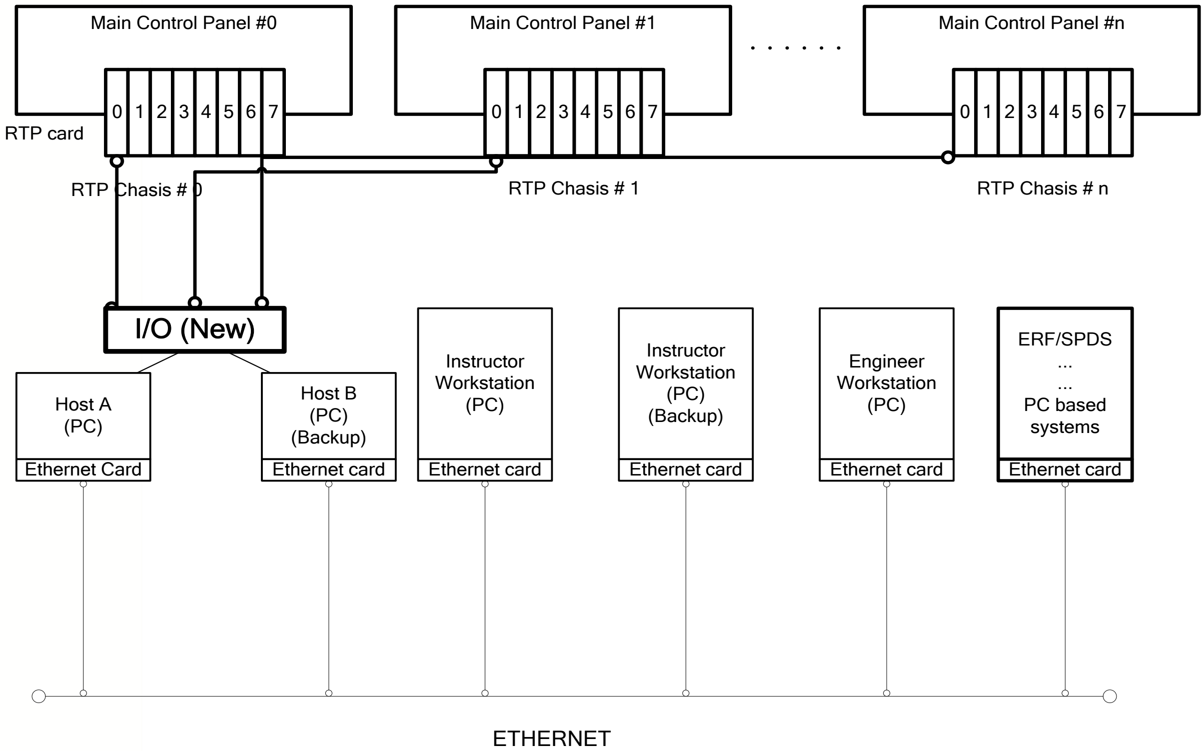

Figure 7. New data communication system solution

4.4 Execution Phase

(7) Project Execution Stage (Non-TRIZ Tool – Project management tools): Project management tools such as Work Breakdown Structure (WBS), Critical Path Method, project monitoring and control tools can be used to breakdown the project tasks, establish project schedule and monitor and control project performance, schedule, and costs.

4.5 Application Exploration Phase

(8) Application Exploration Stage (Non-TRIZ Tool – Product Platform Analysis): When an innovation project is finished, often times some new technologies/products/tools are developed out of the project. It will be a pity if the company stops at this point. The newly developed technologies/products/tools can further be used either within the same industry or

across industries to maximize their usefulness. It is these cross-industry applications that create most innovative and often high-impact results.

Through the product structure analysis, which is associated with market segment and product family, the niche can be achieved by the development of the product platform and its associated processes and production planning. Derivatives of the simulator I/O product platform, the product families, Boiling Water Reactor (BWR) power plant applications, Pressurize Water Reactor (PWR) power plant applications and Fossil power plants applications have addressed one or more of the market segments.

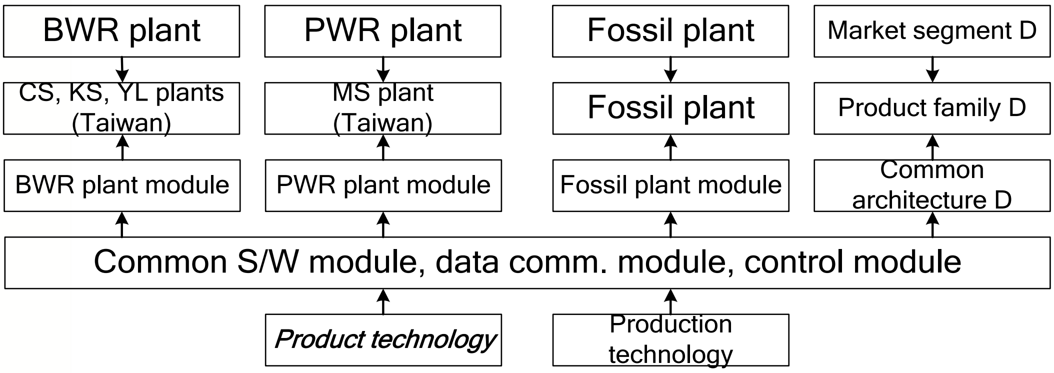

Figure 8. Product platform analysis

5. Conclusions

Unlike brain-storming type innovation activities which are often ad-hoc and highly dependent on luck, systematic innovation is regarding the systematic development of innovative problem solving and/or opportunity identification. A Systematic Innovation Process (SIP) has been constructed and exemplified. The proposed SIP is a series of phases and stages which link the planned business processes from business opportunity identification to technology details to cross-industry application exploitation of newly developed technology/tools/products. The proposed SIP provides a process to facilitate and pace the systematic innovation and a platform to integrate heterogeneous resources and tools, such as TRIZ and non-TRIZ tools, for synergetic utilizations. The SIP provides not only problem solving techniques but also opportunity identification and application exploitation for systematic innovation.

It is believed by the author that although innovation may be accidental, Systematic Innovation is destined (Sheu, 2008). The Proposed Process of Systematic Innovation provides a possible way for destined innovations.

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Appendix SIP tools and functions (Excerpted from D. Sheu class notes, 2008)

Tools	Functions
(1.a) Wide-open Exploration of possible projects/problems/ products/ services	
• 9/12 Windows Analysis	It offers a simple and effective way of encouraging problem solvers to see their problem situation from different perspectives. By changing perspectives among different space/time, the tool opens up opportunities at the different space and time. The contents to be placed in the various windows are often functions/attributes relevant to that window.
• Ideal Final Result	Get to the best possible right project/system for the current problem. It enables users to jump out of psychological inertia of the current problems and constraints.
• Problem Hierarchy	The Problem hierarchy tool helps us to see related problems at different problem levels. It consists of upward thinking and downward thinking. The downward thinking helps users to focus on the root causes of the problem allowing solving the current problem at its root. It is the upward thinking that challenges the existence of the current problem and helps us to find a better problem at a higher level to solve. This effectively solves the current problem without dealing with itself.
(1.b) Explore opportunities within given product/service direction	
• Ideal Final Attribute (IFA)	Identify conflicts between customers, between customer and provider, and between attributes of the subject product for business opportunities. (Maan, 2007)
• Omega Life View (OLV)	Examine extreme people's viewpoints for product/service ideas
• Evolution Potential Analysis	We can use evolution potential relevant to the current product of interest to explore opportunities for improvements.
• Voice of Customer Tables (VOC)	Tools to identify customers' needs and wants.
• Quality Function Deployment (QFD)	It allows us to deploy from customer requirements to design specifications for products. The customer requirements and product specifications are leads to innovative opportunities.
• Perception Mapping	By mapping out perceptions of various stakeholders, people can clarify issues and conflicts thus identifying project opportunities.
(2) Screening for right projects	
• Benefit Analysis	Used to screen out unnecessary projects. (Sanity check)

Tools	Functions
• Constraint Analysis	Locate business/technical constraints in 9-windows
• Resource Analysis	Locate resources in 9-windows. The resources available help us to screen out projects which do not have resource supports.
• S-curve Analysis	S-curve indicates the development maturity of the current system. Different projects are likely to succeed at different maturity level of S-curve thus allowing us to determine which type of projects more is like to succeed at the present stage. The S-curve can be effectively used as filter to screen out projects which are less likely to succeed.
(3) Problem Identification	
• 9/12 Windows	Same tool as in the first phase. However, the contents of the 9 windows can be the problems seen from the various windows.
• IFA	Same as the IFA in Phase I. It allows the users to identify conflicts between attributes and between customers/providers for problem to attack.
• Function (Attribute) Analysis (FAA)	Function Analysis or Function Attribute Analysis (FAA) decomposes a system into its components, analyzes the functional/attributes relationships among the components enabling prompt focusing on the core problems. It is also used as a preliminary analysis for future problem solving.
• STIC (Size-Time- Interface-Cost)	Think about the extreme very big/small cases in size, time, interface, and cost to help up locate problems.
• Problem Hierarchy	Explained previously. Here the downward thinking is used for problem identification.
• Substance-Field Analysis (SFA)	Classify problems by the type of conflict configuration between the 2 substances, its fields, and the function between the substances. SFA is the prelude of Standard Solutions. Certain types of standard solutions can solve certain types of SFA problems. SFA is a way of analyzing problems.
• Root Contradiction Analysis (RCoA)	The Root Contradiction Analysis combines the concept of "Sore-point Analysis" and "Ask Why 5 times" to identify the underlying contradiction of the subject problem. It starts with the sore points felt and ask why to identify either the cause of the problem or the stopping factor to inhibit us from solving the problem. The cause and the stopping factor then constitute a contradiction.
• Red Team Analysis	Red Team analysis is to look at problems from the perspectives of the adversary and various stakeholders. This can help us to explore new problems and aid their selection.
• Kepner Tregoe Method (KT Method)	It is a formalized problem definition tool, used to help problem solvers to identify what has changed in a system: the delta between healthy state and problem state helps to find the root cause of a problem.
(4) Problem Selection	
• S-curve Analysis	S-curve analysis can be used to determine which problems are better solved by which tools or techniques.
• Root Cause Analysis (RCaA)	Root cause analysis analyzes the constituent causes of the problem. It allows user to select appropriate cause to attack and to solve the problem. It is both a problem identification and solution generation tool.
• Red Team Analysis	The Red Team Analysis provide critical viewpoint which can also be used to screen problems.
• Kepner Tregoe Method	Stated previously. It can also be used to aid problem selection.
(5) Solution Generation	
• Inventive Principles	Altshuller's 40 inventive principles provide trigger solutions to problems. The inventive principles can be used with or without Contradiction Matrix.
• Inventive Standards	Matched with the SFA stated previously to provide ways of problem solving.
• Trends	Trends of technical evolutions relevant to the current problem can be used as solution trigger for the current problems.
• Resources	The concept of resources can help us to locate existing resources without additional cost and to turn harm into help
• Patent Database (PD)	PD allows us to search previous problem solving methods possibly across industry to solve our problem innovatively.
• Function/Attribute Database	TRIZ organize solutions according to functions served or attributes hold. As

Tools	Functions
	such, the user can use the database to search for solutions based on functions/attributes desired.
• Smart Little People (SLP)	Looking at the problem at micro level and from the problem itself provides another perceptive for problem solving.
• Anticipatory Failure Determination (AFD)	By intentionally trying to find out ways to make the system fail, it allows us to identify all possible problems and help us to find ways to avoid it.
• Lateral Thinking	Lateral thinking is characterized by the shifting of thinking *patterns*, away from entrenched or predictable thinking to new or unexpected ideas. This provides ideas for solutions outside of regular thinking.
• SCAMPER	It is used as brainstorming aids to make the thinking more systematically. SCAMPER stands for: S - Substitute: components, materials, people C - Combine: mix, combine with other assemblies or services, integrate A - Adapt: alter, change function, use part of another element M - Modify: increase or reduce in scale, change shape, modify attributes P - Put: put to another use E - Eliminate: remove elements, simplify, reduce to core functionality R - Reverse: turn inside out or upside down.
• Oblique Strategy	This is essentially a deck of cards with solution triggers to get problem solvers thinking out of the box. Details can be found in http://www.rtqe.net/ObliqueStrategies/
(6) Solution Selection	
• Multi-criteria decision analysis	Multi-criteria decision analysis allows for selection of best solution considering multi-criteria.
• Feature Transfer	The Feature Transfer module allows transferring of desirable features from one system to another. By transfer multiple features from multiple systems to one system, it effectively generates the best solution which combines multiple desirable features.
• Axiomatic Design	Axiomatic design is a systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables. The design principles or Axioms of Axiomatic Design can be used to screen out infeasible solutions and determine appropriate solutions.
(7) Project Execution	
• Project Management Tools	Many project management tools can be used to monitor/control the execution of the project and to review the project performance either it is a product or service innovation project.
• Six Sigma (6 σ)	A method and philosophy to achieve product or process quality to within at most of 4.3 errors in 1 million error opportunities. The essence includes 1) reduce process variability; 2) increase design tolerance thus the 6 sigma reliability can be achieved.
• Lean Production (Lean)	The essence is to manufacturing the same product with minimum resource inputs and zero waste.
(8) Application Exploration	
• VOC/QFD	By using the VOC and QFD as stated previously, the user may locate other applications which suit customers' desire.
• Product Platform Analysis (PPA)	The PPA plans the expansion of derivative products.
• Product/Technology Roadmap	The roadmaps laid out the expansion of product derivatives and technology usage.

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Abstraction – the Essence of Innovation

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Abstract

Innovative thinking techniques, i.e., heuristics applied during problem solving, stir both subconscious thinking engines into action; our left- and right-brain hemispheres. However, these two engines use different protocols in viewing and analyzing the same problem simultaneously. One parses a problem logically, consciously rationalizing each step while expressing its progress in language – a more tedious process than that of its compliment. The other, which favors images to language, visualizes a problem situation holistically and proffers instantaneously intuitive solution concepts to the conscious. Both dredge the depths of memory searching meaningful, but different, associations with our past experience. One engine uses the preferred thinking of technologists. The other engine uses that of verbal and graphic artisans. Yet, both types of thinking are creative and problem solving.

This paper focuses on problem-solving heuristics commonly used by technologists and describes how these heuristics can be made to spark intuitive solution concepts through effective use of abstraction.

Keywords: heuristics, heuristic innovation, innovation, left-brain logic, problem solving, right-brain intuition, structured problem solving, unified structured inventive thinking.

1. Introduction

All problem-solving methodologies for invention or innovative thinking boil down to the essence of mentally-verbalized heuristics. The full power of these heuristics is hidden in abstraction. At issue in this paper is not the learning of new heuristics but the understanding of how heuristics work. Such understanding can help us to select the most useful heuristics to memorize. It can help also in creating new heuristics by understanding their essential properties. Most importantly, it can make us more efficient users of heuristics for innovative problem solving.

Heuristics are the thinking tools, learned and created, that can generate a new and pregnant view of a problem. Examples include “do it in reverse”, “draw a simple diagram”, “reduce a problem to one unwanted effect”, “make one object do two functions”, “draw a function diagram”, “examine points of contact”, and “separate conflicting functions in space and/or time”. There are enumerable such heuristics. We learn them in school and on the job, and we create them from personal experience. But, what makes them work in an innovative-thinking way?

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When applying them, we verbalize heuristics consciously – a language effort that is the purview of one's left brain, which is dominated by trained logical reasoning. The following is an exercise in introspection. Please pay careful attention to your own thinking process. The issue is not whether you could have gotten the same ideas by a different route, but rather, are differences in logic and intuition evident in your problem solving efforts?

Underlying the essence of heuristics for problem solving are the tricks they play on our two brains.[1] By training, technologists are predominately left-brain thinkers who demand logical reasoning and loathe anything less. We are so captivated with our skills of rational reasoning that, unknowingly, we often disregard potentially creative insights passing through our minds. They may be easier to discredit, for lack of immediately evident rational, than to engage in serious effort to follow. This is evidence of conflicting thoughts from our two thinking engines using different protocols.

A dominant left brain, commanding the power of language, is able to preempt seemingly poetic interjections to problem solving that lack concrete rational. By understanding the preemptive vetting by the left brain, of right-brain's more metaphoric suggestions, we may discover surprising and fruitful insights to problems. But how can that happen? Shouldn't logic prevail? Yes, but new insight comes first followed later by constructive interpretations, then idea elaboration, testing of ideas, and finally culling of the less effective solutions. The process will be seen as a transition from the concreteness to abstraction and back to the concreteness. Key to innovative problem solving (i.e., invention) is creating new thought paths to follow for unusual insights.

The wealth of complimentary problem-solving resources offered by our two brains is illustrated in Figure 1. Left-brain verbalization operates consciously while right-brain intuition develops images subconsciously.

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[1] For simplicity herein, our two brain hemispheres are referred to as left-brain and right-brain. Left-brain implies the center of language and logic while the right-brain refers to the center of metaphoric abstraction and holistic view (seeing the whole problem situation; i.e., without attention to detail – a left-brain function). In some individuals these functions are reversed between the two half brains.

