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Forward & Executive Report

The organizers of the International Conference on Systematic Innovation (ICSI) and Global Competition on Systematic Innovation (GCSI) are pleased to present the proceedings of the conference and the Program of Innovative Project Exhibition which includes 46 papers and 10 finalist innovation projects.

This conference is co-organized by International Society of Innovation Methods (I-SIM), Society of Systematic Innovation (SSI), National Tsing Hua University, and the Journal of Systematic Innovation (IJoSI). Whether the papers included in the proceedings are work-in-progress or finished products, the conference and proceedings offer the authors opportunities to disseminate the results of their research and receive early feedback from colleagues, without the long waiting associated with publication in peer-reviewed journals. On the other hand, the presentations and the proceedings do not preclude the option of submitting the work in an extended and finished form for publication in any peer-reviewed journal. Best papers and projects from the conference will be invited to submit full papers to either IJoSI (SCOPUS indexed) or Computers and Industrial Engineering (SCI indexed) for review toward publication.

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

The conference is a leading SI/TRIZ international conferences in the world in the field of innovation methods and typically has one of the best quality programs. The next ICSI conference will be in the University of Liverpool, Liverpool, United Kingdom. Liverpool is an important center for culture not just for the United Kingdom but also for Europe. It has been recognized as the European Capital of Culture well known for music, histories, arts, and tourism. There will also be the tradition of free one day scenic tours immediate before the conference for international participants. You are invited to continue joining the 2019 ICSI/GCSI events tentatively during July 8-11, 2019.

We are confident that you will find this conference very rewarding. If there is anything needing assistance, please feel free to let the attendant(s) at the service desk know. We are here to serve you.

With best regards,

D. Daniel Sheu, General Chair, the 2018 ICSI/GCSI
Professor, National Tsing Hua University, Taiwan, R.O.C.
President, International Society of Innovation Methods
Honorary President, Society of Systematic Innovation
Editor-in-Chief, the International Journal of Systematic Innovation (IJoSI)
Area Editor, Engineering Design and Innovation Methods, Computers and Industrial Engineering
2018.07.18

Paper List

Part 1. Full Papers in English

Part 2. Full Chinese Papers Preceded by English Title and Abstract

Comparison of two algorithms, ARIZ-85C and a new practical algorithm(ADRIGE)

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Abstract

ARIZ algorithm begins with a Technical Contradiction(TC) and help us to find creative solutions. And then it also helps us to concentrate just one TC, so we can see more detail about problem. Therefore, it makes us to find solution which is usually we can't think about it. And we called this is creative solutions. But, ARIZ algorithm concentrate just one thing, so we can't get diversity of solutions. In our group, we introduce new practical algorithm for overcome that disadvantage. We called "ADRIGE" which consist of Analysis, Define, Resource, IFR, Generate, Evaluate. In this algorithm, especially Analysis part most different from ARIZ. This part has more diversity of problems, that bring to many Defines, IFRs and Generates. In this paper, we show example of practical problem and proceed two algorithms to solve the problem. And then, we compare with two algorithms to show something which is what is different about ADRIGE and why we recommend it. The results of this paper will give a general understanding of the solutions to the ARIZ and ADRIGE issues and demonstrate the usefulness of ADRIGE in industrial field cases for substantial profit. However, since the ADRIGE algorithm is not yet generalized and the number of problem cases applied is limited, solutions to the ARIZ and ADRIGE problems need to be generalized through various cases in the future.

Keywords: ADRIGE algorithm, New algorithm, ARIZ-85C

1. Introduction

1.1 ARIZ

ARIZ process consists of nine parts and 40 steps including Problem analysis, Problem model analysis, IFR, Physical Contradiction(PC) definition, Su-Field and knowledge information data use.(1)

The ARIZ problem algorithm defines initial Technical Contradiction(TC) and draws a PC based on it. During the process, a small person model may be used and solutions may be derived through Effects or Standard solution.

Key points of ARIZ is to derive PC by deepening TC and deriving a solution through principle of Separation. It is a creative thinking process that enables users to think deeply about one problem and helps our to make creative solution.

1.2 ADRIGE

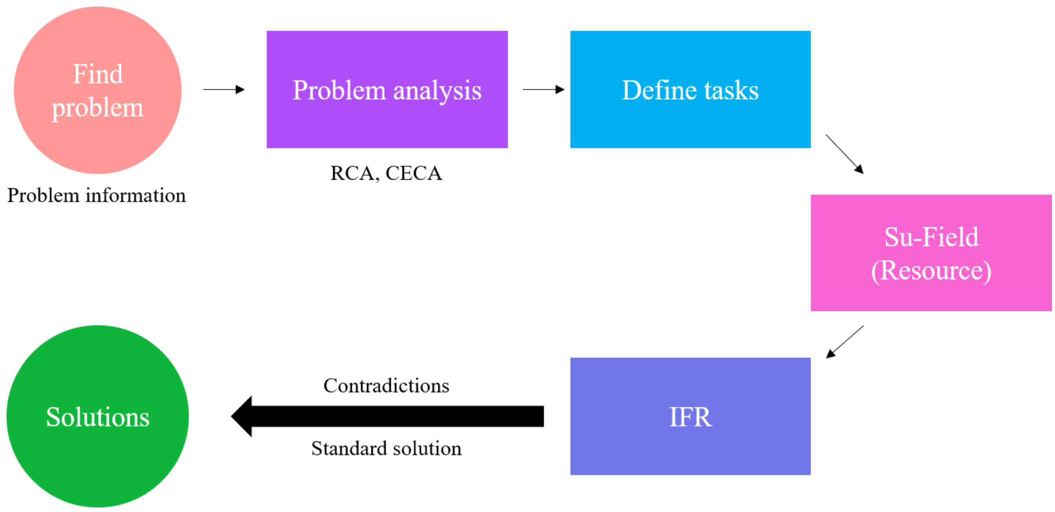

Fig 1. Schematic Diagram of ADRIGE Analysis method

ADRIGE algorithm is one of the creative thinking process that has problem Analysis, Define, Resource analysis, IFR, Generate solutions and Evaluate process. In the process, It has Functional analysis, Cause analysis(CECA·RCA), TC·PC definition, IFR and contradiction solution.

ADRIGE analysis defines various Operating zones(OZs) and Operating time(OT) in the process. This is that ADRIGE reveals a big difference from ARIZ which is focus on one technical contradiction. Therefore, the ADRIGE algorithm has characteristics of diversity and efficiency in whole process. With these characteristics, the ADRIGE algorithm can adopt very well as an ideal problem-solving process for industrial problem cases.

2. Main Subject

2.1 Present industrial problem case for comparison

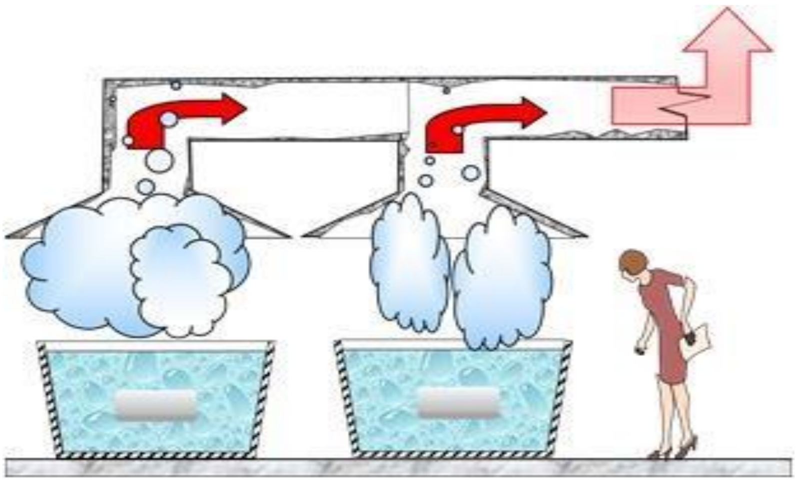

Fig 2. Issue of production trouble caused by replacing ventilation pipe

① Fig 2 shows acid treatment process in industrial site.

② During the acid treatment, generated acid vapor pass through a hood.

③ The acid vapor accelerates the corrosion of the hood.

④ Raising the acid treatment temperature improves productivity, but it accelerates corrosion of the hood, causing the hood to be replaced, which lowers operation rate.

⑤ When the acid treatment temperature is lowered, replacement frequency of hood is lowered and operation rate is increased, but efficiency of the acid treatment is lowered and productivity of the product is lowered.

2.2 ARIZ analysis applied to actual industrial site case

2.2.1. Part 1. Problem Analysis

In problem analysis process as ARIZ Part 1, the process consists of identifying problem factors, selecting Objects and Tools and deriving two TCs. (1)

In our example, system elements, Objects and Tools were selected as follows. Table 1. Identifying Problem factors associated with Industrial case

Components	Heater, Bath, Acid solution(Acid vapor), air, Acid-treated metal, hood, pump
Objects	Hood, Acid-treated metal
Tools	Acid solution(Acid vapor)

Especially, selection of Objects and Tools followed the ARIZ rules proposed by Altshuller and selected Objects and Tools are the criteria for selecting two TCs in the next step. (1)

TC-1: When the temperature of the acid solution**(Tool)** is high, productivity is also high, but operation rate of the production system be dropped due to replacement of the hood**(Object)**.

TC-2: When the temperature of the acid solution**(Tool)** is lowered, operation rate is high, but productivity of the acid-treated metal**(Object)** is lowered.

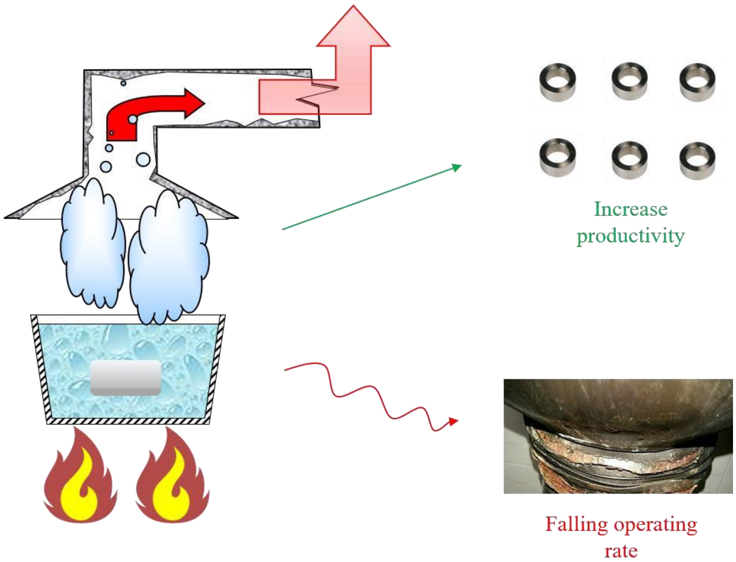

Fig 3. Illustration of selected Technical Contradiction(TC-1)

TC selection must be made in accordance with basic functions of the system.(1) TC-1 is selected as a TC because the basic function of the system in this case is productivity. The selected TC-1 be emphasized that "Acid treatment temperature is very high, acid treatment occurs very quickly, but the hood is corroded quickly". And then, problem analysis situation was defined comprehensively during process of defining problem model.

① Contradiction pairs: Tools - Acid solution (acid vapor) / Objects - Hood, Metal

② Definition of TC: If temperature of the acid solution is very high, acid treatment takes place very well but the hood is corroded quickly.

③ Condition of X-element(1): Maintain acid treatment efficiency / suppress corrosion of hood.

Finally, in the ARIZ problem analysis process, following solution could be derived by applying 1st Standard solution.

Solution: Install a device to block air flow between the hood and acid vapor.

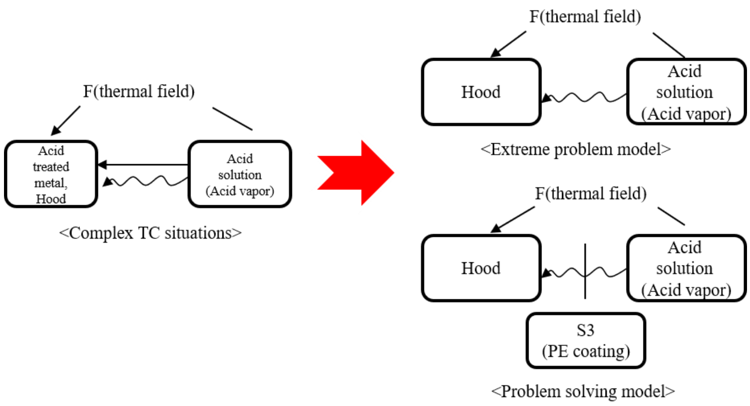

Fig 4. Su-Field using the 1st Standard solution

2.2.2. Part 2. Problem model analysis

ARIZ Part 2 covers OZ and OT selection and resource analysis.(1) In case of the industrial site presented in this paper, OZ and OT were selected based on the Object and Tool selected in Part 1 as follows.

OZ: Point where the acid solution (vapor, Tool) and hood(Object) contact.

OT: Time in contact with acid solution (vapor, Tool) and hood(Object).

OZ, OT are standard for determining internal system. The resources in the internal system, external system, and upper system are obtained through the Resource analysis. It is to select the X-element inside the resources.(1)

Table 2. Resources and Hidden resources obtained through Resource analysis

Position	Resources	Hidden resources
Internal system	Hood(Object)	surface morphology, Alloys, thickness
	Acid solution(Acid vapor,Tool)	Compositions, Vaporization temp.
External system	Air	Compositions of air
Upper system	Bath Heater Pump	Compositions of bath Heating temp. Volume/sec

2.2.3. Part 3. Definition of IFR and Physical Contradiction

In Part 3 of ARIZ, based on the data in Part 2, it follows procedures such as X-factor determination, IFR-1 definition and deepening it.(1)

The X-factor was selected using the Resource analysis table presented in Part 2. In the ARIZ algorithm, it is recommend to select X-elements in order of system inside, outside of system, and higher system.(1) In this paper, the acid solution (acid vapor, Tool) as the internal system is selected as the X-element, and IFR-1 is defined through the selected X-element.

IFR-1: During the time that acid vapor is in contact with hood(OT), acid vapor must be able to remove the corrosion of the hood(remove negative effects) and maintain the acid treatment capacity of the acid vapor (maintain positive effects).

At this moment, deepening IFR-1 means that prohibit introduction of new resources and only use the analyzed resources.(1) The following macroscopic and microscopic PC are defined in accordance with ARIZ rules.(1)

PC at macroscopic Level: The acid vapor(Tool) must have a high temperature to increase the acid treatment rate during the time that contact between the acid vapor and hood(OT). In order to eliminate hood corrosion, acid vapor must have low temperature.

PC at microscopic level: The particles of acid vapor(Tool) must be able to move rapidly to have a high temperature during the contact time between the acid vapor and hood(OT). For low temperature of acid vapor, particles must move slowly.

Based on the microscopic PC defined above, IFR-2 could be defined as follows.

IFR-2: Acid vapor particles must perform a rapid movement in order to speed up the acid treatment by themselves during the contact time between the acid vapor and hood. Also, the acid vapor particles must perform a slow movement in order to eliminate hood's corrosion.