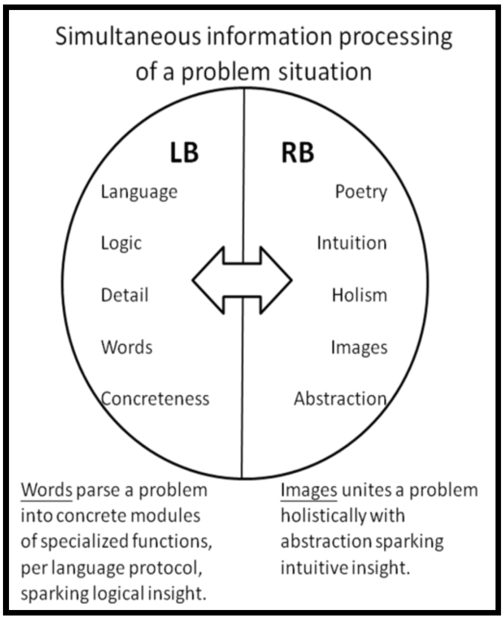

Figure 1. Complimentary problem-solving resources in our two brain hemispheres – left brain, LB, and right brain, RB (Edwards (1999), Levy-Agresti and Sperry (1968), and Sperry, et al. (1973))

Three aspects of heuristics are discussed: their make-up, application, and creation.

2. Targeted audience

The audience targeted for this paper consists of all types of technologists – those highly trained, accomplished problem solvers produced by modern education. Their skills enable thorough analysis of a problem situation. Such analysis sparks rational solution concepts with quick evaluation, and on-the-fly culling of thought paths deemed wasteful of resources. All of which is left-brain thinking. Obscured by this broad-stroke evaluation of technologists is the spottiness of their creativity and innovation as measured by awards, patents, professional envy, and often a sparsity of solution concepts offered in team-solving situations.

My first encounter with this shortcoming of innovative problem solving came in a large industrial company. A small group of engineers, who had conducted a survey of the success of corporate engineers in being awarded patents, discovered an unexpectedly small population of inventors. They approached me to sponsor a monthly luncheon to which young engineers would be invited to meet and discuss personal experiences with the hope of inspiring innovative thinking. This experiment led to development of a corporate, in-house program for teaching structured, inventive thinking. (Sickafus, 1997 and 1998)

3. Make-up of heuristics

Heuristics do not solve problems. Instead they aid the problem solver in creating thought paths that encounter new view points of a problem. Where do these insights lie?

It is taken axiomatically that technologists have adequate heuristics for left-brain thinking. Furthermore, they apply them with such fervor that they tend to squelch efforts of the right brain to solve the same problem. Hence, a potential source of new insight lies in our subconscious communication between the left and right brains. Both brains see the same problem at the same time, pose subconscious solution concepts, and share the information through the corpus callosum – the bundle of nerves joining the left and right brain hemispheres (see Figure 1).

Consider this example of a common heuristic. *"Do it in reverse."* We have said this to ourselves many times on a variety of problem-solving occasions. Of course, before we attempt to apply such a heuristic we will have carefully *constructed a well-defined problem*, which itself, is a heuristic for innovative thinking.

The first characteristic of "do it in reverse" is its simplicity, and the second is its lack of specifics. It is a very abstract statement. This gives a heuristic appeal for memorization and breadth in application. More importantly, it does not constrain the right brain with explicit problem detail. But what does it mean? A specific way of stating this heuristic is "*start with the answer and work back to the problem*".

The process of parsing this statement sets our minds onto new thought paths.

"Do" => (implies) take or modify an action.

"it" => an object or attribute in the problem or in our analysis of the problem.

"in reverse" => a counter intuitive directionality (including process and function).

As the parsing process unfolds, get-the-job-done-type rational thinkers may find themselves out smarted by the abstractionist-type thinkers. Consider these two plausible thinking processes in the following.

4. Application of heuristics

A common approach in structured problem solving is to describe a problem situation and then extract from that description a well defined problem. To this, heuristics are applied for analyzing the problem and then other heuristics for finding solution concepts. The process is then iterated as needed (Figure 2).

In a structured problem-solving process such as heuristic innovation (Sickafus (2006) much attention is given to how heuristics work and how to apply them for creating new thought paths to solution concepts. Emphasis is placed on throttling of left-brain dominance to allow right-brain ideas to be examined. A brief and simple example follows, which is scalable to all size problems of innovative thinking.

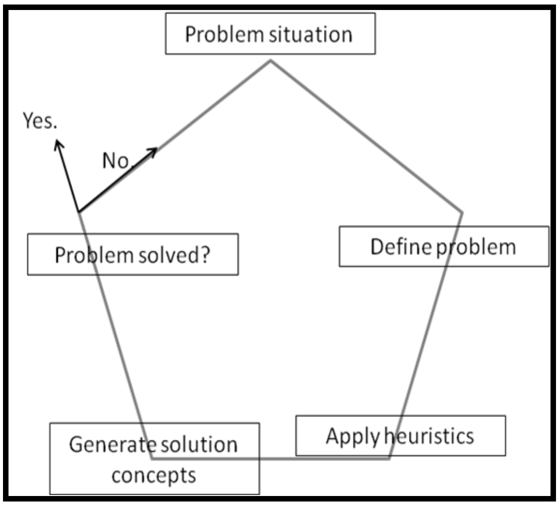

Figure 2. A typical structured problem-solving flow chart

Example of logical-to-intuitive thinking

As an example of emphasizing intuitive thinking at the expense of logic consider this useful classroom demonstration exercise. When told to invent something a class usually is unresponsive. No one knows where to start.

How to start (logic):

> "Pick an object, any object. However, for the limited time of this class, select an object that everyone present can reasonably be expected to understand its function and construction. Now invent a better one!"

Again, the class may be unresponsive. Selecting an object usually goes quickly enough, but 'inventing a better one' gives pause – where to start?

The real power in this exercise is daring one's self to instantly take on any object and subject it to innovative thinking. In order to turn it into a problem, make up a list of things it doesn't do.

An often selected object is a pencil or a pen. I'll select a generic pen for this demonstration. To gain the full value of this exercise thinking needs to be spontaneous, not practiced. I have seen many solutions to this problem from former class exercises. I'll attempt to set out on a fresh path.

"Everyone in this classroom is a technologist of some brand and certification. Hence, brainstorming this problem is a straightforward logical process that we are all familiar with. However, this exercise will attempt to invent a new pen using a mix of logic and intuition, with emphasis on the latter." (A period of brainstorming is now used to 'pick the low-hanging fruit'. Heuristic innovation follows.)

Our first step toward encouraging intuitive thinking is to generify the object. I'll call it a writing implement. 'Pen' and 'pencil' are already implanted in our subconscious. Now we have added 'writing implement'. To invent a better one we need to know what's 'wrong' with it. We can think of that question generically by wondering what does it not do? As will be seen, this question opens the door to innovation.

First establish what the implement does but in generic (or abstract) terms. For example, 'it physically couples a user to a surface on which marks are to be made'. That's its function. Attributes are needed to enable a function. (Sickafus, 1997)

What attributes are active in this situation? *Mass* and *shape* enable the user to grasp and move the implement. Its surface *texture* gives comfort. Its visible *rendering* gives esthetic pleasure in style. It has *capacity* to carry a supply of marking medium. It is pressure *sensitive* and dispenses marking medium on demand by modulating the rate of dispensing medium according to pressure applied.

All of the attributes identified offer logical thinking paths for discovering incremental improvements in a writing implement (resulting from specific focus on concrete attributes). To encourage innovative thinking consider the things a marking implement, that you are familiar with, does not do. No limits are placed on this phase and intuitive ideas yet to be rationalized are allowed. Surprising turns can be expected along any such thinking path.

A possible starting place is the '*point-of-contact* between the user and the implement' – to be thought of as two generic objects. What attributes of these objects might exist at this contact that are not now active? No odor is emitted that could activate one's sense of smell. No flavor is offered to activate a sense of taste. No sound is made to activate hearing. No vibration is made to activate tactile feedback. No light is emitted to activate retinal neurons. The first half of the last five sentences came to mind intuitively (instantly), the last half was motivated by a need of rational, requiring a moment of thought. One could continue this list but we need only to establish the fundamentals here.

An idea that comes to mind now is to look at these five attribute connections from user to implement in a metaphorical sense – moving from concreteness to abstraction. Metaphorically connecting an attribute to a particular human sense is a form of creating or passing information (in personal feedback or to other users of information). This is more of an intuitive jump, from the attributes of an implement, than a logical one if it occurs spontaneously.

Each new word introduced offers a thought path to innovation (Figure 3). Let's try it. (Probably you unconsciously have already investigated a few.) We now move from abstraction back to concreteness.

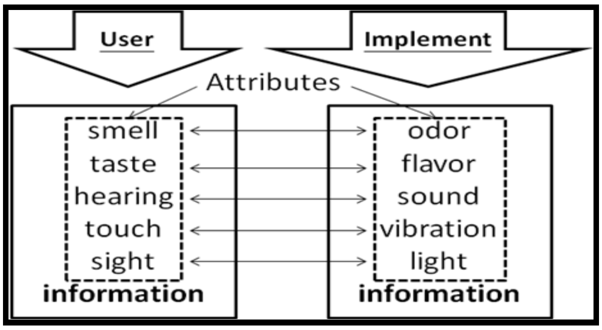

Figure 3. Coupling of two objects at their point of contact, user and implement, via attribute pairs to generate information

How can odor, coupled to smell, lead to innovative creation of information in a marking implement? This question immediately triggers logical brainstorming. These ideas came to mind:

(1) Distinguishing foods for appropriate price marking.
(2) Identifying freshness for dating life of food.
(3) Identifying flora for cataloging. (Notice how an initial idea leads to generic variations on the same theme.)

At this stage in innovative thinking no attempt is made to engineer or critique an idea. Such filtering comes after proof-of-concept engineering. This is the pre-engineering stage of thinking, even the earliest, least developed inkling of a solution-concept stage.

An implement that couples taste and danger warning.

(1) Taste sensors in an implement could identify degree of toxicity for labeling.

An implement that couples sound to hearing:

(1) An automotive instrument-panel button that identifies its function in voice when touched, thus not requiring the driver to take eyes off of the road.

An implement that couples touch and vibration:

(1) A proximity sensor in a walking cane could cause the cane to vibrate with intensity to indicate proximity, and modulation to indicate direction. This would eliminate the need to wave the cane about and thus enable more natural walking.

An implement that couples sight and light:

(1) A narrow beam shining across a page to guide and speed one's reading as the implement (and its beam) is moved along a page.

Generification and metaphorical thinking have different effects on people's brains. To generify leads me to group concepts by functional or technical hierarchy. Whereas using metaphor leads me to poetic type of abstraction. The former is left-brain thinking (logic) while the latter is right-brain thinking (intuition). Their effectual difference, in my thinking, is evidenced by instantaneous and subconscious reaction (intuition) versus deliberated and conscious reaction (logic). As trained technologists we do deliberation well, but we could benefit in search of new insights with some rapid, innovative, right-brain ideas.

5. Creation of heuristics

Heuristics that we create ourselves and test in our own professional environment are quickly adopted into our subconscious. They are reliable. We create these by introspection during and following problem-solving exercises. However, they can be made the more potent by designing them to throttle the left brain while freeing the right brain for recognition of its creativity.

The most important aspect of a heuristic that throttles one brain and frees the other is abstraction. Recall, "do it in reverse". Second in importance is awareness of left-brain's constant vetting of non-rational intuitive insights, and therefore practice is needed in freeing the resources of one's right brain.

6. Conclusion

The practice of structured problem-solving with application of heuristics can be made more broadly applicable and effective through abstraction that encourages use of right-brain resources. This does not replace conventional brainstorming. Rather, it is a potent alternative to turn to after the productivity of brainstorming has waned. Where conventional problem definitions are precise in their verbal and graphic descriptions – fodder of the logical left brain – innovative verbal and graphic descriptions are generic and abstract – fodder for right-brain intuition.

Obviously, both brain hemispheres work in our subsconscious, share information, and then raise ideas to our conscious level of thinking. We readily accept that heuristics applied logically create successful brainstorming with evident cause and effect connections. However, it is more difficult to give attention to instantaneous intuition that has no immediately obvious logical associations and no language with which to plead its case. The conscious practice of abstraction in structured problem-solving gives the left brain pause to withhold critique and evaluate new results.

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Assessment of Patent Legal Value by Regression and Back-Propagation Neural Network

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Abstract

This study aimed at the basis of patent law and proposed a revolutionary valuation model for the monetary legal value of patents. The damage award of a patent infringement lawsuit was deemed to be the legal value of a patent. 65 Effective samples of infringement lawsuits were extracted from 4,289 patent related lawsuits which were retrieved in the U.S. district courts of Delaware, California and Texas. 17 patent indicators were summarized to quantitatively describe dimensions of patents. The linear regression analysis was applied to discuss the linear relationship between each patent indicator and the damage award; finally 7 significant patent indicators were derived. The Back-Propagation Neural Network was then applied to construct the nonlinear valuation model of patent legal value, wherein the 7 significant patent indicators were the input variables and the damage award was the output variable. The proposed patent valuation model was validated to have the predictive power by error analysis. It accommodated to valuate the possible damage award or to negotiate the settlement fee for disputing patent infringement lawsuits.

Keywords: Assessment, Back Propagation Neural Network, Damage Award, Infringement, Linear Regression, Patent Valuation.

1. Introduction

1.1 Background of the Study

As technologies develop rapidly and the era of knowledge economics arises, intangible assets show their higher significance than before. The patent stands for a leading role among various species of intangible assets. The patent contributes to enterprises by revenue, stock performance, reputation, research and development, so as to be an important factor for evaluating enterprises and nations in aspects of operation, management and innovation.

However, when considering the patent value, especially the monetary value, it is hard to valuate the patent because the patent is not only a kind of intangible assets, but also a kind of rights. When thinking about the asset, the financial experts usually concentrate their attention on patent's financial contribution. This contribution, like stock performance or market success, is not directly generated by patents. It is only partly influenced by patents. When thinking about the right, the legal researchers always focus on the scope of patent right and related legal behaviors.

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There exists an important phenomenon recently that patent infringement lawsuits grow distinctly around the world. Damage award, licensing fee, and royalty become conspicuous parts of income, and even turn into the majority of revenue in some new start-up companies. No matter in negotiations of patent licensing, patent transactions, hypothecation of intangible assets, or shareholding by patent-based technologies, monetary value of the patent is always a critical issue. Meanwhile, a reasonable and reliable patent valuation model is always discussed seriously for making patents become monetary assets. The issue of monetary valuation of patents is concerned by people including employees, chiefs, investors, researchers, and professionals among fields of technology management, financial operation, legal strategy, and business administration.

The existing patent valuation models in practice might be briefly summarized to three approaches (Reilly and Schweihs, 1998), such as the cost-based approach, the market-based approach, and the revenue-based approach. These approaches basically originated from financial methods and modifications of them.

The basic idea, on which the cost-based approach is based, is the idea of replacement. This means the value of a patent is identified as the amount that would be necessary to replace the protection right or the related economic benefit potential. The logic behind this approach is that a prospective buyer acting in a logical way would not be willing to pay more for a patent than the amount he would have to pay to obtain an equivalent protection right. The costs compared could be, for example, historical costs, costs of replacement or costs of reproduction, depending on the valuation method used. One advantage of the cost approach is that the evaluator of patents has little influence on the valuation result.

The market-based approach is based on a comparison with a corresponding transaction between independent third parties. That is, the value of a patent is defined through comparison to a similar patent, the market price of which is known through an earlier purchase or sale. In this market, there has to be a sufficient number of comparative transactions in the recent past, for which the obtained retail price is known. If this information exists, the market approach is easy to apply and leads to a valuation result that is acceptable and easy to comprehend. But the prerequisite of an active market is hardly met for patents. Furthermore, the published licensing rates are not sufficient for an adequate comparison.

The basis of the revenue-based approach is the comparison of the future economic benefit of a patent with the future benefit of an alternative investment. So far, the income approach implements the definition of value most directly. With the application of the income approach, the sum of advantages, i.e. the additional returns or saved costs less accruing costs, that will arise from the patent will be ascertained. These economic benefits are compared to the best alternative investment, which shows the same future payment flows and the same investment risk. With respect to the valuation, the comparison is made by determining the future economic benefit of the protection right and then discounting it with a risk-adapted interest rate to its actual cash value. To put it another way, the income approach answers the question: what sum would have to be invested in another way to achieve identical payment flows with the same risk? The valuation results would be somehow risky since the data employed are only prediction-based values and cannot be determined with certainty.

Unfortunately, the aforementioned financial approaches for patent valuation usually disregard the subject matter of the patent and species of enforcement defined and restricted by patent law. These existing patent valuation approaches are more likely named as the

"Technology" valuation approaches. It has to be emphasized that a vital difference exists in the scope of right between a technology and a patent. The vital difference will result in different valuation outcome. The right of a technology is knowledge-based power to make, use, or sell; whereas the right of a patent is the power to exclude others from making, using, selling or importing.

Regarding the topics involved the patent law with the patent value, Lanjouw and Schankerman (1997) discussed patent owner's behaviors in patent litigation events. Lanjouw, Pakes and Putnam (1998) used the cost of patent prosecution as the indicator to evaluate patents. Lanjouw (1998) discussed the behaviors in patent prosecution for evaluating patents. Lanjouw and Schankerman (2001) discussed the behaviors in patent infringement lawsuits for evaluating patents. Reitzig, Henkel and Heath (2007) proposed that the patent infringement lawsuit affected the firm's strategies.

According to U.S. patent law 35U.S.C.154 "*Every patent shall contain a short title of the invention and a grant to the patentee, his heirs or assigns, of the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States, and, if the invention is a process, of the right to exclude others from using, offering for sale or selling throughout the United States, or importing into the United States, products made by that process, referring to the specification for the particulars thereof.*", the right of a patent for the patentee is definitely designated for excluding others from five species of unauthorized behaviors: making, using, offering for sale, selling and importing. Based on the concept of patent law, any patent which can not be enforced the right to exclude others from aforementioned five behaviors would be regarded as legally valueless. The existing patent valuation models in practice usually take this important legal issue aside.

As described above, it's therefore a principal objective of this study to rediscover the patent value in view of patent law by investigating patent infringement lawsuits because the documents of patent infringement lawsuits indicate patents and their momentous, direct and monetary patent values, i.e. damage awards.

It's another objective of this study to construct a monetary valuation model of patents by discussing the mathematical relationship between damage awards and patents.

1.2 Literature Review

Regarding the topic of patent valuation and patent indicators, Cockburn and Griliches (1988) first discussed the relationship between stock performance and patents. Albert, Avery, Narin and McAllister (1991) applied the citation count as the indicator to evaluate patents. Tong and Frame (1994) used the patent claim as the indicator to evaluate national technology outcome. Hirschey and Richardson (2001) suggested that scientific measures of the quality of inventive output were useful indicators to investors. In this literature, the scientific measures of the quality meant the prior arts of non-patent references of patents. Hereof, Schererc and Vopel (2003) suggested that the number of prior arts and citations received were related positively to the patent value; non-patent references were informative about the value of pharmaceutical and chemical patents, but not in other technical fields; patents, which were upheld in opposition and annulment procedures, and patents representing large worldwide patent families were particularly valuable. In this literature, backward citations, forward citations, non-patent references, and worldwide patent families were concluded to be positive to the values of the patent. "Hirschey and Richardson (2004) found a favorable stock-price influence when both the number of patents, the scientific merit of these patents, and the R&D spending were high, where patent citation information could indeed help investors judge the future profit-earning potential of a firm's scientific discoveries". In this literature, backward citations, forward citation, and non-patent references were concluded to be positive to the stock-price. Reitzig (2004) inspected almost all the possible detailed patent indicators with the market value of the patent owner. He concluded that actions of the prosecution were positive to the market value of the patent owner. But legal values of patents in this literature were not considered. Hall, Jaffe and Trajtenberg (2005) used the patent citation count as the indicator and discussed its contribution to market value. Von Wartburg, Teichert and Rost (2005) proposed a methodological reflection and application of multi-stage patent citation analysis for the measurement of inventive progress. In this literature, backward citations and forward citations were concluded to be positive to R&D activities. Choy, Kim and Park (2007) employed patent analysis in cross-impact analysis of syntheses and interactions between various technologies and expected to help practitioners to forecast future trends and to develop better R&D strategies. In this literature, influences of patents were thoroughly analyzed, but legal values of patents were ignored. Hereof and Hoisl (2007) described the characteristics of the German Employees' Inventions Act and discussed which incentives it created with a survey of 3,350 German inventors to test the hypotheses regarding this institution. The study concluded that the law created substantial monetary rewards for productive inventors. In this literature, the patent law was watched and the law-related value of patents was discussed. Silverberg and Verspagenb (2007) focused on the analysis of size distributions of innovations by using patent citations as one indicator of innovation significance. In this literature, backward citations, forward citations, and non-patent references were concluded to be positive to innovations but legal values of patents were not discussed. Van Trieste and Vis (2007) focused on evaluating a patent on the basis of cost-reducing process improvements from the viewpoint of the patent-holding firm by considering the relevant cash flows that resulted from owning the patent, wherein the patent value was determined by licensing fees, royalty income, and the competitive advantage resulting from the patent and patent maintenance costs. In this literature, the law-related value of patents was first discussed, but no relationship was found between this law-related value and patent indicators. Chiu and Chen (2007) proposed an objective scoring system for patents from the licensor side using the Analytic Hierarchy Process to value patents for new products being developed by an actual enterprise. This scoring system was quite interesting; unfortunately, no monetary value was modeled.

The aforementioned literatures discussed lots of patent indicators and their contributions such as market success and stock performance. However, such contributions are not directly generated by patents, but are influenced by patents. Besides, the aforementioned literatures somehow missed an important issue, that is, the patent is a right which given by law. It's more rational to discuss the patent value in view of patent law.

Regarding the topics involved the patent law, Lanjouw and Schankerman (1997) discussed patent owner's behaviors in patent litigation events. Lanjouw, Pakes and Putnam (1998) used the cost of patent prosecution as the indicator to evaluate patents. Lanjouw (1998) discussed the behaviors in patent prosecution for evaluating patents. Lanjouw and Schankerman (2001) discussed the behaviors in patent infringement lawsuits for evaluating patents. Reitzig, Henkel and Heath (2007) proposed that the patent infringement lawsuit affected the firm's strategies.

Though these literatures discussed patents and indicators in view of patent law, there was no corresponding valuation model built yet.

Referring to the issue of a patent's monetary value, Deng, Lev and Narin (1999), Thomas (2001) tried to use multi-regression to model patent indicators and the stock performance. Unfortunately, the R^2 value was too low to explain few. Park and Park (2004) proposed a valuation method that generated monetary value, rather than a score or index, based on the structural relationship between technology factors and market factors. This method of generating the patent's monetary value was more useful in practice than the other indicator-based valuation models. Unfortunately, this method was not in view of patent law.

However, the mathematical relationship between the patent legal value and the aforementioned patent indicators has not been developed yet. A wide gap still exists between the patent and economics while considering the value of patents. In this study, a monetary valuation model for patent legal values is proposed to shorten the gap and link the patent and economics more directly.

2. Methodology

2.1 Population and Sample

This study focused on the patent infringement lawsuits in the U.S. district courts of Delaware, California and Texas. Those lawsuits having final judge determinations with definite patent numbers and damage awards are regarded as effective samples.

2.2 Instrumentation

To describe the possible quantitative dimensions of a patent, 17 indicators are summarized in this study by reviewing previous literatures and authors' own empirical experience in patent engineering, such as patent prosecution, patent search, and infringement analysis.

Samples of lawsuits distribute in different years. The damage award of each lawsuit must be converted to a standard foothold to eliminate the currency revaluation and inflation for consistency of analysis. In this study, the annual interest announced by Federal Reserve System (FED) at the end of each fiscal year is used to convert each damage award to the corresponding value in 2006 by compound interest via engineering economic approach.

By Kolmogorov-Smirnov test, the values of damage awards of all lawsuits are converted by natural logarithm in order to have an approximate normal distribution.

Z-score transformation and Regression analyses are applied for discussing the relationship between each of 17 patent indicators and the damage award, so as to find out significant patent indicators.

Back Propagation Neural Network is applied for modeling the nonlinear relationship between significant patent indicators and damage awards, so as to construct the monetary valuation model.

The Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems. Learning in biological nervous systems involves adjustments to the synaptic connections that exist between the neurons. The key element of the ANN is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. The ANN, like human, learns by examples, and is usually configured for some specific applications, such as pattern recognition or data classification. An important issue in ANN design is determining the number of hidden neurons best used in the network. If the hidden number of neurons is increased too much, overtraining will result in the network being unable to "generalize". The training set of data will be memorized, making the network effectively useless on new data sets. The Back Propagation Neural network (BPN) is one of the most popular known neural networks learning technique, which looks for the minimum of an error function in weight space using the method of gradient descent. The combination of weights which minimizes the error function is considered to be a solution of the learning problem.

The reason of utilizing the neural network in this study to model the nonlinear relationship between patent indicators and the damage award is that, the damage award in any patent infringement lawsuit was first proposed by both parties of plaintiff and defendant, then discussed, argued, adjusted, and finally determined by the judge or the jury of court. The process for finalizing the damage award is quite humanly and nonlinear, so that the damage award resulted from its corresponding patents is suitably modeled by the neural network.

The input variables for the BPN in this study are the significant patent indicators of each lawsuit, and the output variable is the damage award of each lawsuit. For constructing the BPN, basically at least two sets of samples are necessary, i.e. a training set and a testing set, for iteratively tuning the BPN by training and testing. Preferably, for validating the constructed BPN to check its predictive power, another validating set is suggested to be introduced into the constructed BPN. Various parameters could be tuned in constructing the BPN. In this study, the convergence of Root-Mean-Squared-Error (RMSE) is observed when training, testing and validating the BPN, and therefore regarded as the performance index of the BPN.

2.3 Delimitation and Limitation

(1) There are several categories of U.S. patents, such as utility, design, plant, defensive publication, statutory invention registration, and additional improvement, etc. The compositions of all these categories differ from each other. This study discusses the utility patent only because the utility patent plays the major part of all U.S. patent categories. The infringement lawsuits of utility patents are much more than the others.
(2) There are sometimes more than one patents included in a patent portfolio which is enforced in a patent infringement lawsuit to win a lump sum of the damage award. Only damage award of the portfolio is discussed. This study doesn't probe into any specific value of the any specific patent in a portfolio.
(3) Only patent infringement lawsuits with final judgment of determination are analyzed. Actually, settlements always exist to terminate patent infringement lawsuits because the defendant might want to reduce possible damage award of the plaintiff. In settled lawsuits, no damage awards will be found, such lawsuits are excluded from effective samples.
(4) Only patent infringement lawsuits those involved patents possessed all 17 quantitative patent indicators are analyzed. If a patent infringement lawsuit is too old so that the involved patents do not to possess all 17 quantitative patent indicators, such lawsuits are excluded from effective samples. Besides, qualitative features of patents are not considered in this study.
(5) Patent infringement lawsuits are retrieved in district courts of Delaware and California and Texas. These courts have the accelerated timetable strictly adhered to deadlines, resulting in speedy disposition (McKelvie, 2007). The patent law in the U.S. is a federal law, actions for

patent infringement filed in federal district courts. Either plaintiff or defendant can appeal to U.S. Court of Appeals for the Federal Circuit (CAFC) if either party does not agree with the determination of district court. Studying over a long time, it is found that the suit materials including patent damage award are usually disclosed, discussed, and determined in district courts, while only legal topics and questions of law are argued in CAFC. Hence, the patent infringement lawsuits are retrieved through district courts in this study. U.S. patent infringement lawsuits are filed in quantity in every district court, for example, there is up to 2,865 patent lawsuits from 1944 to 2006 in district court of Delaware. Each lawsuit possesses more than 5,000 documents of miscellaneous issues involved. In order to set up an effective way of modeling, this study only directs to three district courts those are famous in huge quantity and fast judgment of patent infringement lawsuits, i.e. district court of Delaware, district court of California, and district court of Texas.

(6) Patent infringement lawsuits are retrieved in the period of 1944 to 2006 in both district courts of Delaware and California. But because district court of Texas is famous in showing favor to plaintiffs, lots of lawsuits get settlements, only few lawsuits with final judgment of determination are found. Hence, patent infringement lawsuits of district court of Texas are retrieved from 1994 to 2006.

(7) The database for retrieving patent infringement lawsuits is the LexisNexis. The LexisNexis database originated in 1966 and was developed into the first full text retrieval system of legislation in the world by the American Air Forces. It is one of the greatest law resources in the world comprising legal documents, industry information, financial materials, and public news of all levels of U.S. courts, newspapers, magazines, and commercial periodicals.

3. Analysis and Result

3.1 Effective Samples of Patent Infringement Lawsuits

By using the searching keyword "patent" in the LexisNexis database, 4,289 patent related lawsuits are searched from district courts of Delaware, California and Texas. However, not all of these lawsuits are infringement involved, further searching is needed. Thereby, the searching keyword selected from the group consisting of "damage" and "$" is then applied to retrieve documents. The retrieved documents are carefully reviewed and checked by professional manpower. Finally, 65 effective samples (lawsuits) including 163 patents are derived, as shown in Table 1. There are 37 samples including 103 patents are in district court of Delaware; 24 samples including 52 patents are in district court of California; and 4 samples including 8 patents are in district court of Texas. In each of these effective samples, the damage award is clearly indicated, and the patent(s) involved has all 17 patent indicators. If a patent infringement lawsuit is too old or short of some patent indicators, the infringement lawsuit was discarded.

Table 1. Samples retrieved and extracted

Lawsuit resource		District Court of Delaware	District Court of California	District Court of Texas	Sum
Lawsuits retrieved		2,865	1,314	110	4,289
Lawsuits extracted	Lawsuits	37	24	4	65
	Patents	103	52	8	163

In the 65 effective samples, the portfolio size in a lawsuit varies from one patent to 17 patents; the damage award varies from USD 470,084 to USD 2,600,000,000. Table 2 shows the counts of infringement lawsuits from 1989 to 2006. Obviously, infringement lawsuits after 2000 are much more than those before 2000. Since lawsuits with final determinations are only a small part of all infringement lawsuits. The information in Table 2 reveals that patent infringement lawsuit gradually becomes a kind of business in 21 century.

Table 2. Patent infringement lawsuits in each year

Year	Lawsuits	Year	Lawsuits
2006	12	1997	2
2005	7	1996	0
2004	11	1995	1
2003	5	1994	0
2002	6	1993	0
2001	4	1992	1
2000	3	1991	2
1999	3	1990	0
1998	6	1989	2

3.2 Patent Indicators

Based on the view point of patent law, throughout the opinion of court in patent infringement lawsuits in the U.S., a product or a method infringes a patent claim if that product satisfies each of the claim requirements, hence what is claimed is recognized as the invisible boundary of a patent right. Usually, the fewer the number of claims in a patent the wider the protected scope and vice versa. An independent claim usually comprises fewer elements, while a dependent claim certainly comprises more elements than the claim being dependent upon. Independent claims are more important than dependent claims, it's therefore not only the number of claims, but also the number of independent claims is considered in this study. International patent Classification (IPC) and U.S. Patent Classification (USPC) are systems for organizing patents. A patent is designated its IPC and USPC by examiners in patent office. The number of IPC and USPC are considered in this study. In addition, according to the U.S. patent rule §1.75 (d) (1) "The claim or claims must conform to the invention as set forth in the remainder of the specification and the terms and phrases used in the claims must find clear support or antecedent basis in the description so that the meaning of the terms in the claims may be ascertainable by reference to the description." The claimed elements and characteristics thereof must be supported by descriptions and drawings, so the number of drawings is also considered. By reviewing previous studies and authors' empirical information and experiences of patent prosecution, patent search, and infringement analysis, 17 patent indicators are selected as shown in Table 3 and defined below.

- X_1: "Assignees", is the count of assignees of each patent.
- X_2: "Inventors", is the count of inventors of each patent.
- X_3: "Total claims", is the count of total claims of each patent.
- X_4: "Independent claims", is the count of independent claims of each patent. Total claims comprise independent claims and dependent claims. X_4 is a part, but the most important part of X_3.
- X_5: "US patent references", is the count of US patent documents listed in the field of "References Cited", i.e. prior arts recognized by the examiner, of each patent. Some literatures called "US patent references" as the "backward citations".
- X_6: "Foreign patent references", is the count of foreign patent documents in the field of "References Cited" of each patent.
- X_7: "Non-patent references", is the count of other publications (non-patent literatures, including papers, handbooks and magazines, etc.) in the field of "References Cited" of each patent. Some literatures called "Non-patent references" as the "science linkage".

- X_8: "Forward citations", is the count of citations by the other patents in the beginning of lawsuit of each patent.
- X_9: "International Patent Classifications (IPC)", is the count of IPCs recognized by the examiner of each patent.

Table 3. Patent indicators defined

Evaluation indicator		Mainly discussed by
X_1	Assignees	Reitzig (2004)
X_2	Inventors	Reitzig (2004)
X_3	Total claims	Reitzig (2004)
X_4	Independent claims	Reitzig (2004)
X_5	US patent references	Hereof, Schererc and Vopel (2003) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005) Silverberg and Verspagenb (2007)
X_6	Foreign patent references	Hereof, Schererc and Vopel (2003) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005)
X_7	Non-patent references	Hereof, Schererc and Vopel (2003) Hirschey and Richardson (2004) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005) Deng, Lev and Narin (1999)
X_8	Forward citations	Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005)
X_9	International Patent Classifications (IPC)	*
X_{10}	US Patent Classifications	*
X_{11}	Worldwide patent family	Hereof, Schererc and Vopel (2003) Reitzig (2004)
X_{12}	US patent family	Hereof, Schererc and Vopel (2003)
X_{13}	Office actions	Hereof, Schererc and Vopel (2003) Reitzig (2004)
X_{14}	Responses	Reitzig (2004)
X15	Examination	*
X16	Drawing	*
X17	Life-span	*

* proposed by this study

- X_{10}: "US Patent Classifications", is the count of USPCs recognized by the examiner of each patent.
- X_{11}: "Worldwide patent families", "is the count of worldwide related patents those claimed at least one same priority of each patent". This count is investigated based on INPADOC database.
- X_{12}: "US patent families", is the count of US related patents "those claimed at least one same priority of each patent". This count is investigated based on INPADOC database.
- X_{13}: "Office actions", is the count of office opinions by the examiner of USPTO of each patent. The office opinions include the selection by restriction, non-final rejection, final rejection, and notice of allowance, etc.
- X_{14}: "Responses", is the count of responses to USPTO by the assignee of each patent. The responses include amendments, response to non-final rejection, response to final rejection, request for continued examination, and appear, etc.
- X_{15}: "Examination", is the time span from filing date to issue date of each patent.
- X_{16}: "Drawings", is the count of drawings of each patent.
- X_{17}: "Life-span", is the time span from filing date to the beginning of lawsuit of each patent.