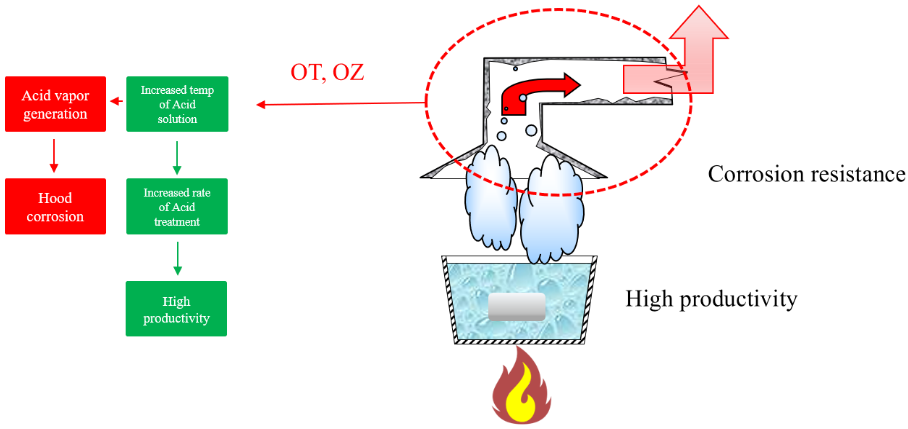

Fig. 5 Schematic Diagram of IFR-2

Derived IFR-2 is the result of the PC from the initial TC. And then, a solution can be obtained by applying a second-order standard solution, or a solution can be obtained by applying principle of separation.(1)

Solution: Connect device to cool the hood surface and reduce kinetic energy of acid particles on the surface.

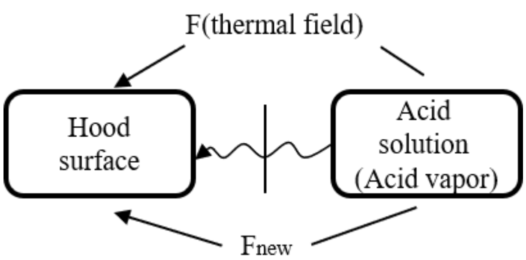

Fig. 6 Su-Field using 2nd standard solution

2.3. ADRIGE analysis applied to actual industrial site case

2.3.1. Part 1. Analysis

ADRIGE algorithm consists of Cause analysis, Definition, Resource, IFR, Generate solutions, Evaluation of solutions.(2,3)

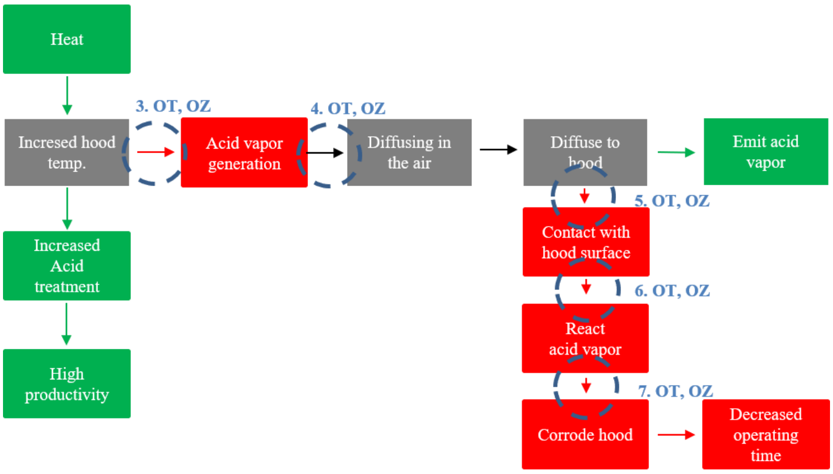

Fig. 7 CECA analysis in Industrial problem cases

In CECA analysis, OT and OZ can be selected at various points as shown Fig. 7. This is a big difference of the ADRIGE algorithm when compared with ARIZ analysis process, and it can take advantage of diversity of final solution.

2.3.2. Part 2. Defining task (Define)

When defining tasks, we derive TCs and PCs based on CECA analysis. In addition, we define various tasks using OZ and OT derived at this process.(2,3)

Task 1: Find ways to improve productivity without heating.

Task 2: Resolve the PC of temperature.

Task 3: Find methods to avoid acid vapor even though there is a PC in temperature.

Task 4: Find methods that does not diffuse even when acid vapor is generated.

Task 5: Find methods that the acid vapor and hood surface do not react even when those contact each other.

Task 6: Find methods that the acid vapor and hood surface do not react even when those reach the hood surface.

Task 7: Find methods to avoid corrosion when the acid vapor and hood surface react.

2.3.3 Part3 Resource Discovery (Resource)

Table 3. Materials and MATCEM using Resource analysis

Position	Materials	MATCEM·Properties
System	Hood(Object)	Thermal, Chemical, Nano field
	Acid solution (Acid vapor)	Chemical, Thermal field
	Air	Thermal, Mechanical, Nano field
	Heated bath	Thermal, Mechanical, Chemical field
	Heater	Thermal field
	Pump	Mechanical field
Circumstance Upper system	Hot or Cold air	High, low energy
	Another solution	Oil
	Another Heating system	Electromagnetic wave heating system

Once the tasks are defined, resources are analyzed based on the OZs and in terms of time, space, material and field.(2,3)

2.3.4. Part 4-5. Ideal Solution (IFR) and Generate

In each of the seven tasks obtained from Definition process, We applied to the Standard solution at each task and problem of the PC is applied to the principle of separation.(2,3) And then, ideal solution and ideas were derived.

Task 2 Solution: Use the principle of separation which is space separation. For accelerate the process, We have to maintain high temperature at the surface of metal parts because of cleaning. Therefore, We had heated the metal parts firstly and placed in the acid solution after. And the acid solution is cooled to prevent diffusing acid gas.

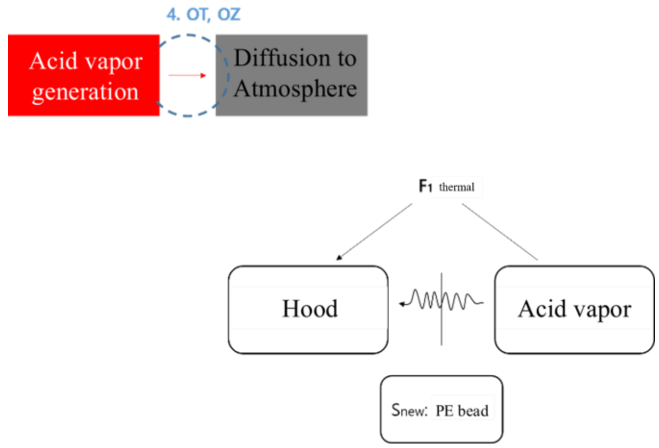

Fig. 8 The Rule 3 in Su-Field was applied to Task 4

Task 4 Solution: PE does not dissolved in acid solution. If you make a small bead of PE and cover it on the surface of solution, the diffusing acid gas will not be blown out and be liquefied in the bath.

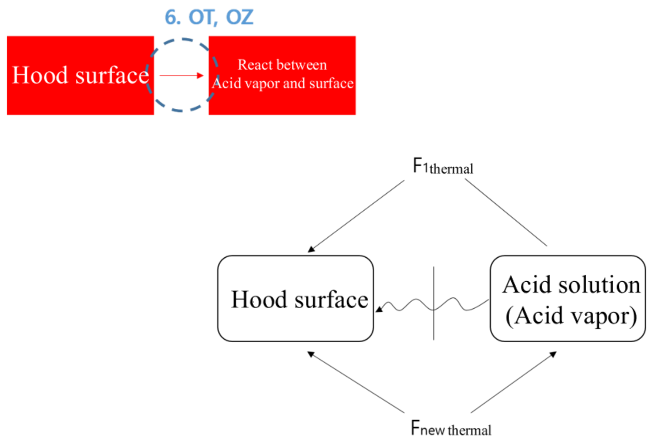

Fig. 9 The Rule 4 in Su-Field was applied to Task 6

Task 6 Solution: Connect the device to cool the hood surface and reduce the activation energy of the acid vapor on the surface.

The ADRIGE algorithm is able to derive various solutions in each task. After then, the final solution is derived and evaluated.(2,3) Needers can be changed according to each task and IFR, solution can be presented according to the Needers. There is an advantage in that a solution suitable for each connected the Needers in a single system can be derived.

3. Conclusion

In this paper, we apply the ARIZ and ADRIGE algorithms to industrial site case, respectively. In the case of the ARIZ algorithm, we could derive a creative solution by starting from a TC and deriving one PC. The characteristics of ARIZ are effective in areas requiring creative solutions, but it will be difficult to maximize positive effects in industrial site which seek efficiency and diversity. On the other hand, ADRIGE showed the biggest difference from ARIZ algorithm in problem analysis. In particular, the selection of various OZs and OTs through CECA analysis provided a good basis for selecting various tasks in the industrial site. Depending on the industrial environment of the company seeking efficiency and diversity, it is believed that not only the commonly used ARIZ but also the ADRIGE algorithm can be applied to many fields and sites.

4. Acknowledgements

This paper has been completed with the help of the National Research Foundation of Korea(NRF). Thank you for help in making this paper.

5. Reference

(1) Altsuller, 2003, Nalczi Ideyu(Russian), Scandinavia.

(2) Y. W. Song, Creative Problem Solving Theory TRIZ, Korea Standards Association Media, 2017.

(3) Y. W. Song, Creativity Technology, Tharnest Media, 2014.

Application example of TRIZ analytical tools to R&D process

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Abstract

In research activities, researchers select a task and build a hypothesis to solve it. The results of the experiment are measured and analyzed to confirm the validity of the hypothesis. And if unexpected results occur, a new study plan should be developed depending on the analysis results of the cause. This process is repeated until the researcher reaches the ideal goal but most researchers undergo many trial and errors in this process.

The result of the analysis is an important indicator of how to set up the next experimental conditions. However, if the researcher analyzes the experimental results without a systematic analysis tool, the results are limited to the researcher's expertise and experience. Therefore, systematic analytical method plays important role in R&D activities.

This paper shows a case of applying TRIZ analysis tool to R & D and suggests a method to perform systematic research. We used Substance-Field Analysis (Su-Field Analysis) and Standard - Solutions to make initial hypotheses. And we Small-Person Models Method were used to identifying phenomenon occurring during the experiment. After the exact cause of the experiment was identified, we a new plan was established using the Standard-Solution.

Keywords: Small People Model, Su-Field Analysis, Standard Solution

1. Introduction

TRIZ is a creative problem-solving theory. It is developed based on the rules and principles of problem-solving from patents and provides effective tools to elicit an ideal solution and improve creative problem- solving skills. Many companies such as Samsung, LG, SK Hynix, Hyundai Motor, Intel, BMW, Ford, Philips, and Panasonic have adopted the TRIZ methodology as a problem-solving tool. TRIZ application areas have been expanding widely and engineers have shown numerous TRIZ success cases in improving the production process and solving technical problems. However, there are few reports of TRIZ application in the process of research and development, even though TRIZ may help the researchers to understand physical phenomena by using TRIZ analytical tools and to make experimental plans for the ideal result.

R&D process in a non-pioneering field is accompanied with many undiscovered and unknown phenomena. Researchers participating in R & D should accurately analyze and understand the experimental results. Research and Development is the process of solving different types of problems; (1) Establish a hypothesis (2) Set up an experimental plan to prove the hypothesis. Then, execute. (3) Measurement and analysis of experimental results. (4) A new hypothesis is set up based on the analysis of the unexpected result. (5) A new experimental plan is set up and (6) the previous steps [(1)-(5)] are repeated until the hypothesis is proved right.

In the analytical process of experimental results, we need to establish proper hypotheses to understand physical phenomena and conduct next experiments to prove if the hypotheses are right. The process of establishing a hypothesis and proving it is continued until we understand the exact physical phenomenon. In this R&D process, researchers should be very objective and be able to accurately analyze the results and to make a hypothesis for the physical phenomenon. Researchers, however, are easily subjected to physiological inertia and sometimes make a false analysis. This disturbs the researchers to conduct effective R&D procedure and makes it difficult to reach an ideal result.

2. TRIZ application in R&D

2.1 Example

We will show examples of actual R & D tasks using three TRIZ methods: Small Person Model, Substance-Field Analysis, and Standard Solution.

2.2 Research background

Orthopedic implants provide mechanical support for the fracture site and fix the bone until the fracture site is completely joined. This process is shown in Figure 1. However, existing orthopedic implants require a second operation for removal after bone joining is complete. These secondary surgeries give the patient a psychological burden, and there is also a risk of additional infection.

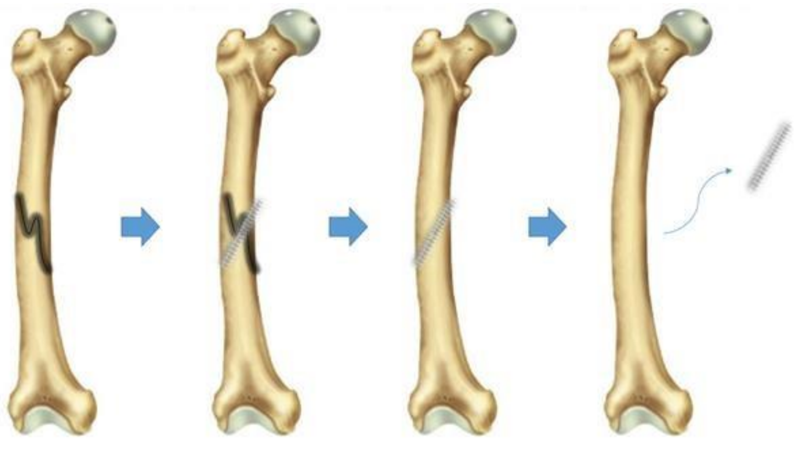


Figure 1. Insertion and removal process of orthopedic implant

Recently, biodegradable implants have been actively developed. Biodegradable implants are inserted into the fracture site to provide mechanical support for a certain period of time, and when bone joining is completed, they are naturally biodegraded in the body and then absorbed or released. This is a next-generation orthopedic implant that can overcome the shortcomings of existing implants.

Magnesium is used as a biodegradable implant material because it has excellent biocompatibility and several physical advantages. Especially, it has similar elastic modulus to a bone, so it can prevent stress shielding which is a serious problem of existing orthopedic implants have. For these reasons, it is well suited as a biodegradable implant.

However, the Standard Electrode Potential of magnesium is -2.37eV, which is lower than other metals. Thus, there is a fatal disadvantage that corrosion is very rapid in the body environment than other metals. Very rapid corrosion in the body produces hydrogen, which causes necrosis of the surrounding tissue. In addition, the mechanical force is quickly lost and the function of the orthopedic implant cannot be performed. Because of these problems, it is essential to control the rapid corrosion rate of magnesium in the body and various studies are underway. In this paper, we show the R & D process using TRIZ tools to solve this problem.

2.2 Establish a hypothesis(Su-Field Analysis, Standard Solution)

In order to establish a hypothesis how to control the corrosion rate of magnesium in the interior of the body, we analyzed the corrosion process of magnesium with Su-Field Analysis and solved the problem by using Standard Solution.

In the Su-Field analysis, the Substances which is involved in the corrosion reaction of magnesium implants in the body are (1) Magnesium implant, (2) body fluid, and (3) fractured bone.

In order to express the action between substances, An substance which affects is referred to 'substance-subject' and the being affected called as 'substance-object'. According to Su-Field analysis, the first interaction consists of a magnesium implant and a fractured bone, and the field that acts between these two substances is a mechanical field. The second interaction consists of body fluids and magnesium implants, and the field that acts on the two material relationships in the chemical field.