3.3 Regression analysis

In regression analysis, if the coefficient of determination R^2 value approximates to 1, then the error of the regression model is small and the linear relationship for each indicator corresponding to the damage award is easily explained.

Before the regression analysis, the descriptive statistics of the means and the standard deviations of all these variables which comprising 17 patent indicators and damage award, is performed as shown in Table 4.

Because these variables X_1 to X_{17} do not have the same unit for counting, the means and the standard deviations of all these variables differ significantly. In Table 4, X_3 (Total claims), X_5 (US patent references), X_7 (Non-patent references), X_8 (Forward citations), X_{11} (Worldwide patent families), and X_{12} (US patent families) have higher means and standard deviations than the others. The high variances of all these variables X_1 to X_{17} will ruin any regression model. In order to improve the consistency of analysis, the normalization of all the 17 independent variables (X_1 to X_{17}) is necessary. It is therefore to transform the 17 independent variables into the Z-scores before the regression analysis.

Table 4. Descriptive statistics of patent indicators and damage award

Patent indicator	Nomenclature	Mean	Standard deviation
X_1	Assignees	2.4000	1.7302
X_2	Inventors	5.2615	4.6579
X_3	Total claims	61.9231	66.8104
X_4	Independent claims	12.4923	14.4462
X_5	US patent references	51.8769	70.0280
X_6	Foreign patent references	6.2615	9.6926
X_7	Non-patent references	31.5077	84.8908
X_8	Forward citations	41.7385	66.6364
X_9	IPC	3.4000	2.8218
X_{10}	USPC	9.3538	7.9440
X_{11}	Worldwide patent families	103.2154	202.7878
X_{12}	US patent families	36.4154	79.6653
X_{13}	Office actions	7.5385	6.7061
X_{14}	Responses	5.4000	5.6397
X_{15}	Examination	5.8531	4.5862
X_{16}	Drawings	15.9077	18.2000
X_{17}	Life-span	21.5538	20.4122
Damage award		16.0695	1.8963

According to the basic idea of the regression analysis, it is suggested to have at least 25 samples for one independent variable. For the cases of 17 independent variables, 425 samples are needed preferably. Since there are only 65 effective samples in this study, the regression analysis will fail. It's therefore to have 17 simple linear regression analyses performed in this study, wherein each normalized patent indicator is the independent variable and the damage award is the dependent variable. Via the tool of SPSS V8.0, the linear coefficient, R^2 and significance for each normalized patent indicator are shown in Table 5.

Table 5. Regression analysis of the 17 normalized independent variables

Normalized patent indicator		Linear coefficient	R^2	Significance
X_1	Assignees	0.154	0.007	0.521
X_2	Inventors	0.314	0.027	0.188
X_3	Total claims	0.205	0.012	0.392
X_4	Independent claims	0.460	0.059	0.052
X_5	US patent references	0.197	0.011	0.411
X_6	Foreign patent references	0.204	0.012	0.393
X_7	Non-patent references	0.599	0.100	0.010*
X_8	Forward citations	0.682	0.129	0.003**
X_9	IPC	0.113	0.004	0.636
X_{10}	USPC	0.094	0.002	0.696
X_{11}	Worldwide patent families	-0.094	0.002	0.696
X_{12}	US patent families	-0.116	0.004	0.629
X_{13}	Office actions	0.202	0.011	0.399
X_{14}	Responses	0.230	0.015	0.336
X_{15}	Examination	0.353	0.035	0.138
X_{16}	Drawings	0.360	0.036	0.130
X_{17}	Life-span	0.342	0.033	0.150

* Significant at 10% level, ** Significant at 5% level

Either the R^2 or the adjusted R^2 in these regression analyses are too low to have enough explanatory ability. However, it's still interesting to have some inferences.

There are two negative patent indicators which negatively affect the damage award and the other 15 positive patent indicators which positively contribute to the damage ward. The two negative ones are X_{11} (Worldwide patent families) -0.094 and X_{12} (US patent families) -0.116. In previous literature, Hereof, Schererc & Vopel (2003) concluded that worldwide patent families were positive to patent values. But in the present analyses, X_{11} (Worldwide patent families) and X_{12} (US patent families) both get the relative values to negatively affect the damage award. It tells that the increase of the worldwide patent family size won't get the corresponding increase of the damage award. Because worldwide patent families cost lots of money, the present analyses suggested that carefully consideration should be taken while planning the patent portfolio strategy.

Besides, Hirschey & Richardson (2001), Hereof, Schererc & Vopel (2003), Hirschey & Richardson (2004), Von Wartburg, Teichert & Rost (2005), and Silverberg & Verspagenb (2007) proposed that citations include backward, forward citations, or non-patent references contribute to the value of patents. In Table 5, X_5 (US patent references), X_6 (Foreign patent references), X_7 (Non-patent references) and X_8 (Forward citations) all have positive values to indicate positive contribution to damage awards. The result echo the observations of previous literatures. In particular, X_7 (Non-patent references) and X_8 (Forward citations) get the highest two positive values among all patent indicators.

In the present regression analyses, X_2 (Inventors) 0.314, X_4 (Independent claims) 0.460, X_{15} (Examination) 0.353, X_{14} (Responses) 0.230, X_{16} (Drawings) 0.360 and X_{17} (Life-span) 0.342 get higher positive values than X_5 (US patent references) 0.197 and X_6 (Foreign patent references) 0.204. It means that these patent indicators contribute more to damage award than X_5 (US patent references) and X_6 (Foreign patent references) do. Hence, this study provides a new vision for reconsidering the influences of patent indicators.

3.4 Back-Propagation Neural Network

Though there are 17 patent indicators proposed in this study, base on the results of aforementioned 17 simple linear regression analyses, the patent indicators with linear coefficients below 0.3 are discarded. Therefore, only the following 7 significant patent indicators were used as the input variables for the proposed BPN study. They are X_2 (Inventors), X_4 (Independent claims), X_7 (Non-patent references), X_8 (Forward citations), X_{15} (Examination), X_{16} (Drawings) and X_{17} (Life-span), while the output variable is the damage award. Meanwhile, the input variables are normalized to z-scores to be within the interval of 2 times the standard deviation for eliminating the affection of some abnormal values; while the output variable is scaled to 0.2 to 0.8.

"Since there are 65 effective samples as shown in Table 1, wherein the 53 samples from 1989 to 2005 are chosen to be the training set and the testing set for constructing the BPN, and the 12 samples in 2006 are chosen as the validating set to validate the prediction effectiveness of the BPN. Moreover, 35 samples are randomly selected from the 53 samples to be the training set and the other 18 samples left are the testing set".

Figure 1 shows the convergence plot of RMSE versus learning cycle, wherein the vertical axis represents the scaled RMSE, the horizontal axis represents the learning cycle, the upper line represents RMSE of the training set which converging to 0.101 (10.1%), and the lower line represents RMSE of the testing set which also converging to 0.101 (10.1%). Both the RMSE values of the training set and the testing set converge after 600 learning cycles, so the learning process of the BPN is successful. Though RMSE 0.101 (10.1%) is not perfect, it's still acceptably reasonable.

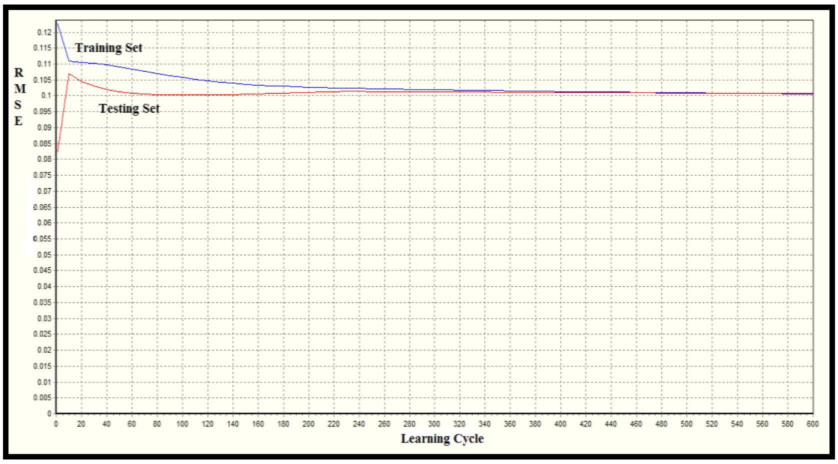

Figure 1. RMSE convergence v.s. learning cycle

In the above-constructed BPN, some optimal parameters used are shown below:

- Neurons in the first hidden layers: 6
- Neurons in the second hidden layers: 2
- Sampling approach for the training set and testing set: random
- Margin for weightings for interconnections: -0.5 to 0.5
- Learning type: batched learning
- Initial value of the learning speed: 1.0

- Decreasing rate of the learning speed: 0.99
- Initial value of the inertia: 0.5
- Decreasing rate of the inertia: 0.99

For validating the evaluation model, the validating set composed of 12 samples in 2006 is then introduced into the constructed BPN to see its RMSE value and check the predictive power of the constructed BPN. Table 6 shows the comparison of RMSE values of the training set, the testing set and the validating set.

After validation, RMSE 0.098 (9.8%) of the validating set is derived. RMSE 0.0.98 (9.8%) of the validating set is superior to RMSE 0.101 (10.1%) of the training set and the testing set, hence the validation is successful. The successful validation means that the valuation model of the BPN constructed by samples from 1989 to 2005 can predict for samples in 2006. The nonlinear relationship between the damage award and the selected 7 patent indicators can be modeled by the BPN with an acceptable error. It proves that the proposed BPN is effective and the valuation model is feasible. Once the significant 7 patent indicators X_2 (Inventors), X_4 (Independent claims), X_7 (Non-patent references), X_8 (Forward citations), X_{15} (Examination), X_{16} (Drawings) and X_{17} (Life-span) of a patent or a patent portfolio are inputted into the BPN valuation model, a possible damage award with an estimated error is outputted.

Table 6. The comparison of RMSE values of BPNt

	Number of samples	RMSE
The training set	35	0.101
The testing set	18	0.101
The validating set	12	0.098

4. Discussion

This study does not claim an unbeatable method to solve the damage award neither in all kinds of patent infringement lawsuits nor in all U.S. district courts. Consequently, this study won't claim the valuation model to solve patent values of non-US patents, such as Chinese patents, European patents and Japanese patents. However, this study tries to combine the knowledge of patent, finance, computation and management, and to provide a brand new concept for analyzing the patent infringement lawsuits so as to propose a monetary valuation model of patent legal value. This study would like to show that the patent infringement lawsuits are not only good for case study but also good for quantitative analysis.

In this study, 17 patent indicators are proposed for quantitatively describing patents. The linear relationship between the damage award and these proposed 17 patent indicators is discussed by regression analysis. It shows that the damage award is not linearly proportional to any one of the 17 patent indicators. The relationship between the damage award and the patent indicators is too complicated to have a linear equation for modeling.

Usually, it is observed that valuable patents accompany large size of patent family. However, via the present regression analyses, it's found that X_{11} (Worldwide patent families) and X_{12} (US patent families) negatively affect the damage award. These findings may provide a new thinking of the patent portfolio strategy.

Furthermore, lots of previous literatures proposed that citations which including backward and forward citations, or non-patent references contribute the revenue, stock performance, or investor's confidence, but in this study, only X_7 (Non-patent references) and X_8 (Forward citations) contribute superiorly the damage award than other patent indicators. The patent indicators such as X_2 (Inventors), X_4 (Independent claims), X_{15} (Examination), X_{14} (Responses), X_{16} (Drawings) and X_{17} (Life-span) contribute more the damage award than X_5 (US patent references) and X_6 (Foreign patent references). These patent indicators might need more and further investigation.

The nonlinear relationship between the damage award and the 7 significant patent indicators is modeled by the BPN. The valuation model of the BPN is constructed via samples from 1989 to 2005 by training and testing, and then is validated by samples in 2006. By RMSE analysis between these samples, the proposed BPN patent valuation model shows its predictive power and is proved to be feasible.

To be best of authors' knowledge, this study proposed the first successful patent valuation prediction model using BPN and statically regressions. The process involve retrieving samples from patent infringement lawsuits, studying judgments of determination, finding out the patent numbers and damage awards, setting up 17 patent indicators for quantitative patents descriptions, finding significant patent indicators by linear regression analyses, constructing the BPN for modeling significant patent indicators and damage awards, and finally validating the predictive power of the proposed valuation model.

Figure 2 shows the architecture of the patent valuation model. For the application in practice, please see the bold lines in Figure 2, once the 17 patent indicators of a patent or a patent portfolio being in evaluation is described to be inputted in the valuation model as the input variables of the BPN, consequently an output variable is generated to be the possible value of damage award. Referring to the dotted lines in Figure 2, the BPN would be certainly improved by feeding more samples of patent infringement lawsuits from the district courts other than Delaware, California and Texas, so as to refine the patent valuation model. More particularly, because the timing issue is already considered in the patent indicators and the converted damage awards, as years go by and recent samples are fed, the valuation model learns to adjust itself dynamically. A single patent or a patent portfolio via this model can be valuated to distinct prices at different time of valuation. It's a live and growing valuation model for providing the monetary legal values of patents.

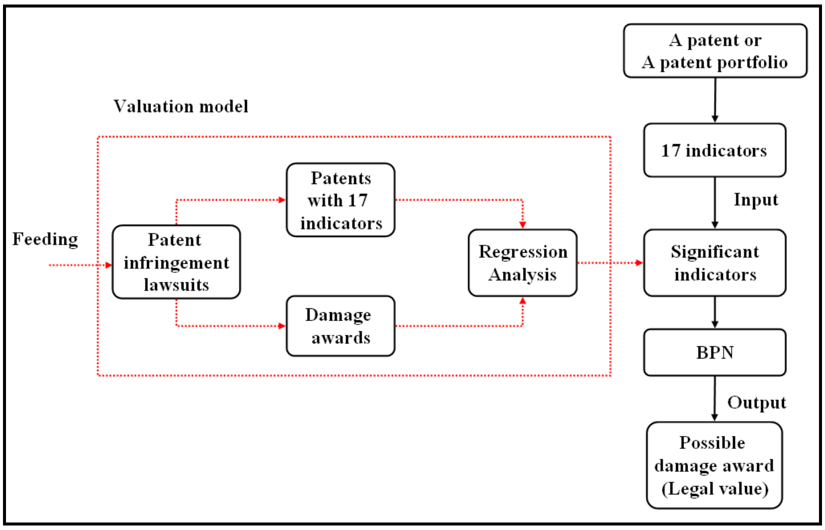

Figure 2. The architecture of the proposed BPN patent valuation model

This proposed valuation model is quite useful in practice. For the patent infringement lawsuit, either the plaintiff or the defendant may use the proposed valuation model to forecast the possible final damage award earned or lost, so as to configure the lawsuit strategy. For technology management purpose, the R&D intensive company may use the proposed model for evaluating the patent assets to distinguish the high value patents from the low value ones. The high value patents should be kept firmly for seeking the chance of lawsuits and "stick license". The low value patents might be used for auction, donation or even abandonment. The proposed model also accommodates to applications of patent transaction deal, patent licensing, hypothecation of intangible assets, and shareholding by patent-based technologies, etc.

5. Recommendation

It is suggested that below topics might be suitable for further studies:

(1) Variance analysis: It speculates that the proposed evaluation model may accommodate to various U.S. district courts, various industries, various technologies, and even various countries. Hence, retrieval of more effective samples and variance analysis are necessary for appropriate adjusting raw patent indicators and optimal parameter settings of the BPN.
(2) Optimal design for patent compositions for maximizing the damage award: It would be possible by setting the damage as the object function while all indicators or indicators as independent variables, so as to get an optimal solution for patent compositions. This would be great helpful to managing R&D, innovation activities, and patent attorneys.

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Applying TRIZ Principles to Construct Creative Universal Design

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Abstract

To promote daily-used products that could be easily used and accessed by all people or at least most of the people, Universal Design (UD), or Inclusive Design, initiatives have been studied and proposed by many researches over last few decades. However, a holistic and systematic approach that considers UD principles throughout its whole product developmental process is necessitated in order to ensure that UD initiatives are fully built into the product itself and versatile and innovative product concept development is also fully explored, resulting in truly benefiting the users.

This research proposed a TRIZ-based innovative product design process that incorporates UD principles. This newly formed methodology started with describing the problem, encountered during the product design and development, in terms of UD principles. The problem statement was then formulated by a 3-step inventive problem solving procedure. Contradiction Matrix of TRIZ was employed to identify proper inventive principles that could serve as resolutions, leading to improved or new product concepts. Finally, a case study was conducted to demonstrate how this creative design process works. Study result shows that this method can help identify the core of the problem and locate the improved product concepts rapidly, resulting in generating more creative resolutions.

Keywords: Product Design and Development, TRIZ, Universal Design.

1. Introduction

Nowadays Taiwan society is facing the trend of increasing aging population and declining birthrate. While accompanying by growing of minority groups, the government and enterprises started to pay attention to the social welfare and relevant issues, resulting in promoting more proper design concepts and products (Preiser and Ostroff, 2001; Duncan, 2007). Among of them, Universal Design (UD) advocated in recent years has been paid the most attention to. UD initiatives take the viewpoint of humanity to design products that emphasizing truly fulfilling the needs by all persons with all ages and abilities. It conforms to the way people pursuing modern lifestyle and interacting with and caring about each other. UD has been well established for quite some time in major countries, such as, America, Europe, and Japan. Among these countries, best practices of UD application can be found from product strategies of companies as well as curriculum in design education (Preiser and Ostroff, 2001). In Taiwan, more and more researches concerning UD are gradually getting more attention. Most of them are focusing on product design and applicability for minority groups. However, research shows that only few Taiwanese companies are applying UD into their product design and development process. UD initiatives deserve more attention by the companies to address the issues mentioned above (Huang, 2005). In general, UD principles are offering more extensive ideas or concepts. It is normally not easy

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to implement them to develop the desired products throughout the product design and development process. Therefore, there is a need to enhance or improve UD with a systematic method such that more specific and concrete resolution can be provided. TRIZ or Theory of Inventive Problem Solving is a perfect tool to help provide creative solutions effectively. TRIZ is employed to come out suitable resolutions, when there is any problem that encounters conflicts or contradictions. Though TRIZ has been introduced to Taiwan for some time and many practical applications can be found in either industries or academia, it is still not popular. Fail to make users easy understanding and using TRIZ is probably the main reason.

This research intended to construct an enhanced universal design approach that integrates both UD and TRIZ principles. This approach will help develop concrete and solid product concept throughout the product design and development with creative and systematic problem solving procedure. With this enhanced approach and personal experiences, product designer or engineer can easily generate more overall and versatile resolutions, resulting in innovative products. In addition, it should help streamline the product development process and conquer the difficulties occurred from the product design, when the approach is applied at the early stage of the product design and development. Since the comprehensive aspects of product development are considered, the developed products can then meet diverse and highly competitive market demand of today.

2. Literature Review

2.1 Introduction to Universal Design

Ronald L. Mace coined the terminology, Universal Design, as early as in mid-1980s (Mace, 1985). Its philosophy is to make all products be accessed by all people, with or without disabilities, fairly and freely, while the products are still maintained their esthetic design and market value. Firstly originated from focusing on improving daily living environment of the disabilities, UD addressed the design issue for a barrier-free environment and initiated accessible environmental design. Later it further expended its scope to promoting better usable and accessible products for all persons with all ages and abilities, resulting in the most recommended UD concepts nowadays.

The critical timing for the UD concepts to be formed is because Americans with Disabilities Act (ADA) passed in America in 1990 (Story et al., 1998; Duncan, 2007). The ADA law is meant to ensure equal opportunity and rights of disabled persons in employment, housing, education, and access to public services (US Department of Justice, 2005). Though conforming to regulations, lots of products and services are not taking people with all ages and abilities into account such that obstacles and inconveniences are still very common in our daily life. In view of this, Mace in 1988 proposed that 'Universal design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.' (Story et al., 1998; Duncan, 2007) Based on this philosophy, seven universal design principles and their corresponding guidelines were cooperatively developed by a team of researchers, including architects, industrial designers, engineers, and environmental design researchers, at the Center for Universal Design and introduced in 1997 (The Center of Universal Design, 1997; Story et al., 2003). The intention of constructing universal design principles and guidelines was to provide suitable and broader common design principles to fulfill promoting universal design philosophy. The principles and guidelines were also employed to assess whether UD conformance is met or not and can serve as a guide to offer design direction at the design stage (The Center of Universal Design, 1997, Story et al., 2003). The seven UD principles are showed in Table 1.

Although the designs can be evaluated by the original seven principles of UD and their guidelines to determine how well they met, the principles principally focused on usability, the marketability of the designs was not considered. By embracing the seven principles of Universal Design, Tripod Design, a Japanese design company led by Mr. Satoshi Nakagawa, proposed three supplementary principles (as shown in Table 2) that take a product's marketability into account and developed a systematic approach, called Product Performance Program (PPP), to evaluate objectively UD performance of a design (Nakagawa, 2006).

Table 1. Seven principles of universal design (The Center of Universal Design, 1997)

1. Equitable Use	The design is useful and marketable to people with diverse abilities.
2. Flexibility in Use	The design accommodates a wide range of individual preferences and abilities.
3. Simple and Intuitive Use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
4. Perceptible Information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
5. Tolerance for Error	The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. Low Physical Effort	The design can be used efficiently and comfortably and with a minimum of fatigue.
7. Size and Space for Approach and Use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Table 2. Three supplementary principles of universal design (Nakagawa, 2006)

Supp. 1. Attention to Product Durability and Production Economics	The design with appropriate price is durable and easy to maintain.
Supp. 2. Attention to Product Quality and Aesthetics	The design is comfortable and aesthetic, commits to satisfactory quality and can use materials effectively.
Supp. 3. Attention to People's Health and the Natural Environment	The design is harmless to human and friendly to the environment and can promote recyclables and reusability.

This research applied both original seven principles and three supplementary principles of UD as the fundamentals to construct a systematic and innovative product design and development process for helping develop the universally usable products.

2.2 Introduction to TRIZ

TRIZ, introduced by Genrich Altshuller, is a systematic and creative approach to reach innovative results by resolving contradictions of problems. The very basis of this systematic inventing problem solving approach was to extract patent inventors' problem solving knowledge to enhance TRIZ practitioner's domain knowledge and inventing problem solving skills (Terninko et al, 1998; Altshuller, 1999; Busov et al, 1999). In addition, the knowledge was classified and induced to enable all scientific and technological fields applying the similar problem solving method. TRIZ puts emphasis on reaching invention and innovation by following systematic steps and procedures and consulting accumulated inventing knowledge of past generations, instead of searching for solutions randomly. In addition, Altshuller (1999) realized that people, constraining to their domain knowledge and tending to look for solution ineffectively by simply employing trial-and-error approach, are normally unable to apply the best practices of problem solving skills and knowledge in different fields to locate the most desired and suitable solutions. To avoid traps and obstacles along the problem solving process, an innovative inventing theory, is necessary. TRIZ is exactly the problem solving theory to address these issues.

Although TRIZ consists of many tools and techniques, such as, 40 Principles, Su-field Analysis, ARIZ, Contradiction Matrix, and Patterns of Evolution, the main problem solving tools focus on contradiction and ideation (Terninko et al, 1998; Ideation International Inc., 1999; Mann, 2007). Altshuller divided the contradictions encountered during the invention process into Physical Contradiction and Technical Contradiction (Terninko et al, 1998; Altshuller, 1999; Ideation International Inc., 1999; Gadd, 2002; Mann, 2007). In Physical Contradiction, while making a decision the same parameter of a system has to be increase and reduce at the same time in order to achieve different purposes. To eliminate the contradictions, Separation Principles are provided by TRIZ. In Technical Contradiction, when improving a parameter, another parameter may be worsened in the system. To resolve the contradictions, a Contradiction Matrix is provided by TRIZ. The Contradiction Matrix was made up by 39 Engineering Parameters and 40 Innovative Principles. While 39 Engineering Parameters help to identify the contradictions between improved and worsened parameters, 40 Innovative Principles help to direct the resolutions to the contradictions. From the extensive literature search, the extremely valuable Contradiction Matrix is the most widely employed tool in TRIZ and considered to be the suitable problem solving tool to help enhance the UD principles to generate the solid and concrete resolutions.

2.3 Product Design and Development by Incorporating UD and TRIZ Initiatives

Universal design initiates can have influences on companies both directly and in-directly. The direct influences are improving product, promoting corporate image, reducing total cost of product development, and developing new commercial interest and emerging product, while the in-direct influences are expending market share, and advocating the community responsibility of the enterprises, etc. Although the user-centered universal design does pay attention to marketable issue, commercial niche and profits are still the keys to attract to most of the companies in order to make the product realization possible. UD as a kind of design philosophy should take versatile aspects into consideration during the product design and development in order to truly fulfill both universally usable requirements and commercially interests. TRIZ is a perfect tool to help address these issues. The main idea of TRIZ is to point out the contradictions of problem and then search for potential resolutions to attack contradictions. It can facilitate exploring problem-solving methods. By applying TRIZ to help resolve problems in the initial stages of design process, it not just can prevent the mistakes occurred later, but also can improve the product development efficiency. TRIZ can help provide solution directions during the product design development and it can facilitate identifying actual reasons to resolve the technological problems (Ulrich & Eppinger, 2006).

Concept generation, concerning brief description of technology, work principle, and product form, is one of the crucial parts in the whole product design and development. It is normally describing how the product to meet customer demand and be used by most users. Essentially, it is in accordance with the concept of Universal Design. It is believed that a sound product concept plays a major role to determine to which extent a product can satisfy customers and whether or not a product can be succeed in the marketplace. Although a good concept is not necessary a guarantee to lead to product success, a bad one is definitely a commercial disaster. Concept development is fairly cheaper and faster to produce, by comparing with other activities in the product design and development process. Good product concepts through the intensive search of the concept generation process can normally enhance the confidence of the development team, since all the potential alternatives have been explored in this field (Ulrich & Eppinger, 2006).

In order to avoid the possibility of failing to locate any good product concepts or introduce more competitive products, all of the potential product concepts have to be explored and reviewed in the early stages of the product design and development. To help launch a product to the marketplace timely and successfully, proper evaluation and assessment on product is necessary. Product Performance Program (PPP) is an assessment tool in the UD field to help evaluate UD performance of a product (Nakagawa, 2006). PPP, based on the seven principles of, is constructed to objectively assess and evaluate UD performance of a product via consumer's point of view. PPP is employed in this research to assess the real case studies.

To help address these issues, TRIZ can be employed to help on concept generation. It is apparent that it should not only consider consumer's demand, but also need to prevent any problems that would take place in the product development process. And it has further shown that TRIZ is closely bound up with UD in the product design and development process.

3.A Proposed Approach to Construct Creative Universal Design

The intention of Universal Design is to develop barrier-free products that are cost-effective and marketable. However, in order to fulfill UD initiatives, it is normally facing more restrictions during the product design and development, resulting in less creative design. To address this issue, a systematic innovation approach was constructed to integrate both UD and TRIZ. With this TRIZ-based approach, the resolution is not just universally usable, but also creative and concrete. This approach also utilized PPP, which was a user-centered validation system, to objectively assess how well the design achieves UD requirements.

The creative product design and development process accommodating both UD and TRIZ principles is described as follows: firstly, the approach starts with product assessment by using PPP. Design problems or issues can be identified. The problems are stated in terms of the seven principles and three supplementary principles of UD. The problems are then formulated by a three-step for solving an inventive problem procedure, introduced by Shulyak (1997). The formulation is to analyze the product in order to determine characteristics that need to be improved. The process is guided by completing the Form F-1 (Shulyak, 1997). In addition, the formulation will help identify potential contradictions from the characteristics that need to be improved. Form F-2 can help complete this process (Shulyak, 1997).

Based on the formulated problem statement, the Contradiction Matrix of TRIZ is applied to locate the suggested inventive principles that can resolve the contradictions from the characteristics to be improved. If the contradictions cannot be easily determined, the most frequently suggested principles against each characteristic is then recommended as the potential concept solutions (Liu, 2001). After finding the inventive solutions offered by TRIZ, re-design directions of the product can be developed. Finally, PPP is employed again to verify whether the UD values of the re-designs are improved. PPP evaluation results can be represented by either numeric value or radar diagram (Nakagawa, 2006). The framework of the proposed Creative Universal Design is depicted in Figure 1.

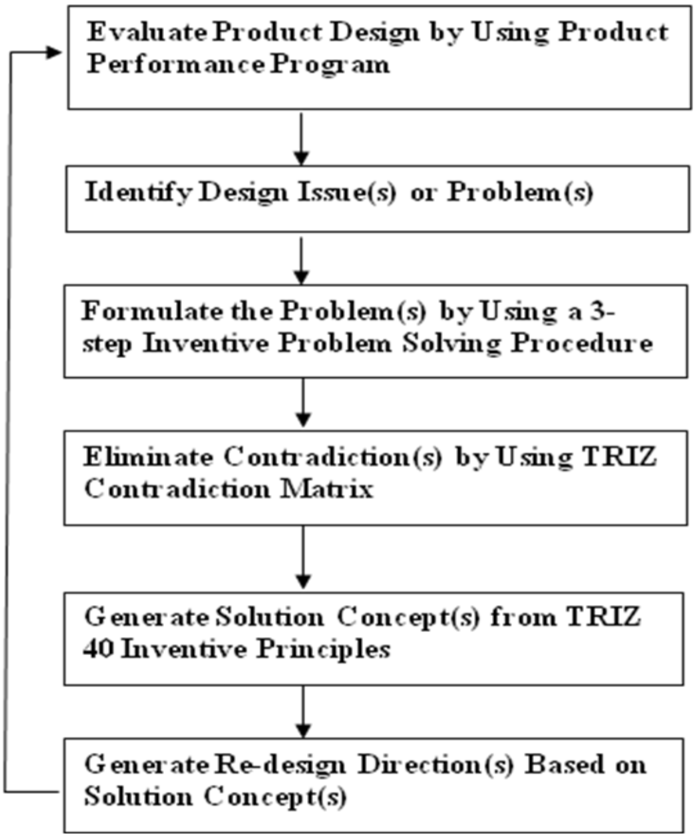

Figure 1. Framework of creative universal design

The PPP system employed by this research is not just for validating UD requirements of the design, but also for improving the UD conformance of the design. To this end, PPP evaluation is carried out twice for comparison before and after the design improvement. The first PPP evaluation is conducted prior to the improvement to identify problematic issues of the original design. The problem-solving skill described above can then be applied to deal with the problems. The second one is taking place after the improvement to assess the re-design or enhanced design. Two PPP results represented by radar diagrams can be compared side by side to validate the degree of UD achievement. To ensure the credibility of this research, all participants who enrolled in this research to conduct UD evaluation were experts or practitioners in UD field in Taiwan. By following the proposed TRIZ-based Universal Design approach, a commercially available toothbrush was chosen to demonstrate the feasibility of the approach.

4.Results and Discussion

By following the steps from the proposed approach, twelve gender balanced participates were recruited to perform PPP evaluation for the chosen toothbrush, which was a commercially available product in the marketplace. The evaluation result, represented by radar diagram, is shown in Figure 2. The lower average scores of Supplementary Principles 1 and 3 from Figure 2 indicate that these two items were the targets for improving the toothbrush design. The evaluation also stated problems in terms of the original seven principles and three supplementary principles of UD and their corresponding guidelines. Three key issues were identified; they were Principle One, Supplementary Principles One and Three. The complete statement is shown in Appendix 8.1.

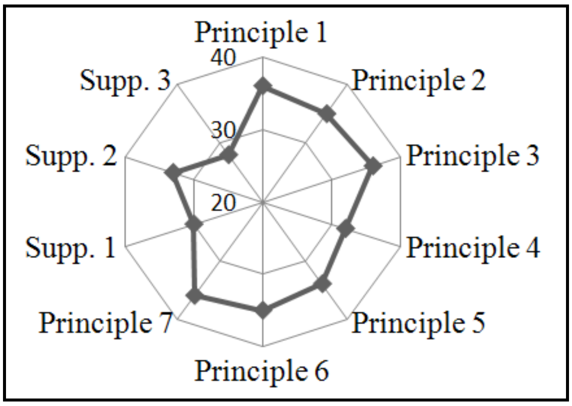

Figure 2. PPP evaluation of toothbrush (prior to the improvement)

The identified problems were then analyzed to determine which characteristic that needs to be improved, by completing Form F-1. Three characteristics to be improved were identified as: (1) equitable use for all users is not possible, (2) bristles of the toothbrush are not durable, and (3) the toothbrush is not durable and is not easily to be maintained. The complete formulation of the characteristics to be improved is shown in Appendix 8.2. After determining the characteristics to be improved, the contradictions with respect to the characteristics were identified by completing Form F-2. The complete formulation of contradictions is shown in Appendix 8.3.

To resolve the contradictions, which were no conflicts in this case, the most frequently used Engineering Characteristics were employed to locate the potential resolutions. By looking over the 39 Engineering Parameters from TRIZ, parameters 35, 34, and 26 were considered to be the most appropriate for the identified problems. The desired inventive principles (01, 35, & 35) were then determined based on the chosen parameters. The suggested inventive principles from TRIZ were provided as design directions to improve the original toothbrush. They were: re-design the size and form of the toothbrush, make the brush to be replaceable and durable, and re-design the toothbrush with improved material, form, and function to be easily adjusted. The characteristics needed to be improved and their potential resolutions are shown in Table 3.

Table 3. The potential solutions for the toothbrush to be improved

Characteristic to be Improved	39 Engineering Parameters	40 Inventive Principles	Design Direction
(1) Equitable use for all users is not possible	#35 Adaptability	#35 Transformation of properties	Re-design the size and form of the toothbrush
(2) Bristles of the toothbrush are not durable	#34 Reparability	#01 Segmentation	1. Make the brush to be replaceable and durable 2. Increase the number of the bristles
(3) The toothbrush is not durable and is not easy to maintain	#26 Amount of substance	#35 Transformation of properties	Re-design the toothbrush with improved material, form, and function to be easily adjusted

In addition to ascertaining the design concepts, the suggested design had to be verified by performing the PPP evaluation again to see whether UD principles are conformed or not. The evaluation was carried out by the same group of participants recruited. The evaluation result after the design improvement is shown in Figure 3. The figure shows that Supplementary Principles 1 and 3 were improved, after re-designing the toothbrush based on the suggested design concepts. By comparing the PPP average scores between the original design and re-design, the PPP result for the toothbrush prior to improvement was 335 and the one for improved design was 340. The higher average score for the latter one indicates that the suggested design resolutions did improve the toothbrush with better UD conformance.