Body fluids (Substance) rapidly corrode (Chemical field) the Magnesium implant (Object). This interaction is referred to as a "harmful action" and is marked by a red snake-like line. Magnesium (Substance) implant do not provide sufficient bearing power (Mechanical field) to fractured bone (Object: note the change of Substance and Object). This interaction is expressed as "insufficient action" and appears as a dotted line. Figure 3 is a schematic of the above description.

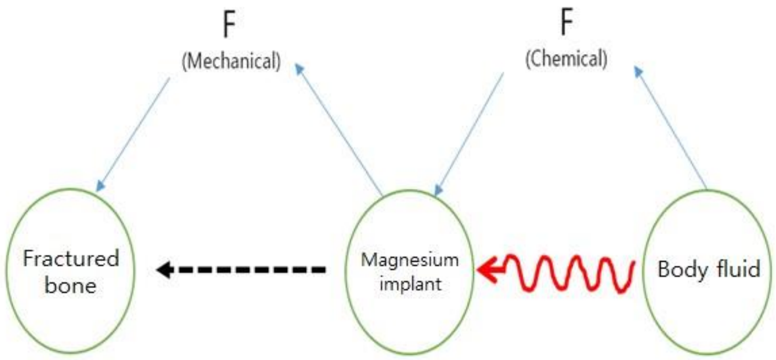


Figure 2. Su-Field analysis model between fractured bone, magnesium implant and body fluid

In the above Su-Field analysis model, the harmful effects of the interaction between body fluids and magnesium implants were selected as the major Conflict Triad (Fig. 3).

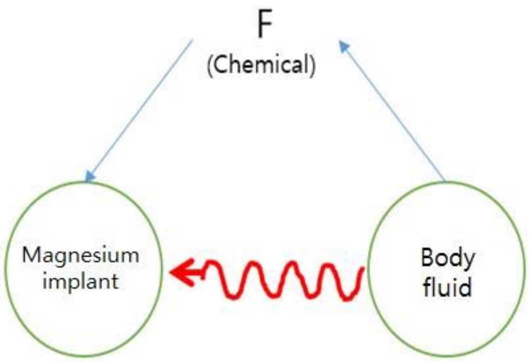


Figure 3. Selected Conflict triad from Su-Field analysis

The Conflict Triad model, in which harmful phenomena occur between substance and object, can be systematically solved by applying 'Standard solution 3' and 'Standard solution 4' (1). 'Standard solution 3' is a model that removes harmful effects by introducing New Substance between substance and object. In addition, 'Standard solution 4' is a model for solving problems by introducing a new field. Among these two models, we have solved the problem by applying 'Standard 3', which introduces a new substance between two substances. Figure 4 is a schematic diagram of this.

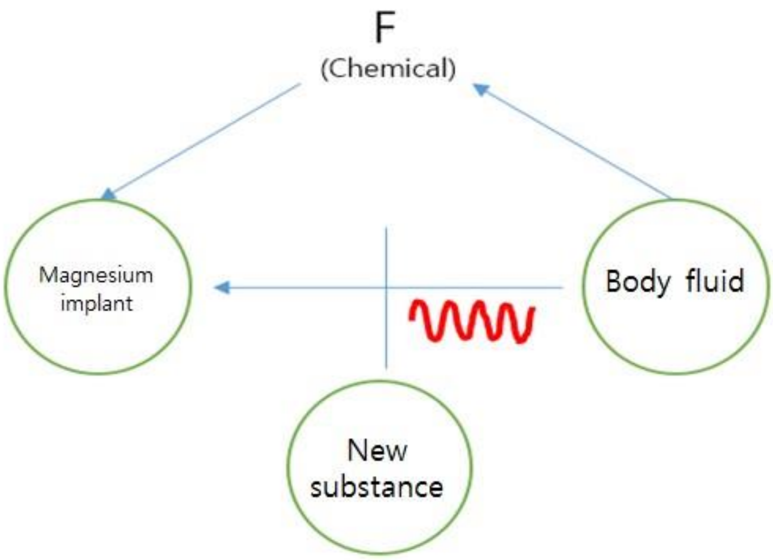


Figure 4. General solution of 'Standard Solution 3' model

The Conflict Triad model, in which harmful phenomena occur between substance and object, can be systematically solved by applying 'Standard solution 3' and 'Standard solution 4' (1). 'Standard solution 3' is a model that removes harmful effects by introducing New Substance between substance and object. In addition, 'Standard solution 4' is a model for solving problems by introducing a new field. Among these two models, we have solved the problem by applying 'Standard 3', which introduces a new substance between two substances. Figure 4 is a schematic diagram of this.

2.3 Design of experiment

Among various methods for depositing an oxide film, the PEO (Plasma Electrolytic Oxidation) coating method has many advantages such as wear resistance and corrosion resistance. And because it can design electrolyte composed only of the human body component, it is excellent in biocompatibility. It is also an environmentally friendly coating method using an alkaline electrolyte. Therefore, PEO coatings were used in this study because they were deemed suitable for implementing the hypothesis.

The PEO is a method of depositing an oxide film by generating a strong plasma on a substrate (Magnesium implant in this paper) in an aqueous solution and can control a very large number of variables such as frequency, voltage, current, process time, temperature and electrolyte composition.

We experimented with controlling the intensity of the voltage among the parameters and carried out with the applied voltage increasing from + 200V to + 400V.

2.4 Result of experiment

Experimental results show that as the voltage increases, the thickness of the oxide film increases, the size of the pores on the surface increases, and the surface roughness also increases. The measurement results are shown in Fig. 5.

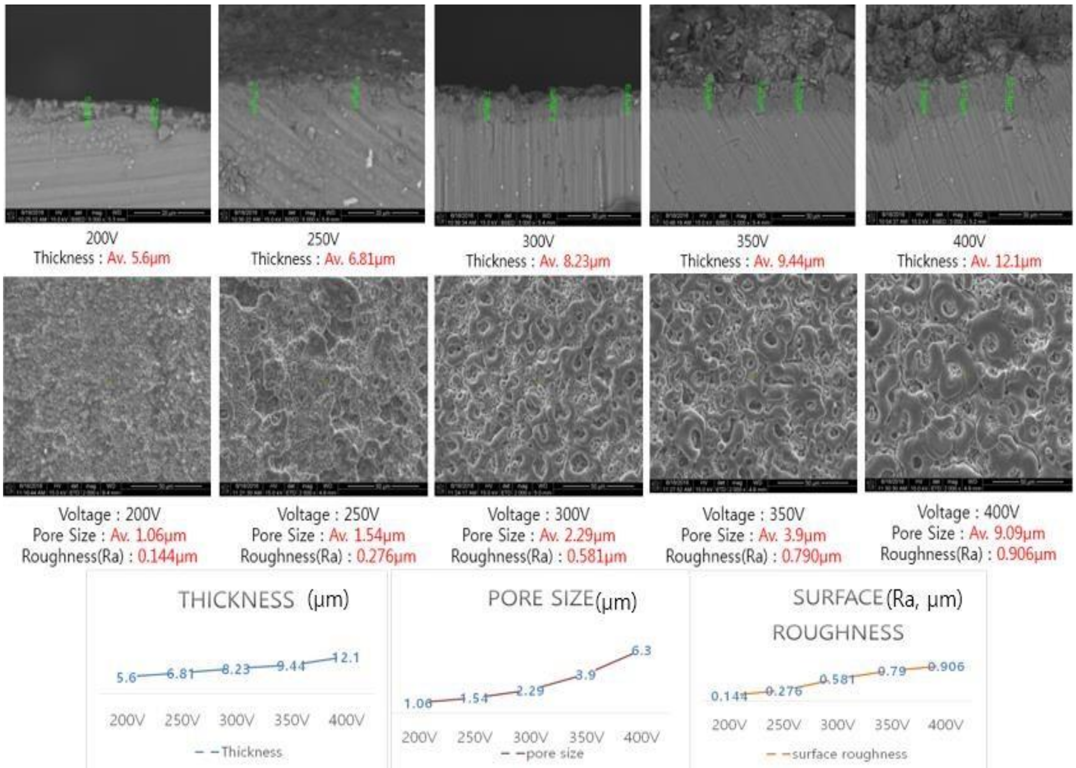


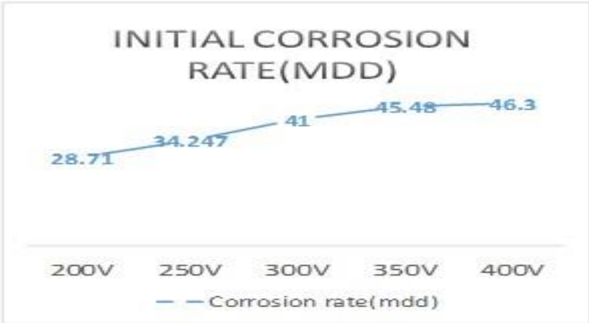
Figure 5. Experimental results with increasing voltage (Thickness, Pore size, Roughness)

The corrosion rate was measured by immersing the coated magnesium in Simulate Body Fluid. The corrosion rate unit was measured in mg / dm2 / day (mdd). The overall corrosion rate is slower with increasing voltage. The results are shown in Table 1.

Table 1. Corrosion rate control ratio with increasing voltage

	Non-coating	200V/30V (+,-)	250V/30V (+,-)	300V/30V (+,-)	350V/30V (+,-)	400V/30V (+,-)
mdd ($mg/dm^2/day$)	150.65	120.704	113.77	106.34	90.752	57.491
Corrosion control ratio	-	x1.25	x1.32	x1.4	x1.66	x2.6

Corrosion rate measurement results showed that the higher the voltage, the slower the corrosion rate (mdd) value. However, measure result during the first week was the opposite. The results of the first week showed that the higher the voltage, the higher the corrosion rate (Fig.6). We needed a physical analysis to understand such unexpected results.



(200V < 300V < 400V)

Figure6. Graph of Initial corrosion rate with increasing voltage

2.4 Analysis (Small Person Model)

To analyze the cause of the unexpected initial corrosion rate, we used the Small Person Model, one of the TRIZ analysis methods. The Small Person Model method helps you understand microscopic phenomena by expressing elements as "Small Person". In this paper, we used this method to understand the phenomenon of corrosion of coated magnesium in the body. Among the elements participating in the reaction, they are represented by a red man (magnesium ion) and a blue man (oxygen ion) and a bond between the atoms is represented by the handheld by small people. For example, magnesium oxide is represented by a blue little person and a red little person holding hands. This is shown in Fig 7 (Expression of other elements is omitted for an efficiency of analysis)

Figure 7. Magnesium ion small person(Left) , Oxygen ion small person(Center) and Magnesium Oxide (Right)

The aforementioned PEO (Plasma Electrolytic Oxidation) is a coating method in which an oxide film is deposited by a plasma generated by applying a high voltage to a substrate. When the positive voltage is applied, the magnesium substrate becomes the positive electrode. Then the anion oxygen ions migrate to the magnesium substrate (Fig.8). The applied voltage is the energy (J / q) applied per particle. So when a voltage is applied, small people are vibrated by energy and vibrated faster as the energy is increased. When the voltage continues to rise, the hand holding it is released by the vibration, which means that the bonds between the ions are broken and that they can move freely. This phenomenon occurs preferentially in the weakest hand holding area (weak binding force).

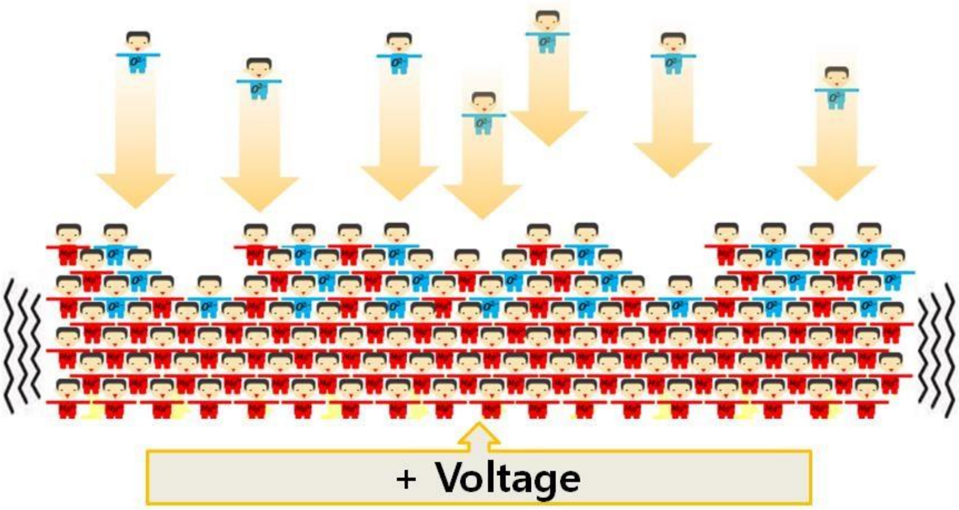


Figure8. Small person model in PEO coating process

At this moment, the plasma is generated by high energy momentarily, and the blue small person is ejected like an explosion and then, the red little person (magnesium ion) and the ejected blue little person (oxygen ion) hold hands (ionic bond). The ejected high-temperature red and blue small persons are instantaneously quenched and solidified as they encounter low-temperature electrolytes and are deposited as magnesium oxide (red small person + blue small person). This phenomenon is shown in Fig 9. In this way, we analyze and understand how the voltage acts on the deposition process through the Small Person Model analysis method.

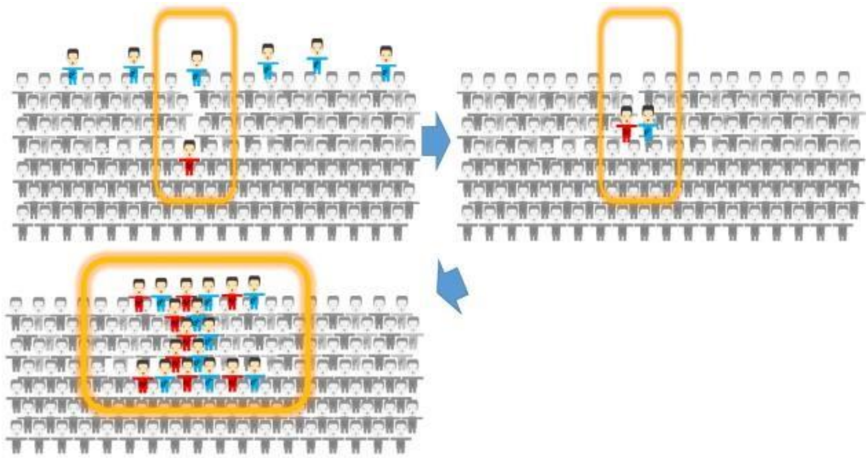


Figure 9. Deposition process of magnesium oxide

Next, we analyzed the cause of unexpected results that the higher the voltage, the faster the initial corrosion rate. Using the Small Person Model, we analyzed the causes by comparing the high voltage and low voltage. As mentioned earlier, when the voltage is applied, the bond is preferentially destroyed in the vulnerable area, and the small person is ejected by the energy of the generated plasma.

At lower voltages, the energy applied is so small that a small person will vibrate weakly. Therefore, it is ejected with a weak force and deposited on the surface in a relatively flat form. At high voltages, A small person receives a relatively large amount of energy and vibrates rapidly. Therefore, a small person is ejected violently like an explosion. This is shown in Figures 10 and 11, along with the surface morphology measured with a Scanning Electron Microscope.