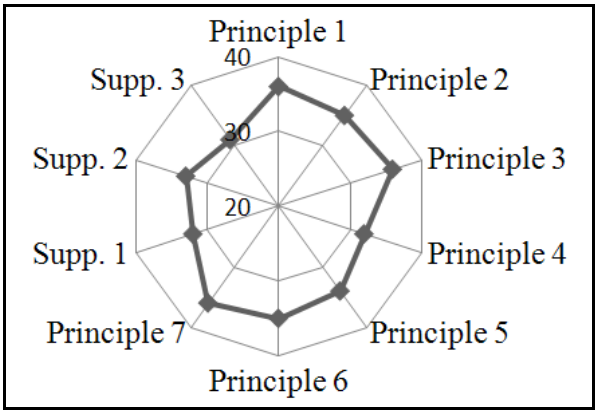

Figure 3. PPP evaluation of toothbrush (after the improvement)

By applying this newly developed innovative design approach, it is found that appearance, function, and usability of a product are not just the mere factors to be considered for design improvement. Versatile aspects need to be taken into account in order to truly reach the most desired and profound design for accommodating wider range of users with all abilities and ages in various environments. The toothbrush chosen in this research is the most familiarly daily dental cleaning tool. With the advance of toothbrush design nowadays, the regular toothbrush is considered a mature design on the market. Therefore, this research found no significant differences between prior to and after the design improvements. It is still encouraging to look into the problems with different perspectives, which may reach breakthrough and inventive resolutions to fully fulfill the satisfaction of the users.

5.Conclusions

This research intended to construct a creative Universal Design process that incorporates both UD and TRIZ principles and was manifested the feasibility of this research results by a case study. It was found that the proposed approach incorporating TRIZ could strengthen the UD principles to provide more concrete and creative solutions. In addition, the validation results from PPP evaluation system, which is employed for the comparisons prior to and after the improvement, further proved that the approach is feasible. This research also showed that both UD and TRIZ principles could work alongside to come out more creative and inventive solutions that conform to UD requirements without the need to make trade-offs.

With respect to the practical application of the newly developed approach, young designers, less experienced product planners, and students can use this approach as a guide to familiarize themselves with UD principles and concepts systematically. It can also further help them reach the creative and inventive design with UD compliance. As for experienced designers and product planners, this TRIZ-based systematic innovative approach can help break the barriers from past design practices and experiences and provide new insights and perspectives, resulting in creative, exciting, and challenging designs. This holistic and systematic approach can also help them ensure that UD requirements are fully incorporated into every aspect while conducting product design and development.

6.Acknowledge

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8.Appendices

8.1 Table for Problem Statement of the Toothbrush

Principle	Guideline	Problem Statement
1	1a. All potential users could use this product in essentially the same way, regardless of differences in their abilities.	Not all potential users could use this product.
	1b. Potential users could use this product without feeling segregated or stigmatized because of differences in personal capabilities.	Yes
	1c. Potential users of this product have access to all features of privacy, security, and safety, regardless of personal capabilities.	No
	1d. This product appeals to all potential users.	No
2	2a. Every potential user can find at least one way to use this product effectively.	Yes
	2b. This product can be used with either the right or left hand alone.	Yes
	2c. This product facilitates (or does not require) user accuracy and precision.	Yes
	2d. This product can be used at whatever pace (quickly or slowly) the user prefers.	Yes
3	3a. This product is as simple and straightforward as it can be.	Yes
	3b. An untrained person could use this product without instructions.	Yes
	3c. Any potential user can understand the language used in this product.	No
	3d. The most important features of this product are the most obvious.	Yes
	3e. This product provides feedback to the user.	Yes
4	4a. This product can be used without hearing.	Yes
	4b. This product can be used without sight.	Yes
	4c. The features of this product can be clearly described in words (e.g., in instruction manuals or on telephone help lines).	Yes
	4d. This product can be used by persons who use assistive devices (e.g., eyeglasses, hearing aids, sign language, or service animals).	Yes
5	5a. Product features are arranged according to their importance.	Yes
	5b. This product draws the user's attention to errors or hazards.	Yes
	5c. If the user makes a mistake with this product, it won't cause damage or injure the user.	Yes
	5d. This product prompts the user to pay attention during critical tasks.	Yes
6	6a. This product can be used comfortably (e.g., without awkward movements or postures).	Yes

	6b. This product can be used by someone who is weak or tired.	Yes
	6c. This product can be used without repeating any motion enough to cause fatigue or pain.	Yes
	6d. This product can be used without having to rest afterward.	Yes
7	7a. It is easy for a person of any size to see all the important elements of this product from any position (e.g., standing or seated).	Yes
	7b. It is easy for a person of any size to reach all the important elements of this product from any position (e.g., standing or seated).	Yes
	7c. This product can be used by a person with hands of any size.	No
	7d. There is enough space to use this product with devices or assistance (e.g., wheelchair, oxygen tank, or service animal).	Yes
Supp. 1	This product is durable under various conditions.	Brush is not durable
	The price of the product is accorded with its performance and quality.	Yes
	The maintenance cost is reasonable.	Yes
	The maintenance is easy and after-sale service is provided.	No. Toothbrush is normally disposed after its end-of-life.
Supp. 2	The product is equipped with desired function and esthetic form and is comfortable to use.	Yes
	The quality of the product can fully meet user's need.	Yes
	The product can flexibly apply the property of the material.	Yes
Supp. 3	The product uses toxic material.	Some
	The product uses environmentally friendly material.	Some
	The product can be reused, recycled, and re-generated.	Some

8.2 Formulation of a Characteristic to be Improved (F1)

1. State the name of the Technical System: Toothbrush
2. Define the goal of the Technical System. The system is designed to: Clean the mouth and teeth and prevent dental problem and bad breath.
3. List main elements of the Technical System and their functions: The commercially available toothbrush.
4. Describe the operation of the Technical System: Apply some toothpaste to the brush of the toothbrush first and then operate the toothbrush by hand to clean the tooth and gum.
5. Determine the characteristics that should be improved or eliminated:
   (1) Equitable use for all users is not possible.
   (2) Bristles of the toothbrush are not durable.
   (3) The toothbrush is not durable and is not easy to maintain.

8.3 Formulation of Technical Contradiction (F2)

State the positive Characteristic that should be improved:

(1) Equitable use for all users is not possible.
(2) Bristles of the toothbrush are not durable.
(3) The toothbrush is not durable and is not easy to maintain.

a. The Characteristic is?
   (1) Clean tooth and remove bacterium.
   (2) Easy to use and understand.
   (3) Can be used freely.
b. State a conventional means to improve the Characteristic?
   (1) Adjust the handle length of the toothbrush.
   (2) Improve the brush material.

(3) Replace the toothbrush regularly.

c. State a Characteristic that is getting worse under conditions in line b? No

d. Formulate Technical Contradiction as follows: If the Characteristic (a) is improved by? Then the following Characteristic will get worse? No

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From Complex Problems to Simple Solutions: a Systematic Approach

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Abstract

A common problem familiar to many researchers dealing with complex technical systems (which can be formally described as non-stationary and/or non-linear multi-degree of freedom systems) is the need to find a meaningful solution which would have physical sense, would explicitly show dependence on the parameters and allow interpretation. Several decades ago the culture of building first approximation, asymptotical or slow time solutions was highly developed and practiced. Nowadays, with the advent of modern computers and numerical packages it often seems straightforward to generate a solution for the given set of parameters and boundary conditions. Therefore, the acuteness of this problem may be less obvious for the researcher. However, this "frontal attack" solution in some cases may be impractical (for instance, if this is an optimal control problem, the solution may require rapid changes of the control, which are hard to realize). In other cases, when the question arises as to what happens with the solution when the parameters change, the only answer may be to run the analysis again, which can be time consuming and still not show an interpretable dependency on the parameters.

Using a model solution can also help in optimization of a complex system, requiring multiple design iterations. The transition to a model solution in this case can be based on identifying a single characteristic or parameters of the system which has to meet contradictory requirements. While identification of such parameter may not be obvious, it can lead to resolving the contradiction for the model system using known problem solving tools (from the game theory to TRIZ). This solution needs then be mapped back to the initial system. The contradiction-solving model solution often offers a way to reach the goal of the project in a different way, obviating the need for the intensive numerical solution. The approach is illustrated by three case studies.

Keywords: closed-form solutions, contradictions, design optimization, model system.

1.Introduction

When dealing with complex technical systems (non-stationary and/or non-linear), it is often attractive to single out a simplified sub-system which carries most of the information needed for the researcher, and consider contribution of other variables or degrees of freedom as refining

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factors which do not substantially change the solution for the simplified sub-system. For the engineering systems having a small parameter, the perturbation methods have been used extensively and are reflected in numerous publications. In many applications, however, the initial (complex) system has no small parameter, and therefore the researcher needs to identify the simplified sub-system, based on his experience and intuition. Generally speaking, the researcher needs to identify in the initial system two sub-systems in such a way that the solution of the first (simplified) sub-system can be easily built and the solution of the second sub-system is small (in some sense) in the vicinity of the solution for the first system.

This approach is illustrated by three case studies, summarized in Table 1. The steps described in Table 1 can be described as follows.

Step 1. Restate the initial problem

The researcher must be able to transform the initial non-linear or/and non-stationary problem into a problem for a model system, which a) qualitatively has similar relationship between input and output variables and is based on the same principle of operation, and b) can be solved analytically, or which a solution is known. While this transformation needs to be selected on case by case basis, some general recommendations are:

- In a multi degree of freedom (DOF) system, single out a one DOF system that corresponds to the resonating natural mode;
- In a system with distributed parameters, seek solution in the form of series over natural modes of the system (eigen-function series), and then separate a sub-system having lower eigen-values (corresponding to slow variables);
- In a system with fast and slow variables, introduce averaging, and make a transition to a system in "slow time", having only slow variables;
- In a system with time dependent variables, "freeze" those variables that change slowly and build a solution for the system with constant coefficients, et al.

It should be emphasized that the use of the procedures listed above can never be formal. The researched needs to deeply understand the problem in order to be able to single out a model sub-system. Applicability of the listed "recipes" needs to be validated in every case by applying the solution, built under the listed assumptions, to the initial system, or by direct experiments.

Step 2. Solve the Restated Problem

This is usually a relatively straight forward step. If Step 1 was done properly, the restated system should allow an analytical or known from a textbook solution, or in some cases relatively simple numerical solution.

Step 3. Apply Solution to the Initial Problem

Substitute the generated solution in the initial system, or, in case of an optimal control problem, apply the generated control variable to the initial system. Evaluate the inaccuracy or residuals. Depending on the achieved accuracy, steps 1 and 2 may need to repeat iteratively.

In what follows the case studies presented in Table 1 are discussed in more detail.

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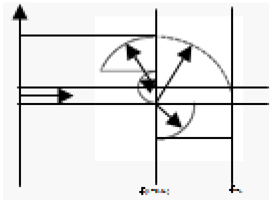
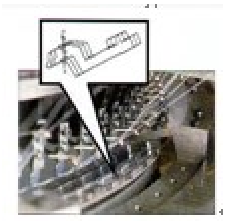
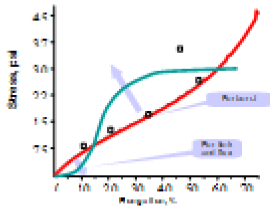
Table 1. Summary of the three case studies

	Case Study 1	Case Study 2	Case Study 3
			
Initial Problem	Optimal control problem for non-linear non-stationary system (acceleration of the rotor)	Analysis of non-stationary system with distributed parameters (fatigue problem for the cam-driven needles)	Optimization of design under contradictory requirements (Finite Element Analysis of high pressure catheter)
Step 1. Restate the Problem	Transform the initial (fast) variables into slow variables	Transform the initial system into superposition of one DOF (degree of freedom) systems	Identify in the initial multi-parameter system a single characteristic or parameter which has to meet contradictory requirements.
Step 2. Solve the Restated Problem	Solve the optimal control problem for slow variables (sub-optimal control)	Use model solution for one DOF system	Exacerbate and resolve the contradiction using known tools
Step 3. Apply Solution to the Initial Problem	Review response of the initial (fast) variables under the synthesized slowly changing control	Build solution for the initial system based on aggregation of model solutions	Map the solution back to the initial system

2.Optimization of the shape of the cam driven needles

The needles of the high-speed circular knitting machines often experience fatigue breakage of the needle head, due to high frequency vibration transmitted to the head from the driving point (the cam). The vibration is especially pronounced at a few frequencies of the spectrum, which are called response frequencies. The optimization goal in this case is to minimize the transfer functions (the ratio of the displacement at the driving point, which is the cam, to the displacement at the response point, which is the tip of the needle). The transfer functions are frequency dependent, and in this problem they need to be minimized at the response frequencies.

The known FEA packages can handle dynamics of a system with impulse loading as a general non-stationary problem, producing extensive output for each design iteration. However, these data will give no indication as to the direction for the required design change. Much more productive for the optimization process would be to use analytical solutions for a one DOF system under recurring impulses (δ-functions of amplitude A) at the moments *0, T, 2T, …*. The available software does not allow doing this directly. However, it is possible to determine from the (digitalized) stiffness and mass matrices of the distributed system, generated by the FEA packages, parameters of the equivalent one DOF systems that correspond to the natural modes of the needle, and response frequencies that provide maxima to the transfer functions from the driving point to the head of the needle. Only those natural modes that correspond to frequencies providing maxima to the transfer functions (from the driving point to the head of the needle) need to be selected. Analyzing the analytical solutions (unavailable in FEA) for each one DOF system makes it possible to identify the modes responsible for accumulation of damage at the tip and suppress these modes by design changes (Author, 1995).

In a more formal way, the solution process can be described as follows.

Resonances of the one DOF system with damping β and natural frequency p under periodically recurring impulses (δ-functions of amplitude A at the moments $0, t, 2t, \dots$)

$$\ddot{x} + \beta\dot{x} + p^2 x = \sum_{n=-\infty}^{\infty} A\delta(t - n\tau), \tag{1}$$

where $\tau = 2\pi/\omega$ occur at frequencies $\omega = p/k, k = 1,2,\dots$

There are at least four possible ways to construct an analytical solution of (1); the most compact and computationally effective one was proposed by H. Duffing (Author, 1995). It is based on the condition of periodicity and has the form, in case of zero damping

$$x(t) = \frac{A}{2p}[\cot(p\tau/2)\cos(pt) + \sin(pt)], \quad 0 \le t \le \tau \tag{2}$$

The FEA model of the needle (Figure 1) is essentially a multi-DOF system, with the loading being a periodic function of time. It would be natural to generalize the approach which works well for a one DOF system to the multi-DOF case. In order to do that, the

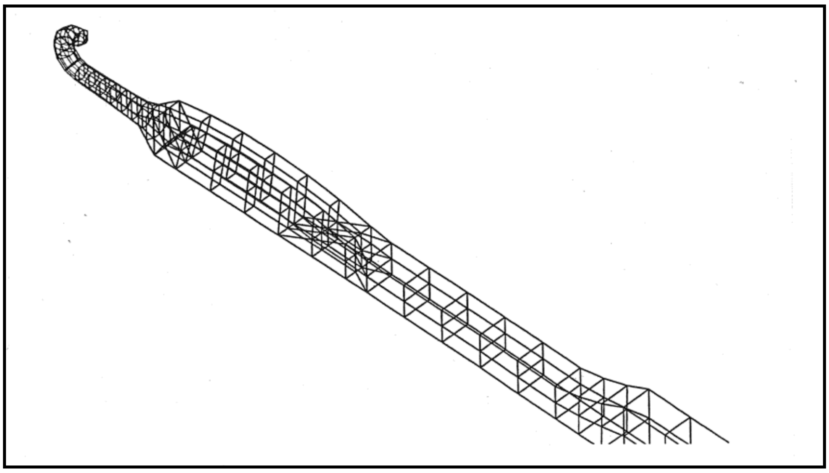


Figure 1. A FEA model of the needle of a high speed knitting machine

Following procedure was developed to estimate the fatigue life of the needle:

1. (a) construction of the direct analytical solution (2) for a one DOF system with damping and periodic non-harmonic excitation;
2. (b) modal analysis of the system by a FEA package (ALGOR, ANSYS, et al), in order to obtain parameters of the respective one DOF systems, corresponding to the response frequencies;
3. (c) superposition of the solutions for the response frequencies and summation of fatigue damage according to a selected hypothesis

This procedure made it possible to obtain stresses in the hook of the needle for the baseline design and determine that the stress level was close to the endurance level. The analysis is illustrated by Figure 2, showing simulated stress history. It is important that only some specified harmonics need to be included in the stress estimates. Use of the analytical solution made it possible to identify those components of the needle that are mostly responsible for the transmission of the respective harmonics. The design of the needle was appropriately modified.