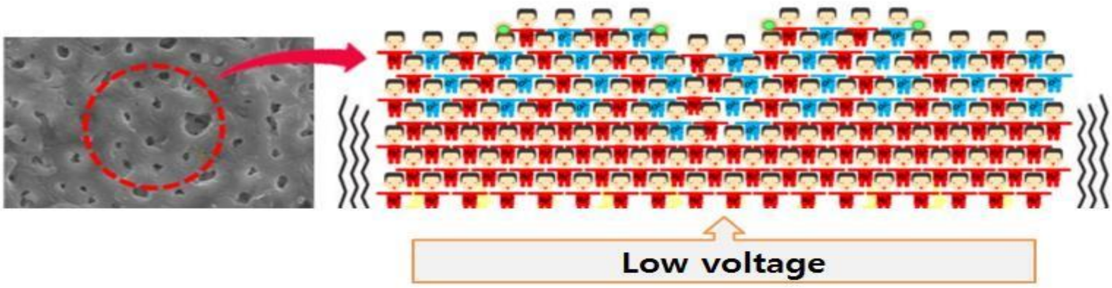


Figure 10. Surface morphology at low voltage expressed by Small Person Model

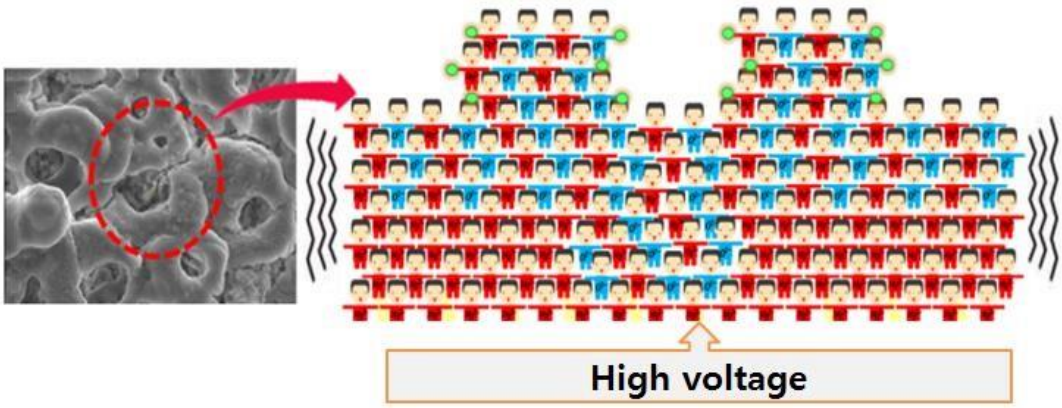


Figure 11. Surface morphology at high voltage expressed by Small Person Model

If you look at the small people who were newly deposited in the previous process, there is a part that does not hold hands. This is indicated by the green dots in Figs. 10 and 11. Small people who do not hold hands will try to hold hands with someone to be in a stable state. There are a lot of small people who try to get hold of a deposited surface at a voltage higher than a low voltage. This means that the surface area that can react with the surroundings is wide. For this reason, it can be understood that the sample deposited at high voltage reacts with Simulated Body Fluid (SBF) on a relatively large area when immersed in SBF, so that the corrosion rate is fast during the first week.

After a small person who does not hold the hand reacts, a stable intermediate layer is exposed and the corrosion is controlled stably. Through the Small Person Model, we analyzed the cause of the earlier erosion rate as the voltage increased.

2.5 Establish a hypothesis for problem solving and plan next experiment

The cause of the fast corrosion rate for the first week is on the principle of PEO deposition. PEO is rough and has a large surface area because it is a principle of generating plasma by ejecting and depositing plasma. The surface area is wide because it is ejected with relatively strong force at high voltage. The large surface area is large enough to react with the Simulated Body Fluid. Thus, the wider the surface area, the faster the corrosion rate is. In conclusion, I understood the reason why the corrosion rate for the first week at high voltage is fast because of Small Person Model.

3. Conclusion

A Hypothesis was established by applying Substance-Field Analysis and Standard Solution in Research and Development, and the phenomenon occurred during the experiment was analyzed through Small Person Model. First, we used Substance-Field Analysis and Standard Solution to accurately analyze the problem and to derive a reasonable hypothesis for the situation. Second, the experiment is planned based on the hypothesis. Third, we used the Small Person Model to analyze microscopically the phenomenon that the researcher would like to know. Fourth, analyze the cause of the phenomenon based on the analysis results and re-establish the hypothesis. Finally, plan the next experiment. An example of the process of research and development through TRIZ analysis is shown in this paper.

In conclusion, the research and development process through TRIZ helps the researcher to analyze and understand the research in detail, and analyze the phenomenon in a more accurate and broad view. In other words, the researcher can make accurate analysis and understanding by using TRIZ analysis and can do 'TRIZ thinking' to appropriately utilize the surrounding resources. This makes it easier to approach the ideal solution required in the R & D process.

4. Reference

(1) Yong Won Song, TRIZ Creative Problem Solving Theory, Korea Standards Association Media, 2017.

(2) Yong Won Song, Gennadi Ivanov, Technology of creativity, Sunest, 2014.

(3) IouriBelski, Improve your Thinking Substance-Field Analysis, TRIZ4U, 2002.

(4) Liang, Chen-Jui, *In-situ Impedance Spectroscopy Studies of the Plasma Electrolytic Oxidation Coating Process.* PhD thesis, University of Sheffield.

5. Thanks for

This paper was supported by the National Research Foundation of Korea (NRF).

Resolving the OXO Measuring Cup Problem

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Abstract

The OXO measuring cup was invented to solve the easy indicia reading problem and its technical features were published in Patent US6263732. When trying to circumvent patent US6263732, people tend to do the function analysis of the first independent claim and use trimming or other techniques to come up with a new solution. However, this approach needs to compare the new solution with other patents similar to Patent US6263732. Similar patents can be obtained from the forward citations of US6263732, but the comparison procedure is tedious. Here we propose a new solution by tackling the original problem solved by the OXO measuring cup, which is how to achieve easy indicia reading. An analysis of the contradiction problem reveals that to solve the easy indicia reading, a line can be drawn along the indicia in the measuring cup. This creates another problem, that only certain measurements can be taken. This renders a technical contradiction. This problem can be solved by a contradiction matrix that will suggest a few inventive principles to trigger the inventive solution. However, the problem can be solved even in a simple way. If the line drawn along the cup can be dynamic, then the problem is solved. A few thoughts reveal that a rubber band can be placed along the indicia. However, experiments show that the precise measured quantity can be difficult. Further thoughts indicate that if the width of the rubber band can be bigger, the precise measured quantity could be obtained easily. Finally, a reflective wristband can meet the requirement of easy indicia reading. The solution is confirmed by experiments.

Keywords: indicia reading, technical contradiction, contradiction matrix, forward citations, reflective wristband.

1. Introduction

Measuring liquid quantity is a common chore in laboratory and food preparation. To measure the liquid in a container with indicia, the user needs to either hold the container up to the front of their eyes or to bend the body up and down until a precise measurement is made. To overcome this awkward situation, the OXO proposed an angled measurement cup (OXO, 2018). With a sloped ramp affixed in the inside of the container, the indicia labelled in the ramp can be easily seen from the top when pouring the liquid unto the container. In this way, a precise measurement of liquid quantity can be obtained without moving the container or the body. Several other attempts have been proposed in the US patent database of USPTO (United States Patent and Trademark Office). All those patents are related to the structural modification of the container which make the manufacturing process complicated. There are two ways when trying to resolve this problem. One is to perform the function analysis on the components in the first independent claim of the patent US6263732. Then a trimming process is applied to the objects in the function analysis so that some objects can be trimmed and their functions are transferred to the other objects in the system or in the super systems. After a new design is made, its components need to be compared with other similar patents in the forward citation of the original patent to make sure it indeed circumvents all the other patents. It is a tedious process. The second way is to tackle the root cause of the original problem directly, which usually can lead to an innovative solution. This research follows the second approach. The solution is very elegant and costs almost nothing. A solution which is very close to the ideal final result.

In this paper we will give a step by step procedure showing how to come out with the solution. It is the goal of this paper to show a roadmap of TRIZ innovation in simple steps so that TRIZ can be even more appreciated by those who are outside the TRIZ community. The rest is as follows: Section 2 provides a literature review on the problem definition. Section 3 describes the construction of the ideal final result. Section 4 concludes the paper.

2. Literature review

In this section, two things will be covered: one is the problem formulation and the other forward citation of Patent US6263732 (Hoeting and Hoeting, 2001), a patent for the OXO measuring cup. It is well known that different perspectives of the problem can affect its direction of solution. For example, if one place lacks water. There could be at least two ways to form the problem. One is how to search for water in another place, the other is how to guide the water into that place. These two problem formulations render two different styles of living when searching for a solution. One is the nomadic style where people move from place to place and the other is the agriculture style where people stay for a long time in a place (Gelb, 2000). Similarly, TRIZ offers different tools in problem formulation so that people can look at the same problem from different angles. According to the Gen3 training material (Sun and Ikovenko, 2015), there are three major steps of solving problems in contemporary TRIZ and each step is with different TRIZ tools. These three steps are problem recognition, problem solving, and concept verification. With problem recognition, its goal is to identify the key problem by the process stated in Figure 1. Although it is suggested that users in TRIZ should go through the process to come out with the key problem, users will seldom apply all the tools to derive the key problem. One of the famous trimming examples provided as a training case in Gen3 is the overflow of the painting problem. A part of heater is coated with paint to enhance its heat conduction. The painting system is shown in Figure 2. The parts are carried along the conveyor from the left to right. When they are in the middle of the paint container and going through the basin, the paint is coated on the part. In this way, the paint in the container is reduced to a point that a switch on the right is turned on to outpour the paint from the tank on the left. This system runs well until the paint attached to the buoy becomes dried up to a point that the buoy becomes so heavy that it cannot float up in the container. In this way, the buoy cannot trigger the turn-off-switch and the motor keeps pumping paint from the tank causing an overflow of paint. The whole process can be described in function analysis as shown in Figure 3. This function analysis is based on a snap shot when the pump is out of order for the overflowing of paint. The dashed line is for insufficient function whereas the curly line is for harmful function. When the air solidifies the paint, it causes the paint to adhere to the buoy. Then the buoy moves the lever insufficiently, rendering the lever to control the switch insufficiently. Thus, the switch controls the motor insufficiently; the motor drives the pump insufficiently, and finally; the pump moves the paint insufficiently. This means the pump does not sensor the time to stop pumping the paint into the container causing the overflow problem.

Using the trimming to trim off unnecessary parts, one can form a radical thought that if the pump is trimmed out, then the motor, the switch, and the buoy will all be trimmed out. This means that the negative function of adhering will be eliminated automatically. Then the overflow problem is solved. The sketch of that part of the partial function analysis has become Figure 4. But which one will perform the function of moving paint? By examining the remaining four objects, the paint container, tank, paint, and the air, it becomes obvious that only the paint can do the job. That is, the paint moves by itself. One can use the gravity to make the paint move by itself. Thus, the complete function analysis after trimming is shown in Figure 5. The paint moves by itself as shown in the loop of function. A practical way to perform this function is to invert the tank so that the paint from the tank will flow out unto the container automatically due to gravity. However, when the spout of the pipe touches the paint, the flow automatically stops due to Pascal's principle (Wikipedia, 2018) where a change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid. As shown in Figure 6, when the spout of pipe connecting from the tank to container touches the surface of the paint, the atmosphere will exert pressure on the paint to fight against the gravity of the paint in the tank so that the paint from the tank will not flow out from the tank. However, when the spout of the pipe is not immersed in the container, the air will go into the pipe and the gravity of the paint in the tank prevails. Thus, the paint flows out the tank automatically. This is shown in Figure 7.

As shown in the previous example, function analysis and trimming are used to identify the key problem, which is how to move the paint. Then, a solution can be derived via the brain storming, without even implementing the TRIZ tools in problem solving. This shows that in order to identify the key problem, one does not need to follow through each step in the flow chart of problem recognition. Perhaps one or two TRIZ tools needs to be used to identify the key problem.

Another issue we are addressing here is the forward citation of the patent of Patent US6263732, a patent for the OXO measuring cup. The forward citation of a patent is the patents which cites it (Sharma and Tripathi, 2017). It could be done by the inventors or the examiner of the patent. For example, if patent A1 cites three patents B1, B2, and B3 by the inventors of patent A1, then the forward citation of B1 is A1. Of course, there may be other patents such as A2 and A3 also cites B1. Then we may say that the forward citation of B1 is A1, A2, and A3. Their relationship is shown in Figure 8. When constructing the forward citation of a patent, not all the patents citing the patent should be included. It is because some patents do not contain the feature we want. The forward citation of US6263732 is US7306120 and US9354098, as shown in Figure 9. The filed dates are indicated below the patent number. All the three patents contain a common feature: easy reading indicia. Their drawings are shown in Table 1. The indicia are located in the sloped ramp in US6263732. And the indicia in the US7306120 (Hughes, 2007) are on the horizontal surfaces of each step at the corners. Lastly, the indicia in the US9354098 (Breit and Kushner, 2016) are printed along upper and lower surfaces of a reference member disposed near a central portion of the measuring cup. With this information available, one can be illuminated and triggered with a new solution. Since each patent is with its own patent right as shown in its claims, thus, one can say some territories have been occupied by those patents. The drawings and their claims can show us which pieces of land are still not occupied. And those lands are the targets of the new invention.

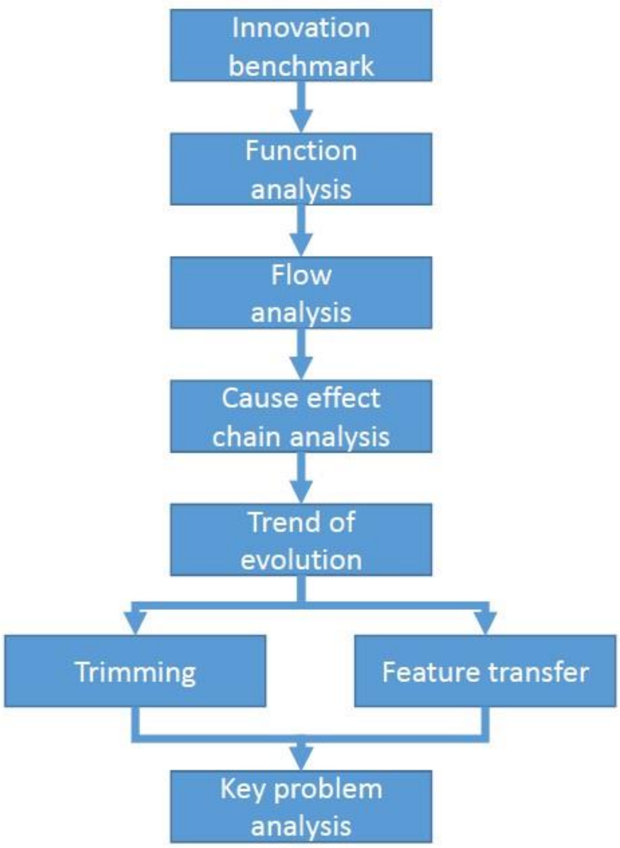


Figure 1. Flow chart of problem recognition

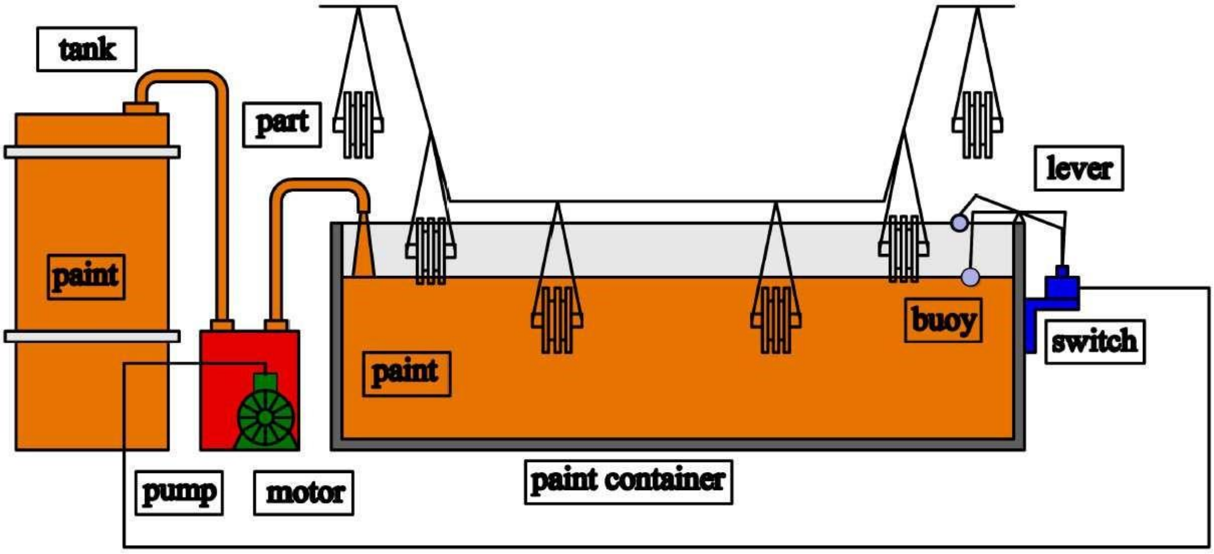


Figure 2. Sketch of painting system

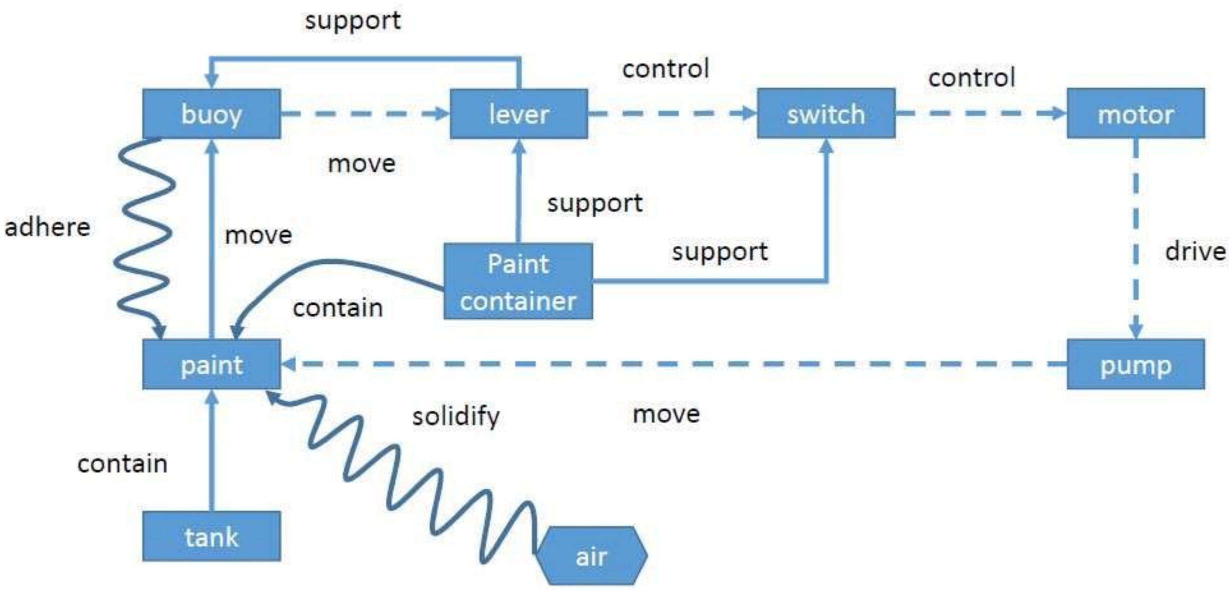


Figure 3. Function analysis of painting system

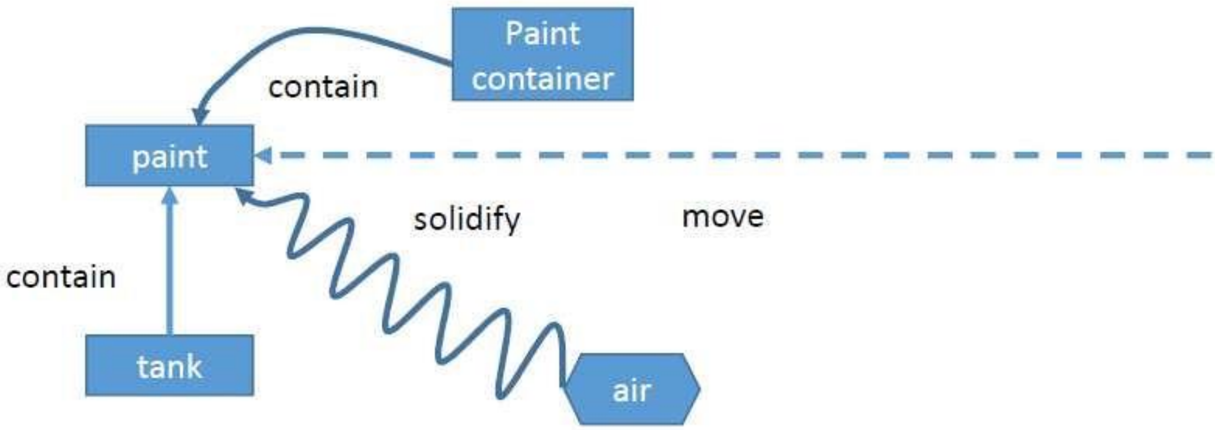


Figure 4. Partial function analysis after trimming

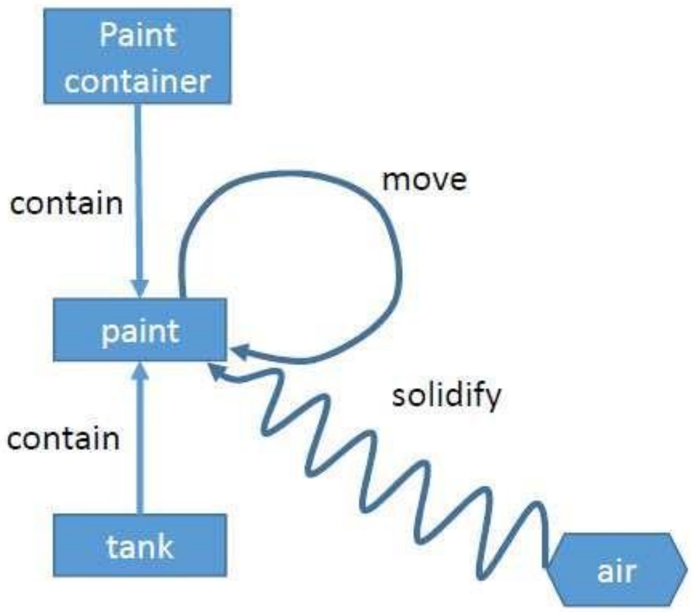


Figure 5. Complete function analysis after trimming

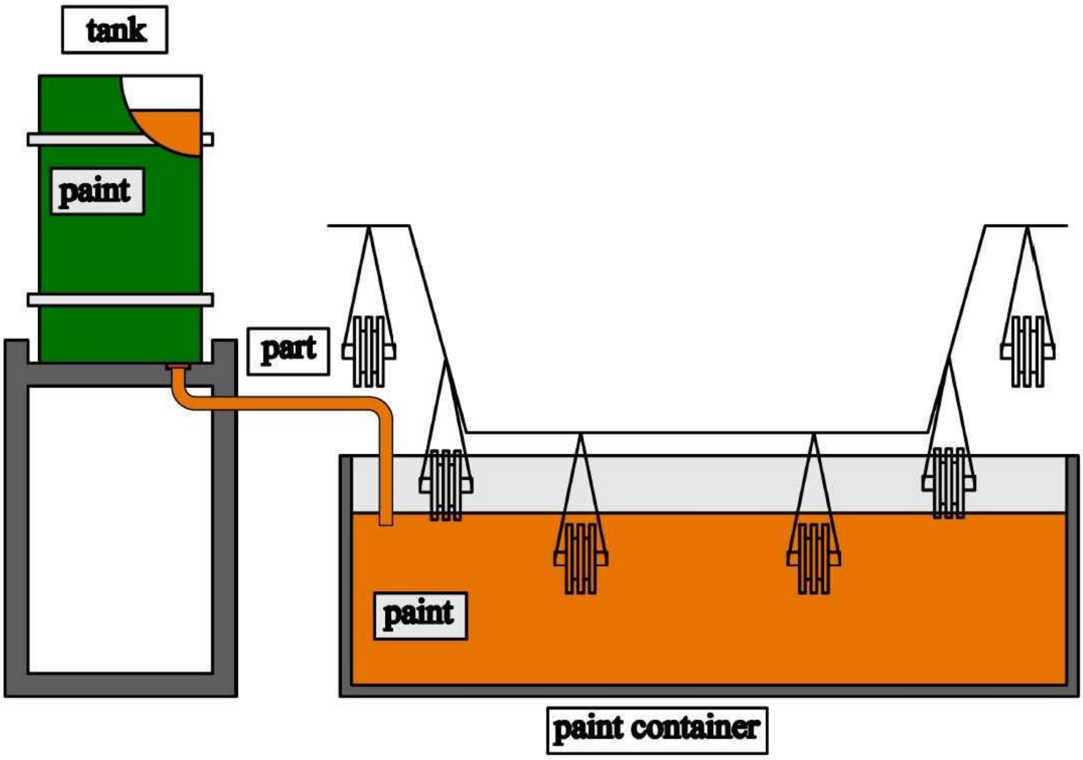


Figure 6. Sketch of solurion painting system – stop flowing

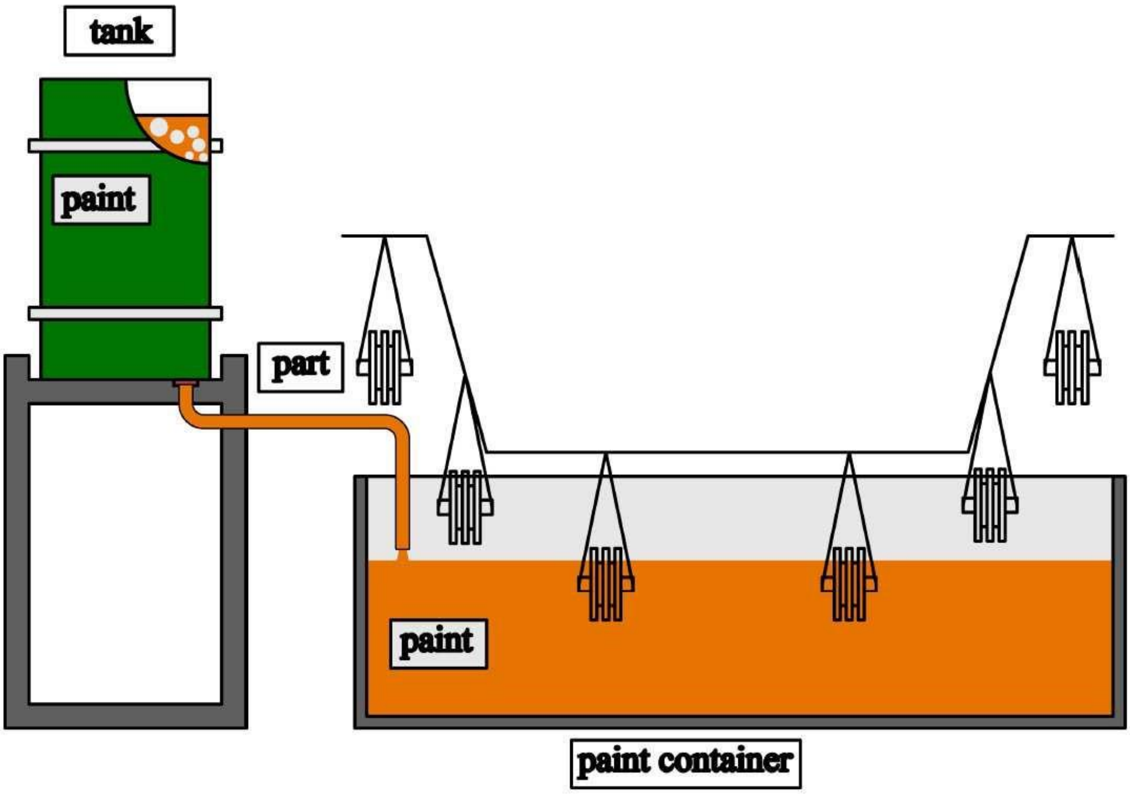


Figure 7. Sketch of solurion painting system – start flowing

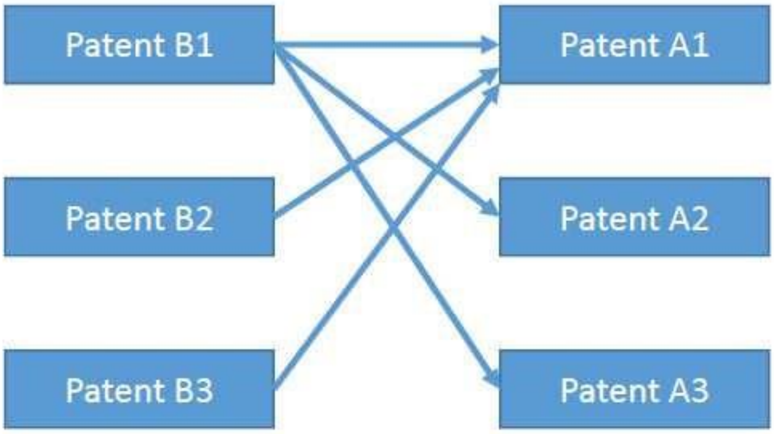


Figure 8. Forward citation of patent B1

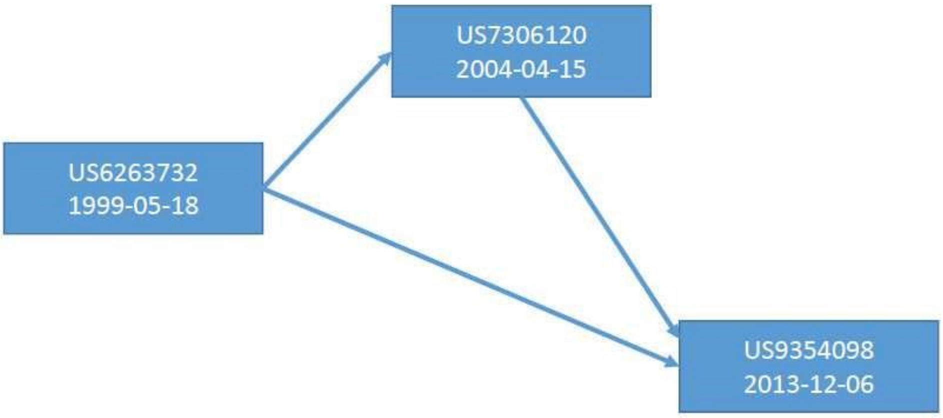
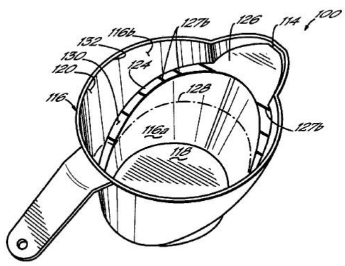
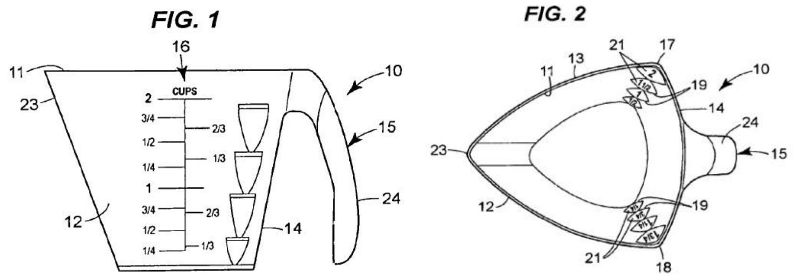
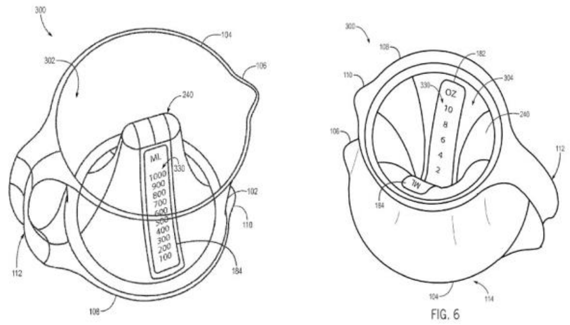