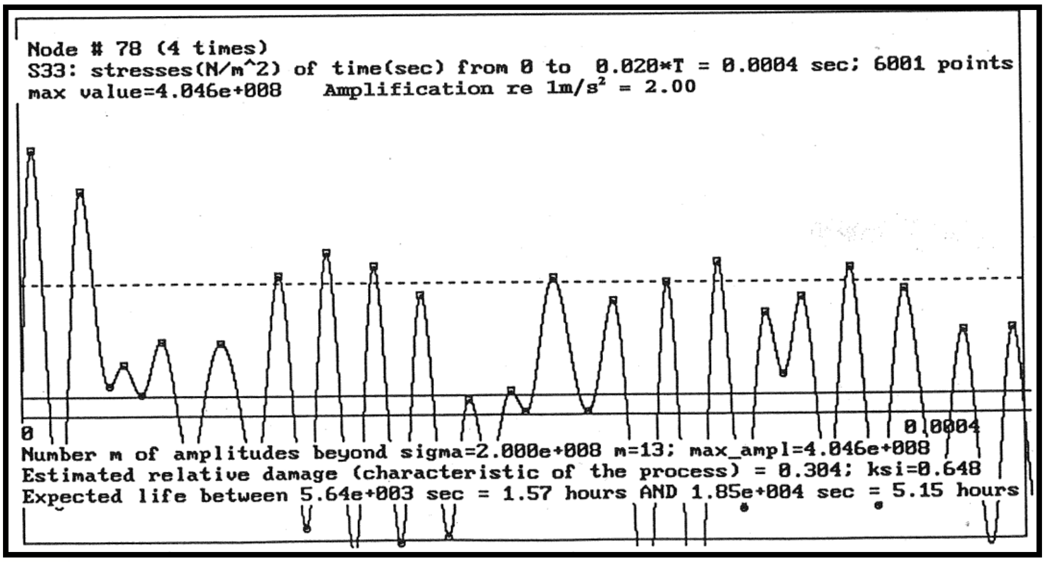


Figure 2. Simulated stress history in one of the node of the hook

3.Optimal control of acceleration of an imbalanced rotor through its critical speed

A more complicated situation arises in the optimization problem for an unbalanced rotor which needs to be sped up through its critical speed (a shaft, or rotor, rotates on a critical speed when rotation frequency of the shaft becomes close to its natural frequency, causing excessive vibrations of the rotary machine). If the operational speed of the rotor is higher than its critical speed, the process of acceleration of the rotor machine to its operational speed often becomes the most critical regime of the machine. In most cases, speeding up is done simply by turning the drive on, with no attempts to influence or control the process. Thus, the acceleration regime determines power requirements (the driving torque is increased in order to speed up the rotor and shorten the time required to pass the critical speed), level of vibration and other major parameters of the rotating machine.

An estimate of the minimum driving torque $u_{\min}$ required to speed up the rotor through the critical speed is known from literature (Gasch et al, 1979). This estimate is obtained under the assumption that the torque is constantly on over the time of acceleration. However, once the driving torque is considered as an available control influence, then the optimization goal can be stated as to minimize power of the drive (or the maximum torque) which is capable to accelerate the rotor above its critical speed.

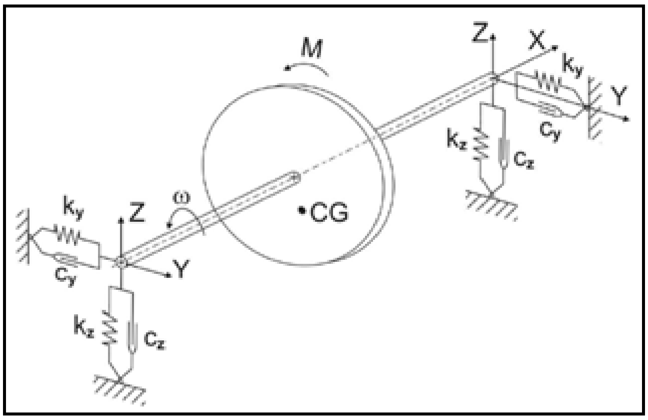


Figure 3. Three DOF Laval rotor. X, Y, Z – coordinate system, c_y, c_z – damping coefficients, k_y, k_z – stiffness coefficients, ω – angular velocity, M – torque, CG – center of gravity

The optimization problem, if based on the initial non-stationary non-linear dynamic equations which describe acceleration of the rotor, is insurmountable for the available numerical algorithms, even for the 3 degrees of freedom Laval rotor (Figure 3) , represented by Equations (3).

However, within the framework of the proposed approach, this problem can be addressed in a sequence of the following steps (Author, 1992):

(a) Make a transition from the initial fast variables in the dynamic Equations (3) to slow variables in Equations (4).

$$\ddot{Z} + 2D\dot{Z} + Z = \cos\varphi,$$

$$\ddot{Y} + 2D\dot{Y} + Y = \sin\varphi, \qquad (3)$$

$$\ddot{\varphi} = u + \mu^2(Y\cos\varphi - Z\sin\varphi),$$

$$\dot{v} = -(1-\omega)w - Dv,$$

$$\dot{w} = -1/2 + (1-\omega)v - Dw, \qquad (4)$$

$$\dot{\omega} = u + \mu^2 w,$$

where $v = A\cos\delta$, $w = A\sin\delta$, $A = \sqrt{Z^2 + Y^2}$, $\tan(\varphi - \delta) = Y / Z$.

In Equations (3), (4) differentiation takes place with respect to dimensionless time $\tau = \Omega t$; $\Omega = \sqrt{k/m}$; k is the stiffness of the shaft; m is the mass of the disk; $Z = z_s/\varepsilon$; $Y = y_s/\varepsilon$; ε is the eccentricity, z_s, y_s are the coordinates and φ is the angular coordinate of the disk's center of mass in a non-moving z, y coordinate system; $D = r/2m\Omega$; r is the external damping coefficient; $u = M/m\kappa^2\Omega^2$; $m = \varepsilon/\kappa$, M is the drive torque, κ is the radius of inertia of the disk.

(b) "Freeze" one of the slow changing variables in the obtained system (4). One can see that the derivative v' is proportional to a small parameter (in the vicinity of the critical speed, 1-ω is small, and damping D is also small). This will result in a linear system (5) for every value of the frozen variable v.

$$\dot{w} = -1/2 + (1-\omega)v - Dw,$$
$$\dot{\omega} = u + \mu^2 w \qquad (5)$$

(c) Build an optimal feedback-based solution for thus obtained linear system (with respect to the variables w, ω). To that end, we shall abandon the assumption that the torque u (or, M) is constant, and attempt to find a law of variation $u = u(t)$ that ensures that the rotor will reach an above-critical speed ($\omega(T) = \omega_T > 1$) at a time T and minimizes a certain functional J (quality criterion) with limitations on the drive torque:

$$u_- \leq u \leq u_+$$

with the focus on the case when $u_+ < u_{min}$, and $u_{min} = 1.3\mu^{4/3}$ is the estimate (for D=0) for the minimum dimensionless constant torque u = const necessary to pass through the critical speed ($\omega_c = 1$) (Gasch et al, 1979).

(d) Apply the solution to the initial non-linear non-stationary system (3) to confirm its workability.

For a real rotor machine, and extra step prior to step (a) would be to diagonalize the system, presenting it as a set of sub-systems each described by Equations (3) for the respective critical frequencies (similar to how it was done in the previous case study for the knitting machines).

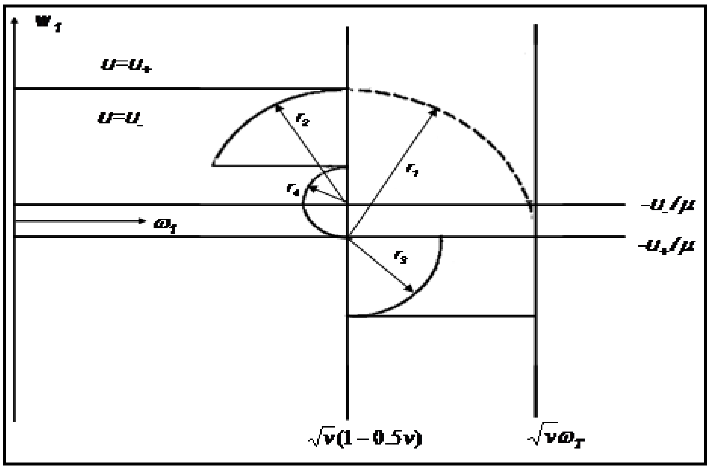


Figure 4. Switching lines in the phase plane of slow variables (ω, *w*)

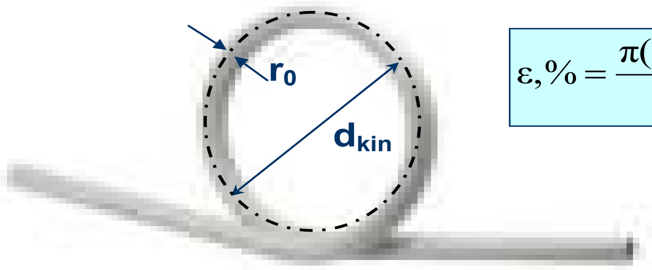
This approach makes it possible to synthesize a feedback-based solution, which can be then applied to the initial (fast) system. The optimal control is of relay (bang-bang) nature, with the driving torque u taking in turn maximum u_{max} and minimum u_{min} values (the drive is on and off). The switching lines in the phase plane of the slow variables (w, ω) are shown in Figure 4. Extensive modeling and experiments (Author, 1992) have confirmed efficiency of such a control system with feedback of a measurable phase coordinate, which ensures acceleration of the rotor at greatly reduced drive torque.

3. Material optimization

Catheters are routinely used to transfer fluids into the body without repeatedly inserting a needle through the skin. In many cases, the catheter must be able to operate in multiple modes, which can present contradictory requirements to the design and material of the catheter. For instance, a peripherally inserted central catheter (PICC) must be able to hold sufficiently high pressure and at the same time be highly flexible to withstand the so-called kink tests.

The first requirement is stipulated by the regime when fluids, which are infused through the catheter, are supplied from a pressurized source. The speed of infusion is important, as faster infusion reduces the time to administer a treatment and the cost of the procedure. Infusing under pressure demands sufficient strength of the catheter.

The second requirement, the kink tests (Figure 5) and related high elasticity of the catheter, reflect operational conditions when the catheter can be folded many times at the arm of the patient.



$$\varepsilon,\% = \frac{\pi(d_{kink} + r_0) - \pi d_{kink}}{\pi(d_{kink} + r_0)} 100$$

Figure 5. Kink deformation of the catheter

Table 2. High elasticity for the kink test is only needed at low deformations

6-4F	Tip		Body	
d_{kink}, *mm*	r_0, *mm*	ε, %	r_0, *mm*	ε, %
6.985	0.673	9	1.00	13
15.24	0.673	4	1.00	6

This leads to contradictory requirements to the design of the catheter, which are usually addressed through multiple material and design iterations that represent a trade off between the two contradictory requirements. However, this problem can be recast as identification of a catheter material with contradictory properties, high elasticity (for the kink tests) and at the same time high strength (for the burst tests). This boils down to identification of a material which meets contradictory requirements to a single characteristic, its stress-deformation curve. The contradiction can be resolved based on the realization that high elasticity (the kink tests) is required at low deformations (Table 2) and high strength (burst tests) at large deformations, therefore, the requirements can be separated in *the space of elastic parameters* of the material (Figure 6). The desired (non-linear) stress-elongation characteristic would represent very elastic material at low deformations, toughening up as the deformations grow. The material with the desired characteristic can be indeed designed, as shown in (Bell et al, 2008; DiCarlo et al, 2007).

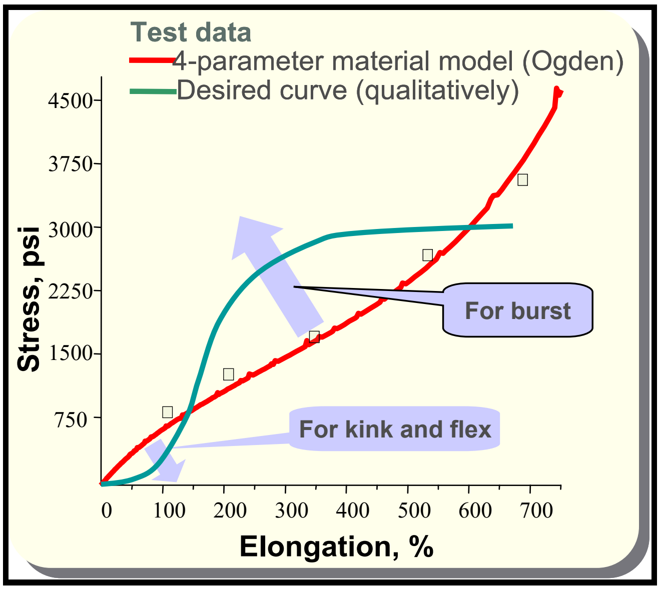


Figure 6. Elastic characteristic of the catheter material: existing material (red curve, 4 parameter Ogden model) and proposed material (green curve)

4. Conclusions

The approach outlined in this article can be summarized as follows: when dealing with a complex engineering problem, construct a simplified subset or sub-system of the initial system having the main features of the initial system but for which an analytical closed form solution can be built or is known. Study how the model solution depends on the parameters of the constructed sub-system. Generalize or back propagate the model solution to the initial system. Conduct computer modeling or direct experiment to validate the solution.

This approach is illustrated by three case studies: optimization of a needle shape, optimal control of rotor acceleration, optimization of material properties of a catheter.

5. Acknowledgements

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The Development of a Device for Draining Floodwater and Incrementing Groundwater or Collected Water Based on TRIZ Contradiction Matrix

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Abstract

Taiwan is often visited by spells of drought and flood, problems which are not in the least helped by global climate change and the greenhouse effect and which adversely affect industrial development in the island. They threaten danger to life and limb and damage to property, and in general impair the quality of life. The related important issues are how to efficiently drain floodwater emanating from rainstorms, reduce land subsidence and increment the reserves of usable water. This research aims to provide a solution by using contradiction matrix (CM) to design a new device to cope with draining such floodwaters, reduce land subsidence, and increment water resources. The method uses CM to identify two inventive principles (IPs): IP22 (harm to benefit) and IP2 (taking out). Moreover, transferring floodwater during a typhoon to water reserves of use against drought is based on a time separated principle. Based on the above principles, the design of the device is innovative. It comprises sets of vertical parallel pipes lowermost and a fence uppermost, separated by a net. It solves the above-mentioned problems and helps achieve the research aim. The device has obtained a Taiwanese patent, and it was awarded the Bronze Medal in the Taipei International Invention Show & Technomart invention contest in September, 2008.

Keywords: contradiction matrix, draining floodwater, increasing water resources, innovative device design, reduce land subsidence.

1. Introduction

Serious land subsidence along the southwest coastal region of Taiwan, caused by pumping groundwater beyond reasonable limits, has been a long term problem. One consequence of the practice is the structural damage caused to buildings in the locations affected. Government has allocated considerable funding to deal with the matter but with no clear signs of amelioration, rather the opposite. Adding to and closely linked to the difficulties are the frequent alternating spells of flooding and drought that Taiwan suffers in the train of global climate change and the

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greenhouse effect, all of which also have a harmful impact on industrial development. As well as the threats to life and limb and the damage to property there is a general deleterious effect on the quality of life. The important issues relating to this problem are how to efficiently drain floodwater resulting from rainstorms, reduce land subsidence and increment usable water resources.

Groundwater accumulates from rainfall filtering through the soil surface over the long term, the essential nature of the process being that it is continuous and gradual. Imprudent excesses of pumping groundwater have harmful consequences that are not easily or quickly remedied. Extraction beyond reasonable limits can lead directly to land subsidence with damage to built structures. The main method of countering such threats is to increment groundwater by recharge. At the same time, because of flood and drought spells, measures must also be taken to efficiently drain floodwaters and increment reserves of usable water. Hence, the aim of this study is to address these three issues together by presenting a device that uses the CM (contradiction matrix) method to drain flood water and to increment groundwater or the collected usable water reserves.

2. Literature Review

2.1 Flooding

Recent decades of intense economic development and demographic change have made Taiwan one of world's most densely populated areas. Urbanization increases the extent of impermeable paving, which is an important causal factor in flooding. Because the plains area occupies only a quarter of Taiwan's surface, there is a scarcity of land suitable for development and a consequent pressure to expand into hilly areas. But, not enough consideration has been given to water conservation work on hillsides and as a result there has been considerable run-off of water and soil that has placed strains, at times overload, on flood drainage structures (Tsai and Chang, 2004).

According to official hydrology data, the density of a 2-hour period of rainfall in Taiwan is the highest in the world, as is the regional ratio of daily rainfall in excess of 1000 mm (Water Resource Agency, Taiwan Ministry of Economic Affairs, 1996). Despite these special conditions, the design of drainage capacity in Taiwan cities is almost the same as that found in cities elsewhere that do not face such conditions. Moreover, land subsidence and flooding during typhoons restricts industrial and commercial development and threatens life and property. Added to that, Taiwan like the rest of the world has its share of problems arising from global climate change and the greenhouse effect, namely heat waves, flooding, drought, and windstorms (Lin, 1999).

2.2 Drought

Global climate change brings not only extremes of water excess in the shape of rainstorms but also extremes of water shortage. Taiwan experiences frequent, damaging spells of drought. A typhoon might well produce a large amount of water, but water that is not usable if it is polluted by soil. In Taoyuan, for example, a growing population means a growing demand for water, but Typhoon Aere in 2004 was followed by 21 days of drastic water shortage in that city, during which performance for 350 companies was badly affected, to the tune of 43 hundred million NTD.