Figure 9. Forward citation of patent US6263732

Table 1. Forward citations of US6263732

Patent	Drawing
US6263732	

US7306120	
US9354098	

3. Construction of ideal final result

The way we tackle the OXO measuring cup problem is to resolve its original problem. Instead of doing the function analysis and trimming of the patent US6263732, we analyze what is the problem patent US6263732 is trying to solve. It is clear from the background of the invention in US6263732, the inventors try to solve the reading difficulty of indicia in the measuring cups. People either bend their body to look into the indicia on the surface of the measuring cups after pouring the liquid into the cups or have to lift up the cups in front of the eyes to confirm the precise quantity they need. Both ways are tedious and inconvenient, especially to those who are weak in their hands and legs. Sometimes it could be even dangerous when pouring some toxic liquid with such weakness. In order to eliminate these problems, something has to be done and the easy way to detect the indicia is looking from the above of the measuring cup while pouring the liquid. The OXO solved this problem by making a sloped ramp inside the cup with indicia marked on the surface of the ramp.

Analyzing the measuring cup, one finds that the key problem is to make the indicia clearly seen from the above. A few thoughts after brain storming reveals that one can draw a thick line around the cup to show the indicia. This seems to solve the easy reading indicia problem; however, it creates another problem where only a few lines can be drawn along the surface of the cup. It is a technical contradiction. We can use the IF THEN BUT structure (Mann, 2002) to form the technical contradiction. IF we draw the line along the surface of the cup, THEN the indicia can be read easily from above, BUT there are only a few lines that can be drawn. Further thought on the generalization of the effects from the drawing line, the improving parameter is 37, complexity of control and measuring, whereas the worsening parameter is 24, loss of information. The contradiction matrix based on the improving parameter 37 and worsening parameter 24 gives inventive principles 35, 33, 27, and 22 (Altshuller, 2001) as a trigger to search for the inventive solution as shown in Figure 10. One can pursue the solution with the suggested inventive principles. However, an even simpler way will be used to solve the problem.

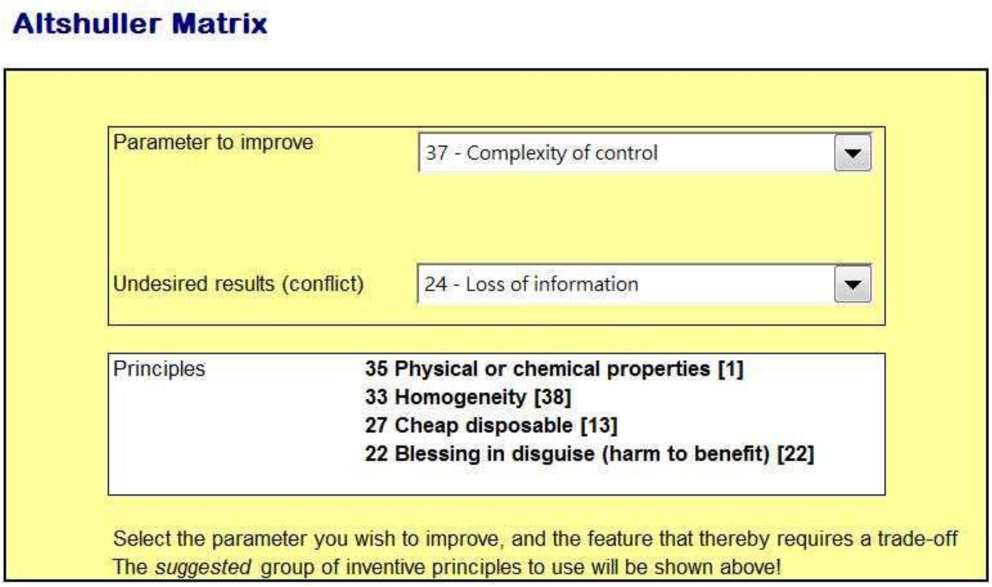


Figure 10. Contradiction matrix

The TRIZ tool we use is the trend of evolution. In the classical TRIZ there are eight trends of evolution. Each trend shows how a technological system evolves towards its ideality. The ideal result of any technological system is that it provides the function without any cost while occupying no space. The eight trends of evolution are: trend of increasing ideality, trend of uneven progression of the sub-systems, trend of dynamics and controllability, trend of harmonization of sub-system, trend of going towards micro-scale and using the field, trend of conglomeration and further trimming, trend of energy transfer, and trend of completeness. When applying the trend of dynamics and controllability to the line drawn on the surface of the cup, it has come to us that the next level of ideality of the line is the dynamics. We can make the line more dynamic than just a fixed line. Then we think of using the rubber band to replace the fixed line. A rubber band can be moved along the surface to show any quantity. Thus, it is closer to ideality than a drawn line in term of dynamics. An experiment is performed to verify the concept as shown in Figure 11. However, it turns out that the rubber band cannot be seen clearly from the above of the cup due to its narrow width. Now the sub-problem becomes how to find a band which is both flexible and has a bigger width. A few thoughts lead to the reflective wristband (Ebay, 2018) for bicycle riders which is used to tie the bottom of pants. The second experiment shows that reading of the indicia is much better as indicated in Figure 12. When applying the wristband to the ordinary measuring cup, the wristband sometimes will not completely cover the surface of the measuring cup. However, the part of the surface covered by the wristband can be used as a guideline to guide the user to pour the water unto the cup in a precise manner, as shown in Figure 13.

The advantage of using the reflective wristband as an accessary to assist the precise measurement is that no need should be changed in the ordinary measuring cups. It is easy to be applied to any type of measuring cup. And the reflective wristband can be easily carried on the user when not using it to take measurements of liquid. Thus, the reflective wristband fulfills the inventive principle 6 of universality. It can perform several functions, as its reflectivity means that during the night time one can tie the shirt unto the wrist and tie the pants unto the legs. And more, it can assist the easy reading indicia of measuring cup. It is truly an inventive solution, solving the problem without extra cost.

The logic to solve the easy reading indicia can be explained in the flow chart in Figure 14. First, we identify the key problem by reading the patent US6263732. Here the key problem is how to achieve easy reading indicia. Second, an initial solution is proposed, to draw a line along the surface of the measuring cup. Third and fourth, using the trend of dynamics and controllability, a rubber band is used to replace the drawn line to increase the dynamics of the drawn line. An experiment of a rubber band with glass shows that the rubber band cannot give a precise measurement due to its narrow width. Fifth, a second modification is proposed with the reflective wristband. And an experiment with the wristband and glass shows that it indeed enhances the quality of easy reading of indicia. Finally, an experiment with a wristband and measuring cup shows that the wristband performs well in showing the indicia.

Figure 11. Rubber band with glass

Figure 12. Wristband with glass

Figure 13. Wristband with measuring cup

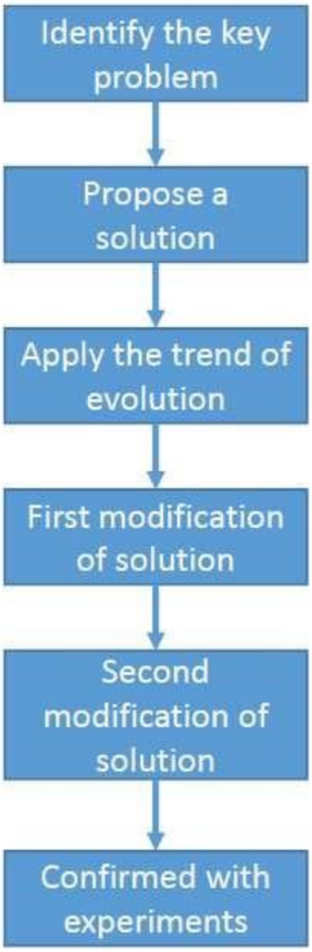


Figure 14. Flowchart of problem solving

4. Conclusion

In this paper a key problem of easy reading indicia is solved when designing a new way to measure quantity in using the measuring cup. A conventional way to solve this problem is by changing the structure of the measuring apparatus to provide an index inside the cup so that the user can see it from the above while pouring the liquid. However, this method makes the structure of the measuring cup complicated. Here we propose a new way to solve the problem by proposing an initial solution of drawing a line along the surface of the measuring cup. Then one can further improve the solution by applying the trend of evolution to the drawn line. There are eight trends of evolution and here we use the trend of dynamics and controllability. A rubber band is used to replace the drawn line to increase its dynamics. An experiment of rubber band and glass is performed to verify the concept. The experiment shows that due to the narrow width of the rubber band the easy reading indicia is not completely achieved. Brain storming of how to increase the width of the rubber band leads to the reflective wristband. It owns the property of flexibility of a rubber band and a wide band. A second experiment of a wristband with glass confirms the concept. Finally, we apply the wristband to the measuring cup to confirm that it can achieve the easy reading of indicia while pouring the water into the measuring cup.

▪Reference

Altshuller, G., 40 Principles-TRIZ Keys to Technical Innovation, 2001, Technical Innovation Center.

Breit, O. and Kushner, R. G., Measuring cup, US patent, US9354098, 2016.

Ebay, Reflective Cyclists Safety Bands Slap Wrap on Hi Visibility for Arms and Ankles, (2018, April 28). Retrieved from https://www.ebay.co.uk/itm/REFLECTIVE-CYCLISTS-SAFETY-BANDS-SLAP-WRAP-ONHI-VISIBILITY-FOR-ARMS-AND-ANKLES/182680916605?hash=item2a88a1927d:m:m6CR QSvmboed4OiCJh8mhGg.

Gelb, M., How to Think Like Leonardo da Vinci: Seven Steps to Genius Every Day, 2000, Dell.

Hoeting, M. G. and Hoeting, S. C., Measuring cup, US patent, US6263732, 2001.

Hughes, W. S., Measuring cup with volume marking visible while pouring, US patent, US7306120, 2007.

Mann, D., Hands-on Systematic Innovation, 2002 (CREAX Press).

OXO - 3 Piece Angled Measuring Cup Set, (2018, April 28). Retrieved from https://www.oxo.com/products/preparing/measuring/3-piece-angled-measuring-cup-set.

Sharma, P. and Tripathi R.C., Patent citation: A technique for measuring the knowledge flow of information and innovation, World Patent Information, 51, 2017, 31-42.

Sun, Y. and Ikovenko S., TRIZ: A Golden Key to the Door of Innovation: Part I, 2015, China Science Publishing & Media Ltd. (In Chinese)

Wikipedia, Pascal's law, (2018, April 28). Retrieved from https://en.wikipedia.org/wiki/Pascal%27s_law.

A Study of Using Resources Analysis of TRIZ for Business and Management to Improve Students' Understanding of the Operation of the School Learning Management System

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Abstract

There are many problems when students of Off-campus special courses using school learning management system. Students miss the activity notices and summit their homework late when using the system. They also seldom use the Email account and hard drive space which the system offer. Because of the long distance or special controlled area where students of Off-campus special courses are, it is hard for employees to manage students' questions for the system. Thus, we use resource analysis to come up with some ways to improve the situation, hoping that the students will be more familiar with the system.

Keywords: TRIZ for Business and Management, Resources analysis, Improve the Understanding of the School Learning Management System for Students.

1. Introduction

1.1 Why do we need resource analysis?

Innovation often comes with changes in a currently existing technical system. These changes have to consume resources. Where can we get resources is a big problem.

We must make full use and find out the resources inside the technology system and the environment that could be used in the innovation. We introduce additional resources only when there are really no resources available in the system and the environment. Having the ability to use the limited resources in the technology system and the environment efficiently often plays an important role to a successful innovation.

In the process of solving conflicts and achieving innovation, choosing and using resources appropriately is an important issue. It is an issue that even determines whether the innovation is successful or not.

Being creative when using resources inside and outside the system is an important way to overcome difficulties and to improve the ideality when innovating. Therefore, the choice of the resources is proper or not will determine the success of the innovation.

1.2 Uniqueness of resource analysis

Resource analysis is a method hoping its users improve the system's ideality of the use of resources. That is, increase function, reduce cost, and reduce harmful effects. If users can identify resources and transfer their problem properly, they can find out more ways to solve their problems.

Resource analysis can help users find more ways to use resources. With this systematic analysis, users can find out more possibilities of the use of resources. Many things can be resources if you properly use them. Good identification helps creation. Bad identification holds back creation.

2. Literature Review

Resource analysis is mentioned in some TRIZ books (Genrich Altshuller. 1996, 1999; Gordon Cameron. 2010; Isak Bukhman, 2012; Nikolay Bogatyrev, 2014; Victor Fey 2005). However, there are seldom detailed descriptions in the books. Without detailed descriptions, beginners of Resource analysis may not know how to use resource analysis to help them solve their problems. For this reason, this study arranged the contents, steps and cases of resource analysis of some books, hoping to help beginners understand resource analysis more easily.

3. Methodology

3.1 The choice of resources

The choice of resources needs to be aware of five aspects:

1. We must make full use and find out the resources inside the technology system and the environment that could be used in the innovation. We introduce additional resources only when there are really no resources available in the system. This way, we can simplify the system and reduce costs.

2. Use the same resource in multiple ways.

3. Exploring hidden resources that are not easy to be identify at first sight in the system.

4. Use as much free resources as you can, for example: sunlight, air, wind, temperature, free network and cloud hard drive.

5. Transform harmful resources into useful resources.

When using the resource can't develop equivalent or higher value of the consumed, the use should be eliminated.

3.2 Kinds of resources

Resources are the sum of all available things. Resources for Business and Management can be further classified into 6 categories. The types of resources for Business and Management includes: Space, Time, System, Supersystem, Mono-bi-poly, and Information.

1. Space resources: The space which can directly be used or organized to complete a function, such as idle space, unused space, network space and virtual space.
2. Time resources: Change the pace of the operation of the system.
3. System resources: Use the characteristics of components in the system to increase efficiency.
4. Supersystem resources: Use the characteristics of components of the surrounding environment to increase efficiency.
5. Mono-bi-poly resources: Reduce or expand the scale of the activities. Combine existing activities. Divide the current activity into smaller parts.
6. Information resources: Change interactive methods or rules such as positive or negative feedbacks, information exchanges, testings, measurements, knowledge, experiences and feelings.