2.3 TRIZ (Theory of Inventive Problem Solving)

Genrich Altshuler (1926~1998) developed the Theory of Inventive Problem Solving (TIPS/TRIZ) including CM and 40 Inventive Principles (IP). TRIZ is a problem-solving method that can be used to analyze problems, find contradictions, and then offer solutions. CM is the tool of frequent use.

Systematic contradiction solving is frequently employed by engineers to deal with engineering problems. While one Engineering Parameter (EP) may provide a beneficial result, that is, an improvement, another may provide an adverse result, that is, a worsening. TRIZ can help solve the problem of systematic contradictions. The first step is to locate the contradictions in the system. The second is to identify the corresponding Altshuller EP. The third and final one is to use CM to identify the corresponding IP with which to solve the problem (Mann, 2007).

(1) Engineering Parameter

Altshuller compiles a list of 39 frequently occurring systematic characteristics in technology. He terms them Engineering Parameters (EPs) and notes that some may contradict one another (Domb et al., 1998). One purposeful use of EPs is to transform real engineering design contradictions into general or standard technology contradictions.

(2) Inventive Principle

There are 40 IPs used to solve similar contradiction problems repeatedly in different time periods, backgrounds, and fields (Joglekar, 2007; Retseptor, 2008a; Retseptor, 2008b).

(3) Contradiction Matrix

CM is a 40-row multiple 40-column matrix. The procedure for its application is as follows: First, identify which EP worsens a product or process and which improves it. Then, find the corresponding EP numbers in the row and column. Finally, find the intersecting matrix elements in the corresponding row and column. These elements give the numbers of the recommend IPs. For example, Figure 1 shows that the EP that improves is 2 (Weight of stationary object), while the one that worsens is 39 (Productivity). So, find the intersecting matrix element in corresponding row 2 and column 39. This gives 1, 28, 15, and 35, which are the numbers of the recommended IPs.

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Parameter that Improve \ Parameter that Worsen	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		

Suggested Inventive Principles

Figure 1. Contradiction Matrix.

3. Selection of Inventive Principles for an Innovative Device to Drain Floodwater and Increase Groundwater or Collected Water

Groundwater accumulates from rainfall filtering through the soil surface over the long term. The EPs of this research are as follows:

(1) The parameter of improvement is EP30 (Harmful factors acting on an object). Flooding brings into a location a large amount of water that threatens life and property.
(2) In situation 1, the parameter of impairment is EP22 (Waste of energy): draining the floodwater requires a motor to pump, which is an undesired waste of energy. In situation 2, the parameter of impairment is EP23 (Waste of substance): draining the floodwater is an undesired waste of substance.

Table 1 shows the IPs selected by CM. Table 2 indicates that situation 1 uses CM to identify IP22 (harm to benefit); in this situation, a great amount of water is transferred underground to charge the groundwater and thus reduce the likelihood of land subsidence, an overall benefit to the location. Situation 2 uses CM to identify IP 2 (taking out), by which the surface floodwater is taken out and used to form groundwater.

Table 1. Device's Inventive Principles Selected by Contradiction Matrix

Parameter that Improve \ Parameter that Worsen		EP22	EP23
		Waste of energy	Waste of substance
EP 30	Harmful factors acting on object	21,22, 35,2	33,22 19,40

Table 2. The device's selected Inventive Principles for Draining floodwater and Incrementing Groundwater or Collected Water

Improve demand	Design principle	Corresponding solution
EP30 Harmful factors acting on object	IP22 Harm to benefit IP2 Taking out	Transfer harm (ground level floodwater) to benefit (underground groundwater)

The following describes the design concept. In situations 1 and 2, this research identified IP22 (harm to benefit) and IP2 (taking out). The design of the device based on the above principles is innovative. Its threefold aim and function is to drain floodwater, increment groundwater [and thus by incrementing groundwater, reduce subsidence] and increment reserves of collected water. Draining floodwater takes water out of the system. Draining floodwater into soil increments groundwater and thus reduces subsidence, which is to say that harm is exchanged for benefit. An equal exchange of harm for benefit also occurs when floodwater is drained into soil and thus increments the reserves of collected water.

4. Designing an Innovative Device for Draining Floodwater and Incrementing Groundwater or Collected Water

The device is designed in two versions of the basic unit: a primary structure and a box structure. Given the versions, there are four types of application: (I) a structure used at ground level with plants; (II) a structure used on pavement; (III) a structure used for watershed (in an area for water collection); and (IV) a structure used on rooftops with plants. The details are explained in the following sections.

4.1 Basic structure unit

Primary Structure Unit

Figure 2 shows the primary structure of the device. This comprises a large number of vertical parallel pipes lowermost with a fence uppermost, separated by a layer of net. The device can be installed in the ground for the purpose of draining floodwater and incrementing either or both groundwater and collected water. The sets of hollow pipes is placed in a suitably large excavation in the ground and covered with the separating net and fence. The soil layer spread above the fence forms the ground surface. As surface water filters through the soil layer it can quickly escape, reach and flow through the vertical pipes, which is the main function of the device.

Box Structure

Figure 3 shows that this version of the device is constructed as an all-in-one box structure. This structure comprises a set of vertical rectangular hollows, a fence above those, and an intervening layer of net. This structure helps water flow through the provided hollows, and at the base of the box structure there is a side channel that directs the flow into the local drainage system.

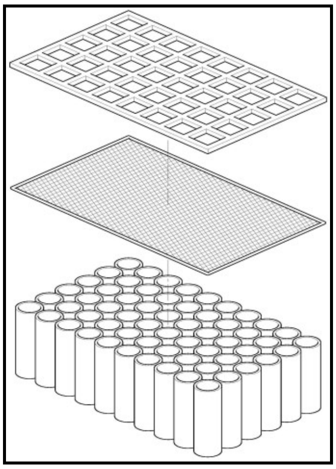

Figure 2. Primary structure

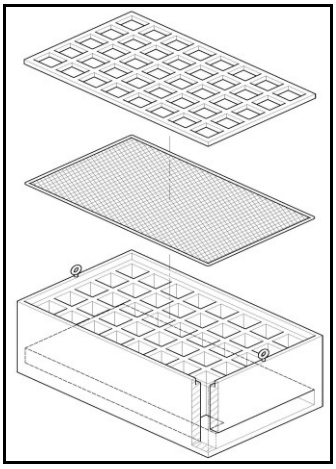

Figure 3. Box structure

Installing the Structure Below Ground

Figure 4 shows how to install the structure below ground. The first step is to excavate a hole in the ground big enough to take the vertical parallel pipes. Second, place the pipes in the hole. Third, a separating net is placed above the pipes and above that a fence. Finally, a layer of soil is spread above the fence, and leveled to form the ground surface. In this way, collecting water is made easy. Vegetation can be planted in surface soil as desired. When surface water filters through the soil, it can easily flow through the fence and separating net to reach the vertical pipes, and then quickly downwards to reach deeper soil levels. Floodwater is thus drained and groundwater incremented.

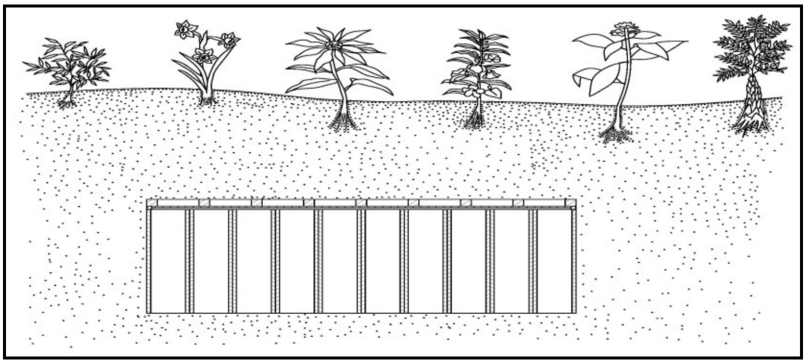

Figure 4. Installing the structure below ground

4.2 Application types

Type I: a structure used at ground level with plants

Figure 4 shows a structure installed in a single place while Figure 5 shows a structure in a continuous ground space with plants. First, excavate a suitably sized space to take one or more structures (No. 6 in Figure 5). Second, place the required numbers of structures side by side in the excavation to form a water flow path. Then spread and level the required layer of soil (No.4 in Figure 5) above the structures. Finally, plant the surface soil layer with vegetation as desired

(No.5 in Figure 5). When rainfall reaches the surface above the structures, most of the water will flow through the plants and into the fence (No.3 in Figure 5) and separating net (No.2 in Figure 5). It will next flow into the vertical parallel pipes (No.62 in Figure 5) of the structures and penetrate from there rapidly to deeper soil (No.44 in Figure 5). In this way, the groundwater under the continuous ground space is incremented. The increment in continuous ground space is much more than in any single place.

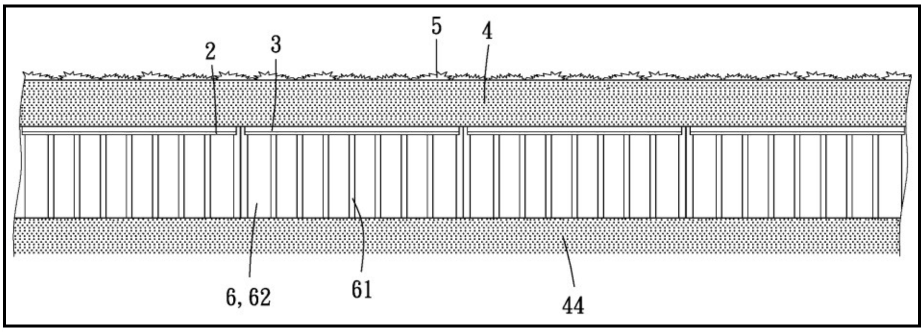

Figure 5. Type I: Structure used at ground level with plants

Type II: a structure used on paving

Water accumulation on a footpath is usually avoided by laying down a layer of gravel on the surface. Figure 6 shows the pavement structure for such as a scenic area footpath. First, excavate a suitably sized space to take one or more of the device structures (No. 6 in Figure 6). Second, install a suitable number of structures side by side into the excavation to form a water flow path. Spread a layer of soil (No.4 in Figure 6) above the structures and level off. Finally, add the gravel layer (No. 41 in Figure 6) above the continuous structure. The rainfall gathers in the excavated space above the structure, with most of the water flowing through the gravel and then into the fence (No.3 in Figure 6) and the separating net (No.2 in Figure 6). It then flows into the vertical parallel pipes (No.62 in Figure 6) of the structure and is carried rapidly downwards to the deeper soil (No.44 in Figure 6) below the pipes. In this way, groundwater is incremented in continuous ground space. The increment in continuous ground space is much greater than in any single place.

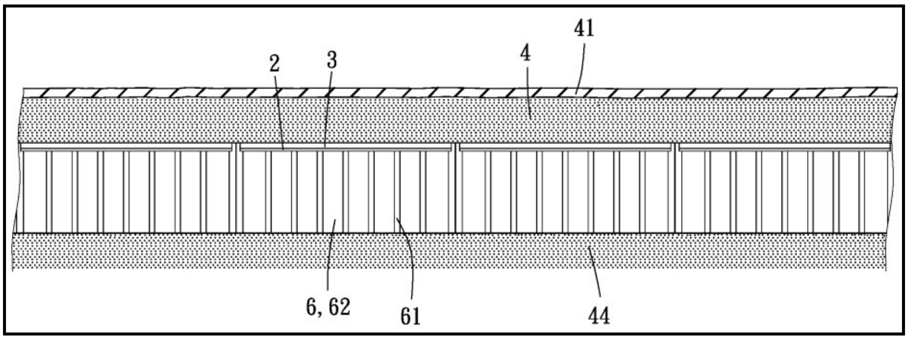

Figure 6. Type II: Structure used on pavement

Type III: a structure used for watershed (an area for water collection)

Figure 7 shows a structure constructed on a watershed in continuous ground space. A side channel (No. 64 in Figure 7) is established at the base of the box structure (No.6 in Figure 7).

This channel collects the water flowing from the vertical parallel pipes (No. 62 in Figure 7). The structure is installed near an area for water collection, such as a reservoir or pool, so the water flow is directed to the watershed. A layer of soil (No. 4 in Figure 7) is spread above the structure and leveled. When the rainfall reaches the surface above the structure, most of the water flows into the fence (No.3 in Figure 7) and separating net (No.2 in Figure 7). It then flows into the vertical parallel pipes of the structure, and from there is quickly carried via the side channel towards the watershed. In this way, the amount of usable water in the continuous ground space is incremented.

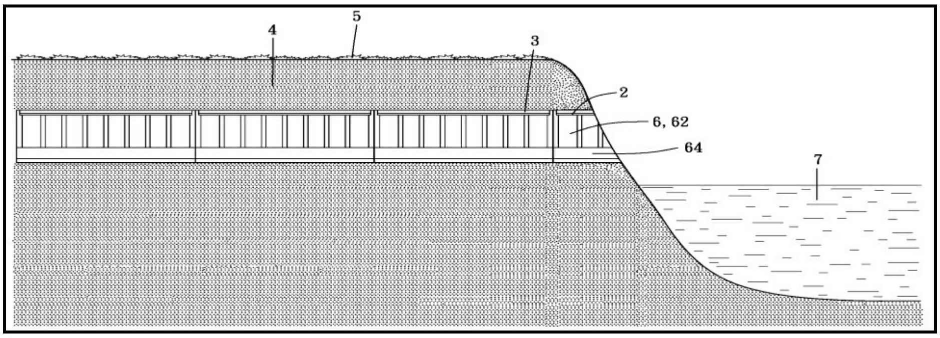

Figure 7. Type III: Structure used for watershed

Type IV: a structure used on rooftop with plants

Here the device can be used not only on the ground, but also on buildings. For example, it can be installed on a rooftop or balcony, or in a parking lot. Fig. 8 shows a rooftop structure (No.81 in Figure 8) with plants in a continuous space – on a concrete surface (No.8 in Figure 8). Soil (No.4 in Figure 8) is spread above the structure and the desired vegetation (No.5 in Figure 8) planted. A side channel (No. 64 in Figure 8) established at the base of the box structure (No.6 in Figure 8) is connected to the drain pipes (No.82 in Figure 8) of the buildings which in turn are connected to a collection space, such as a tank or pool. When rainfall reaches the surface of the space above the structure, it filters through the soil and then flows through the fence and separating net to reach the vertical parallel pipes. From there, it flows into the side channel and drain pipes, and then to the collection space. In this way, usable water resources are incremented in continuous ground space and possible mishaps of slipping on wet concrete floors are averted.

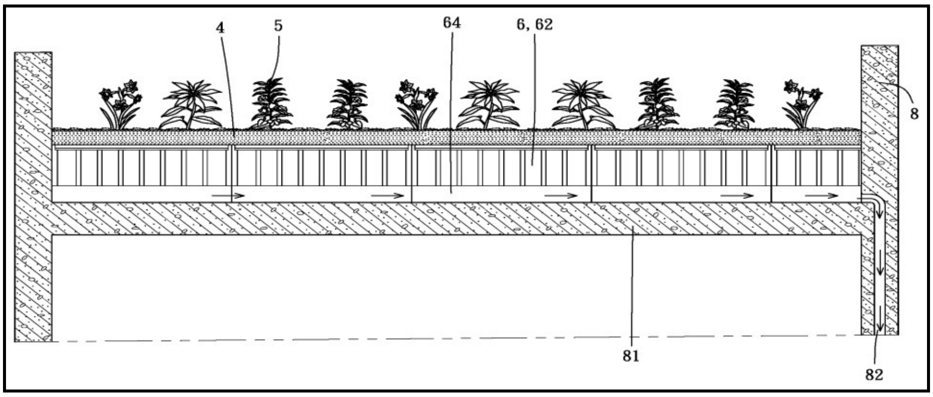

Figure 8. Type IV: Structure used on rooftop with plants

5. Conclusions and Suggestions

The device gained a Taiwanese patent and has featured in many exhibitions. It was also awarded the Bronze Medal at the Taipei International Invention Show & Technomart invention contest in September, 2008.

This research used contradiction matrix (CM) to identify two IPs (inventive principle): IP22 (harm to benefit) and IP2 (taking out), which were instrumental in designing the device for controlling the draining of rainstorm floodwater, for incrementing groundwater, thereby reducing land subsidence, and for incrementing reserves of collected water.

Situation 1 used CM to find IP22 (harm to benefit); effective in transferring large amounts of water (surface flooding) to below ground, i.e., in incrementing groundwater and thereby reducing land subsidence, and thus transforming harm (flood) into benefit (groundwater) in the region. Situation 2 used CM to find IP2 (taking out): effective in using surface floodwater to increment groundwater. In addition, transferring floodwater during a typhoon into water reserves against a spell of drought is based on a time separated principle.

The aim of this research has been to employ the IPs obtained from CM to design the device. It comprises sets of vertical parallel pipes lowermost and a fence uppermost, separated by a net. There are two versions of the structure: a primary structure and a box structure. These can be used in four ways: (I) ground–level structure with plants; (II) structure on paving; (III) structure for a watershed (for water collection); and (IV) rooftop structure with plants.

The research demonstrates that TRIZ can help solve systematic contradiction problems in engineering. It is altogether likely that other researchers will find it useful for designing devices to solve problems in quite different fields.

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