3.3 Comments for use of resources

Resource Analysis is to list out the system and super system components to decide which component parameter values should be changed for reaching the demand of solving the problem.

Use the problem solution that has the lowest cost and produces least harm.

Use existing resources to create the next generation of the systems or processes.

Through changing the parameter value of the resource, we reach specific requirements of the solution.

Finding the methods to change the parameter values is the way to come up with solutions.

4. The use of resource analysis

There are three steps: clarify requirements, list out resources, and decide how to use resources.

1. Step one: Establish a list of principal requirements to the solution of the problem.

2. Step two: List out resources and identify each parameter of those resources.

3. Step three: Decide which resource parameter value should be changed to reach requirements to the solution of the problem.

The following is the case of how to improve the students' understanding of the Network platform of Extension Education Center courses. We use it as an example to illustrate how to use the method.

4.1 step one: Establish a list of principal requirements to the solution of the problem.

4.1.1 Describe the system and problems

a. Describe the problem that needs to be solved.

The course information is not complete and clear on school learning management system. Another problem is that the system is not easy for students to register the course. Thus, students who have problems using the system have to ask Extension Education Center employees in person or by phone. It increases the workload of Extension Education Center employees. Also, because the system is hard to use, the usage rate of the system is low.

Current state: The usage rate of the system is low.

It increases the workload of Extension Education Center employees.

b. Draw system structure diagram and label names of the components.

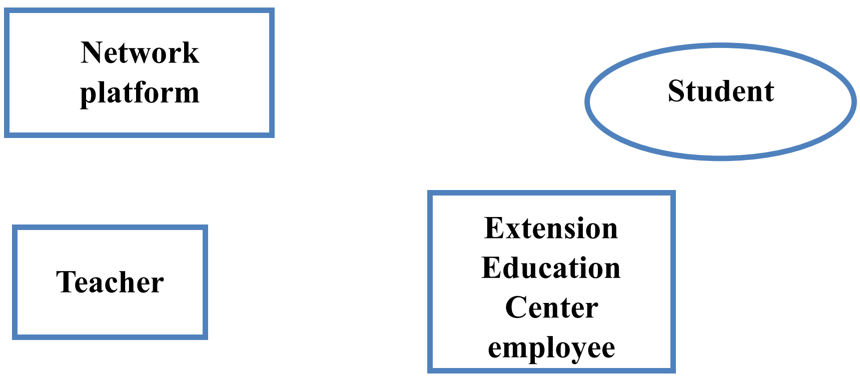

Figure 1. Structure diagram and names of the components of Extension Education Center courses

4.1.2 Establish a list of principal requirements to the solution of the problem: Describe the specific requirements that need to be met to solve the problem

1. Increase the usage of the Network platform.

2. Increase the Operation familiarity of the Network platform of students (Easy to find courses and to submit materials for courses).

3. Increase course enrollment of students (Increase tuition income).

4.2 step two: List out resources and identify each parameter of those resources.

What is the interaction between resources?

Relatively speaking,

1. The complexity of the Network platform interface reduces the will of students to use it.

2. Insufficient students select the course results in a low success rate of opening a course.

3. The tuition fees from students are insufficient to pay teachers' salaries.

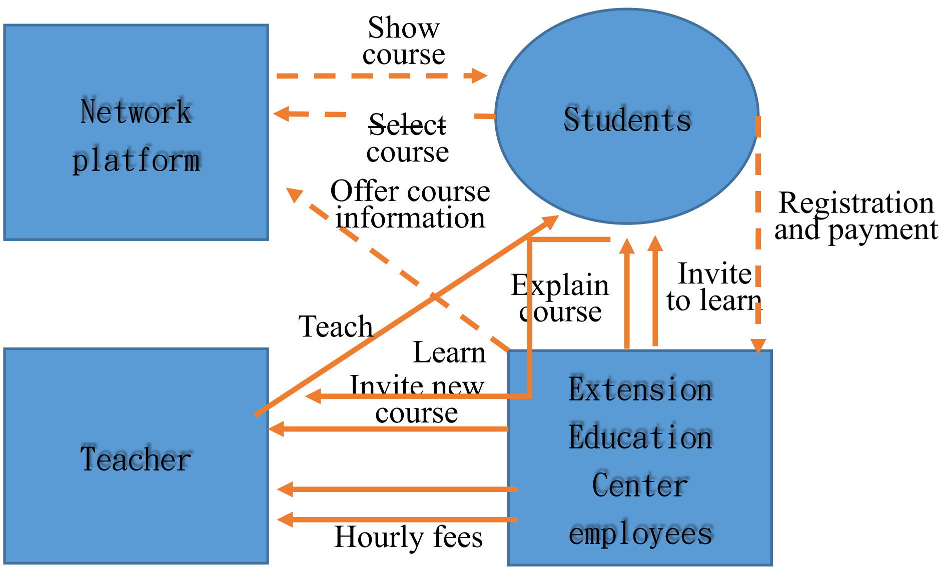

Figure 2. Interaction diagram of the components of Extension Education Center courses

4.2.1 List out resources according to the distance and rank of function of the target (object)

Table 1. Resource table inside and outside the system of 'Extension Education course'

Region	components	Parameter
in-system resources	Students, Teachers, Teaching materials, the Network platform, Extension Education Center employees	Types and characteristics of students, Teaching methods and contents, Types of teaching materials, Types of courses, Duties and working hours
out-of-system resources	Old students, Course advertisements, the Digital environment	Types and characteristics of old students, the time of advertisements, the Digital space

4.2.2 List out resources and identify the name, function, and parameter of resources

Table 2. Resource analysis table inside and outside the system of 'Extension Education course'

Name	**Function(effect)**	**Parameter**
Students	**Target (object)** Learning knowledge, registrations and payments	Gender, age, education, expertise, Network platform familiarity…
Teachers	Teaching knowledge	Gender, age, education, expertise, Network platform familiarity…
Teaching materials	Passing knowledge and information	Weight, area, thickness, Number of units, Materials, Content type…
Network platform	Passing information, Submit materials	Course information, activity Information, operation methods, Content types…
Extension Education Center employees	Invite teachers to open classes, invite students to register classes, introduce courses, accept students registration and fees, pay teachers' salaries	Gender, age, education, expertise, Course familiarity, Network platform familiarity…

4.3 step three: Decide which resource parameter value should be changed to reach requirements to the solution of the problem.

4.3.1 Choose to change resources and features

Change a characteristic of a resource. As the result, a required function will be reached.

1. Change the characteristics of students. As the result, students' understanding of the Network platform will be done automatically.

2. Change the characteristics of teachers. As the result, students' understanding of the Network platform will be done automatically.

3. Change the characteristics of the teaching material. As the result, students' understanding of the Network platform will be done automatically.

4. Change the characteristics of the Network platform. As the result, students' understanding of the Network platform will be done automatically.

5. Change the characteristics of Extension Education Center employees. As the result, students' understanding of the Network platform will be done automatically.

4.3.2 The generated solution

1. Extension Education Center employees may train a student face by face to understand the operation of the Network platform. This student can help other students to find courses and submit course materials in future.

2. Extension Education Center employees may train a teacher face by face to understand the operation of the Network platform. This teacher can help other students to find courses and submit course materials in future.

3. Extension Education Center employees may edit a detailed network platform manual and give it to students so students know how to operate the Network platform.

4. Extension Education Center employees may train a student by videos to understand the operation of the Network platform. This student can help other students to find courses and submit course materials in future.

5. Extension Education Center employees may record instructional videos and place it on the network platform so student can watch the video to understand the operation of the Network platform.

6. Extension Education Center employees may find an old student who is familiar with the operation of the network platform to help students.

5. Summary and Discussion

Many sources mentioned about Resource Analysis, but when should we use it? The best time for using Resource Analysis is when we know what our key problem is, since the best resources are those that are close to the problem.

Management problems are not solved by resource analysis usually. This study attempts to propose a solution to the management problem with systematic steps of using resource analysis. By showing the case, we wish it will be easier for beginners to handle resource analysis for solving management problems.

▪Reference

Genrich Altshuller, *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving*, Technical Innovation Center, Inc., 1996. ISBN 978-0964074026

Genrich Altshuller, *The Innovation Algorithm: TRIZ, systematic innovation and technical creativity*, Technical Innovation Center, Inc., 1999. ISBN 978-0964074040

Gordon Cameron, *Trizics: Teach yourself TRIZ, how to invent, innovate and solve 'impossible' technical problems systematically*, CreateSpace Independent Publishing Platform, 2010 .ISBN 978-1456319892

Isak Bukhman, *TRIZ Technology for Innovation*, Cubic Creativity Company, 2012, ISBN: 9789868563520

Nikolay Bogatyrev, Olga Bogatyreva, *Inventor's Manual*, BioTRIZ, 2014. ISBN 978-1500453657

Victor Fey ,*Innovation on Demand: New Product Development Using TRIZ*, Cambridge University Press, 2005. ISBN 978-0521826204

Digital Transformation in the Shipping Industry

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Abstract

A synthesized *management as a practice* and *service dominant logic* thinking is employed to study digital innovation, in particular the digitalization process and outcomes, in an industrial services context. We elaborate the shipping digitalization case, as an instance of digital transformation, where the "micro foundations of organizational logics, strategies and business behaviors" of shipping companies are changing, henceforth demand new approaches to comprehend and responsibly influence. Our aim is to devise a theoretically updated and practically relevant approach that shipping companies as well firms in various industrial contexts can consider, while seeking to determine and actualize their digital transformation process and goals. Diverse shipping sectoral and organizational contexts, business value formation stages and digital maturity levels are considered, towards contributing in the ongoing multidisciplinary and multivocal dialogue on industrial services digitalization.

Keywords: digitalization, shipping, Shipping 4.0, design science, big data, IoT

1. Introduction

State of the art IoT and data analytics technology are nowadays significantly diffused in the maritime sector, enabling the transformation of the shipping industry into a digitally endowed, knowledge-intensive sector, beyond its capital and scale intensity.

Robotics and autonomous systems technology are transforming ship management; furthermore new artificial intelligence technology and applications bear new possibilities for strategy making, decision-making and technical and commercial operations management in shipping companies. Henceforth, a new wave of Shipping 4.0 technologies is nowadays emerging; it is embedded in Shipping Cyber Physical Systems, which comprise large-scale configurations of interconnected physical and digital components, applications and infrastructures, primarily related with IoT and big data technology. Consequently, Shipping 4.0 technologies shape and are being shaped by novel approaches to value creation, digital business models and the provision of new maritime services (Levander, 2017; George et al, 2014).

Research and development efforts, in the maritime sector, have been concentrated primarily on the following indicative application areas: predictive vessel maintenance applications, energy efficiency monitoring - vessels' and fleets' fuel consumption, vessel emissions monitoring platforms, as well as safety and security platforms for critical incidents monitoring. A wealth of commercial enterprise software for shipping companies (i.e. platforms for real time vessel and fleet performance monitoring) are currently developed and diffused, along with a number of new entrants covering relatively mature products and platforms (i.e. Maersk Digital, Kongsberg Digital platforms, INTTRA). Autonomous ship research is a parallel, major endeavor of the industry, with eminent incumbent companies like Rolls-Royce and MOL, or competent new entrants. i.e Yara paving the way forward.

A connected ship (Levander, 2017; Porter and Heppelmann, 2014; Jokioinen, 2017) is nowadays considered to be an integral part of a larger maritime and supply chain system, which could include, i.e. fleets of ships, shipyards, or port terminals, and monitor key performance indicators of the vessels and individual machines' components to optimize the overall efficiency of the larger fleet or even maritime logistics infrastructure, energy production and trade systems, commodities production and trading systems and so on and so forth. Henceforth, the combination of multiple, previously disparate service systems, e.g., fleet systems, weather data systems, commodities trading systems, may lead to systems of systems, which have the capacity to transform the nature of the shipping firm and expand traditional industry boundaries (Mayer, 2017). The competitive dynamics of the shipping industry (similar to a number of other sectoral trajectories) are anticipated to broaden to encompass new products (i.e. software platforms), services (i.e. commodities' trading or digital supply chains' synchronization) and business models.

In this context, the "micro foundations of organizational logics, strategies and business behaviors" of shipping companies and their maritime clusters' stakeholders co-evolve and necessitate new approaches to comprehend and responsibly influence (Storbacka, Kaj, et al., 2016; Demirkan, 2015; Loebbecke and Picot, 2015).

2. A Service Innovation Lens of Shipping Digitalization

Shipping 4.0 enabled value (co-) creation is observed to be enacted nowadays primarily within Porterian maritime clusters (i.e. those geographically located in North Europe and Asia), viewed as the original form of *maritime digital innovation ecosystems*. Also, inter-cluster knowledge exchanges are enacted, beyond geographical proximity (i.e. Norway's SINTEF initiatives – Singapore hub). Referring to information systems and service science nomenclature, it is these ecosystems that foster "the resource generation or sharing, and service-exchange activity, coordinated through institutional arrangements for mutual value creation" of maritime actors connected by compatible dispositions, perceptions and expectations (Barrett et al., 2015; Demirkan, 2015).

More in specific, a number of R&D projects, falling within the exploration phase of Shipping 4.0, are currently in work in progress mode: i.e. the DNV GL- MPA project on Autonomous Systems and Intelligent Shipping, a joint industry project (Advanced Autonomous Waterborne Applications - AAWA). These primarily regional clusters' maritime initiatives, namely the Norwegian or Japanese Autonomous Ship projects, play a pivotal role, actually acting as the *Shipping 4.0 platforms* upon which firms can develop complementary products, technologies, and services (Henfridsson and Bygstad, *2013*; Rubalcaba et al, 2012; Yoo et al., 2010), as well as digital capabilities throughout the maritime organizations involved (Nambisan et al., 2017; Barrett et al., 2015). Seen from a different angle, Shipping Cyber Physical Systems technology platforms also represent a juxtaposed, multilayered, emergent network organizational form for Shipping 4.0 value exploration today and value exploitation and appropriation in the medium term future (Gawer and Cusumano, 2014).

Against this background, resources (data, hardware and software but also customary financial and vessel assets) and *digital innovation capabilities* are observed to being *(re) combined and exchanged* in novel ways and create new possibilities for efficiency, transparency, profitability, sustainability, safety and reputational capital, which constitute primary Shipping 4.0 *value drivers* (Barrett et al., 2015). In addition, reputation, trust and non pecuniary *value components* in their digital essence are expected to become increasingly important. An interesting discourse between value extraction rationales, market power embedded value creation and socially responsible value creation is expected to develop.

▪2.1 Stakeholders, power structure and the struggle for ecosystem centrality

Congruent with the above analysis, shipping *business networks* are evolving, with new stakeholders and roles, constituting the digital maritime clusters-innovation ecosystems. Collaborative development of autonomous, semi-autonomous vessels and Shipping 4.0 technologies and platforms is a new organizational form, bringing together traditional maritime players with digital and marine technology providers, namely forming business networks and alliances pertaining ship classification societies and leading shipping companies, shipbuilding companies (including new entrants of autonomous ship manufacturers), marine equipment manufacturers, electronics vendors, business software and satellite communications providers.

Creating and sustaining a central role in the emerging autonomous ship and Shipping 4.0 emergent technology and business platforms is apparently perceived and pursued as a defining factor of the new rules of competition in the Shipping 4.0 era. New digitally enabled services, i.e. cyber engineering and ship design, cloud service provisioning, and Shipping Cyber Physical Systems hardware and software applications development, namely "extended shipping services" ranging from real time cargo tracking to shipping big data analytics enabled commodities trading are observed to be incorporated by both established players (and alliances thereof) and new entrants in the shipping business environment.

The *engagement dynamics* of digital maritime actors in the developing shipping platforms in different shipping sub-markets (liner, bulk) and geographical locations (Asia, Europe) present an interesting heterogeneity and determine shipping companies' positioning and their "control leverage" in the Shipping 4.0 landscape. A quadruple of shipping digital innovation is defined, comprised of the following pertinent components: porterian maritime cluster, shipping sub-sector, Shipping 4.0 platform(s), actors' engagement properties (Thomas et al., 2014; Jarvenpaa andVälikangas, 2016; Dattée et al., 2017).

More in specific, maritime clusters in the digital era still exhibit positive externalities, apparently are more cross-sectoral, and less geographically, proximity constrained than pre-digital era clusters. The significance of regional clusters as the dominant engagement platform pertains important moderating socio-cultural factors. The juxtaposed, Shipping 4.0 platforms and platform engagement modalities are considered as instances of heterogeneous regulatory, market and firm governance regimes (libertarian or protectionist, centralized or more dynamic forms of both cluster/platform and individual actors' governance).

Hence, value co-creation among effectual actors, acting purposefully (or in emergent modalities) within shipping service ecosystems, with shared institutional logics, mental/behavioral frameworks defines the shipping digitalization exploration and exploitation process. Prevailing principles of regulatory compliance, environment protection, and safety, seafarers' wellbeing along with a strong market and entrepreneurial orientation and the newly discovered digital innovation saga are coevolving, consequential to Shipping 4.0 outcomes and their repercussions for management practices.

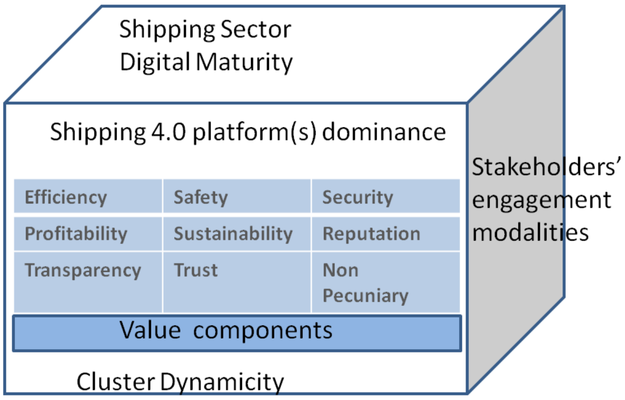

Figure 2. Framing Shipping Digitalization

Against this background, the interpretive and normative analysis of the "design or architecture of the value (co-) creation, delivery, and capture mechanisms", as a prevailing articulation in the generic digital innovation literatures, and applicable artifacts of service science are proposed as a relevant approach to be employed towards further theory development and validation also support of the shipping management practice needs (Marco and Galliers, 2017; Nylén and and Holmström, 2015; Svahn et al, 2017).

3. A Design Science Component

We further synthesize the value centered, service innovation approaches with a juxtaposed, ontologically consistent but practice-orientated *artifact* (Hevner et al, 2014), namely the *maturity model*. We postulate that experimenting with tools that are popular and familiar to practitioners will provide us with an insightful iteration in theory development (Matook and Brown, 2017).

A maturity model consists of dimensions and criteria, which primarily portray key areas of action, also maturity stages that indicate the *evolution path* towards the optimal digitalization end (maturity). Maturity models are a tool that mainly enable an assessment of the current state and indicate a typical development path to a future, presumably identifiable and critically acclaimed optimal state. Maturity models are used in descriptive or prescriptive capacity, the firm being the unit of analysis (Becker et al., 2009). Maturity model elements are coherent with the conjoint business model artifact, which is latently inherited in service innovation research (Zott et al, 2011).

Based on the basic maturity model properties and the articulation of the shipping digitalization and value formation determinant factors (highlighted in the previous sections), we hereafter populate a matrix for digitalization elicitation, strategizing and action points.

Digital Maturity Model for Industrial Services			
	Digitalization Realization	**Digitalization Exploration**	**Digitalization Implementation**
Innovation and Strategic Orientation	*Degree of Innovation Orientation *Degree of Market Orientation *Digitalization Awareness	*Degree of Learning Orientation *Degree of Entrepreneurial Orientation	*Digital Governance *Digital Implementation Capabilities
Predispositions –Digital Culture & Skills	Openness	Harnessing Digital Culture and Skills	Orchestration & Enactment
Resource Orientation	Internal vs. External Resource Identification and Allocation	Resource Generation, Sharing-Exchange and Integration Unstructured-Interdependent Actors Interactions	Resource Deployment Structured – Independent Actors' Interactions

Figure 1. Digitalization elicitation, strategizing and action points

Our analysis of industrial services digital maturity, treated in the case of the shipping sector, highlights a particular instantiation of prevailing factors of the digitalization process and modes (Salerno et al, 2015; Gremyr et al. 2014):

> Innovation orientation (in various nuances), as intertwined but not coinciding with the strategic orientation of shipping firms, bears considerable impact on the unfolding and management of the discreet phases of the digitalization (awareness, exploration, and implementation). Different sets of traditional and digital innovation capabilities are effectual in the discreet phases of digitalization.
>
> At the micro level, an idiosyncratic type of maritime culture, skills and perceptions are affecting the digitalization modalities and outcomes.

Different degrees of nuances and impact of effectual dimensions (vertical axis) are postulated for the stages (realization, exploration, application) of the digitalization unfolding:

> Digital innovation and strategic orientation manifest different priorities and engagement modalities throughout the digitalization phases, whereas resource orientation exhibits different properties throughout the digitalization phases (interdependent/independent modes).

4. Discussion and Summary

Our motivation is the study of "the architecture of the value (co-) creation mechanisms and its managing affordances" as a relevant approach to be employed towards further theory development also support of the emergent shipping management practice needs, today (Gremyr et al., 2014; Kindström, and Kowalkowski, 2009; Salerno et al., 2017). The research corps of service science and digital innovation offers solid foundations for studying the particular industrial services context, and may enable management scholars to further broaden the research avenues for understanding the nature of the firm, business networks and innovation ecosystems as tightly intertwined organizational forms in the IoT and big data era.

We consider the specificities of the maritime industry, as constituting an interesting and relevant instance (case) of industrial smart services to investigate; in specific the value co-creation principles and digital innovation management ramifications, and "how value creation elements are linked together in an architecture that transcend the firm boundaries".

By researching the particular maritime case study, in a phenomenological mode, we seek to address the fundamental question of the nature and attributes of the contemporary firm, intertwined with the structure and power relationships of the emergent digital business networks. We investigate value formation as intertwined with the emergent forms of digital (maritime cyber physical) platforms and associated innovation ecosystems.

Value emergence is initially approached though the exploration vs. exploitation dichotomy of maturity models, while seeking further clarity and granularity in the actors, resources and practices significance and their pertinent nuances in digitalization enactment, in various platform engagement modalities.

The methodological approach employed is a post-positivist angle (service science perspectives), combined with a practice-orientated perspective (maturity model), in the context of the particular industrial services case study. Our work in progress incudes the mathematical modeling of the combined normative frame of shipping digitalization towards a scalar diagnostics and action orientated design science artifact.

5. Reference

Barrett, M., Davidson, E., Prabhu, J., & Vargo, S., Service Innovation in the Digital Age: Key Contributions and Future Directions, *MIS Quarterly*, 2015, 39 (1), 135-154.

Becker, J., Knackstedt, R. and Pöppelbuss, J., Developing Maturity Models for IT Management – A Procedure Model and its Application, *Business & Information Systems Engineering*, 2009, 1(3), 213-222.

Demirkan, H., Bess, C., Spohrer, J., Rayes, A., Allen, D., & Moghaddam, Y., Innovations with smart service systems: Analytics, big data, cognitive assistance, and the Internet of everything, 2015, *Communications of the AIS*, 37 (1), Article 35.

Gawer, A. & Cusumano, M. A., Industry Platforms and Ecosystem Innovation, *Journal of Product Innovation Management*, 2014, 31, 417–433.

George G., Haas M. R., & Pentland A., Big data and management, *Academy of Management Journal*, 2014, 57: 321–325.

Gremyr, I., Witell, L., Löfberg N., Edvardsson, B., Fundin, A, Understanding new service development and service innovation through innovation modes, *Journal of Business & Industrial Marketing*, 2014, 29 (2), 123 – 131.

Henfridsson, O., & Bygstad, B., The generative mechanisms of digital infrastructure evolution, *MIS Quarterly*, 2013, 37 (3), 907-931.

Hevner, A., March, S., and Park, J., Design Science in Information Systems Research, *MIS Quarterly*, 28 (1), 2014, 75-105.

Jarvenpaa, S. L., & Välikangas, L., From Governance Void to Interactive Governing Behaviors in New Research Networks, *Academy of Management Discoveries*, 2013, 2(3), 226-246.

Jokioinen, E., Remote and Autonomous Ship – The next steps, *AAWA Project Position Paper*, 2017, http://docplayer.net/19502019-Remote-and-autonomous-ships-the-next-steps.html.

Kindström, D., and Kowalkowski, C., Development of industrial service offerings: a process framework, *Journal of Service Management*, 2009, 20 (2), 156 – 172.

Levander, O., Forget Autonomous Cars—Autonomous Ships Are Almost Here, *IEEE Spectrum*, 2017, 54 (2), 26-31.

Loebbecke, C. & Picot, A., Reflections on societal and business model transformation arising from digitization and big data analytics: A research agenda, *The Journal of Strategic Information* Systems, 2015, 24(3), 149-157.

Marco, M., and Galliers, R., A reflection on information systems strategizing: the role of power and everyday practices, *Information Systems Journal*, 2017, 27 (3), 347-366.

Matook, S., and Brown, S., Characteristics of IT artifacts: a systems thinking‐ based framework for delineating and theorizing IT artifacts, *Information Systems Journal*, 2017, 27 (3), 309-346.

Mayer, C., Wright, M., & Phan, P., Management Research and The Future of the Corporation: A New Agenda, *The Academy of Management Perspectives*, 2017, 31(3), 179-182.

Nambisan, S., Lyytinen, K., Majchrzak, A. & Song, M., Digital Innovation Management: Reinventing Innovation Management Research in a Digital World, *MIS Quarterly*, 2017, 41 (1), 223-238.

Nylén, D. and Holmström, J., Digital innovation strategy: A framework for diagnosing and improving digital product and service innovation, *Business Horizons*, 2015, 58 (1), 57-67.

Porter, M. E. & Heppelmann, J. E., How Smart, Connected Products Are Transforming Competition, *Harvard Business Review*, 2014, 92 (11), 64–88.

Rubalcaba, L., Michel, S., Sundbo, J., Brown, & S.W., Reynoso, J., Shaping, organizing, and rethinking service innovation: a multidimensional framework, *Journal of Service Management*, 2012, 23(5), 696 – 715.

Salerno, M., Gomes, L., Silva, D., Bagno, R., Freitas S, Innovation processes: which process for which project, *Technovation*, 2015, 35, 59–70.

Storbacka, Kaj, et al., Actor engagement as a microfoundation for value co-creation, *Journal of Business Research*, 2016, 69 (8), 3008-3017.

Svahn, F., Mathiassen, L., Lindgren, R., Embracing Digital Innovation in Incumbent Firms: How Volvo Cars Managed Competing Concerns, *MIS Quarterly*, 2017, 41 (1), 239-253.

Thomas L. D., Autio E., & Gann D. M., Architectural leverage: Putting platforms in context. *Academy of Management Perspectives*, 2014, 28(2), 198–219.

Yoo, Y., Henfridsson, O., & Lyytinen, K., Research commentary-the new organizing logic of digital innovation: An agenda for information systems research, *Information Systems Research*, 2010, 21(4), 724-735.

Zott, C., Amit, R., Massa, L., The business model: recent developments and future research, *Journal of Management*, 2011, 37, 1019–1042.

Exploring the Use of TRIZ in Combination with AHP for Multi-Criteria Decision-Making within the Service Industry

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Abstract

Addressing complexity within a multi-criteria decision-making environment requires an analytical and systematic approach. This paper explores the use of the Theory of Inventive Problem Solving (TRIZ) in combination with the Analytic Hierarchy Process (AHP) to determine the best approach to create a travel package to Belize, Central America. The country of Belize is highly dependent on tourism as a source of foreign revenue; thus, sustaining the inflow of visitors is invaluable to its economy. The objective of this study is to first identify the most influential consumer and business factors, then solve any business contradictions to create the best suitable package. The study uses a survey approach to collect qualitative and quantitative data from experts, visitors, and designated organizations. It applies TRIZ and AHP tools like the ideal final result (IFR) business contradiction matrix, 40 inventive principles, pairwise comparison, and the Delphi method. The results show that the most influential consumer factors are: natural attractions, affordability, safety and security, and people; whereas, the most influential business factors are: cost, complexity, risk, feasibility, and satisfaction. The study analyzes the data using the Super Decisions software and provides an example of how to solve the business contradictions by using the most common inventive principles to create the best package for a budget traveler. All in all, the study provides important insights into the Belize tourism industry and serves as a TRIZ-AHP application guide for multi-criteria decision-making.

Keywords: Analytic Hierarchy Process (**AHP**), Belize, Decision-Making Process, Delphi Method, Theory of Inventive Problem Solving (**TRIZ**)

1. Introduction

A decision-making process becomes challenging when a complex problem has too many related factors, which our traditional logical thinking cannot solve. Thus, a new multi-criteria logic is needed to address this complexity and solve the problem. This study explores the use of the Theory of Inventive Problem Solving (TRIZ) in combination with the Analytic Hierarchy

Process (AHP) to determine the best approach to create a travel package to Belize, Central America.

Belize is both a Central American and Caribbean nation, it shares borders with Guatemala, Mexico, and the Caribbean Sea. According to the Belize Tourism Board (BTB), which is the key executing agency of tourism in Belize, the main reasons for visiting Belize are: (1) unique attractions: Maya ruins, Maya caves, the Great Blue Hole, etc.; (2) Belizean food; (3) music; (4) friendly people; (5) lots of islands with white sandy beaches; (6) wildlife: sea turtles, butterflies, big wild cats, monkeys, whale sharks, birds etc.; (7) adventure travel: island hopping, extreme sports, diving, snorkeling, cave tubing, rafting, horseback riding, fishing, sailing, etc.; (8) luxury: cruises, villas, casinos, resorts, etc.; (9) ease of travel and location; and of course (10) the weather, a tropical climate paradise, which is perfect for weddings, honeymoons, anniversaries, etc. (BTB, 2012). Visitors can choose from a variety of travel packages for any special kind of vacation. Thus, determining the best suitable package is crucial for travel agencies.

The TRIZ-AHP combination has been used mainly to address issues like improvement of manufacturing, quality, and design. Rosli et al. (2013) used TRIZ and AHP to design an automotive door panel. Hsieh et al. (2015) applied TRIZ and Fuzzy AHP to develop an innovative design of a new shape for machine tools. Although this study applies TRIZ and AHP similarly to these studies, it focuses on the "production cycle" of a service – a travel package, instead of improving a physical product or technical system. In addition, for validity and reliability reasons, the study implements the Delphi method, which consists of a group of experts who provide the "official" list of factors and contradictions for the AHP and TRIZ framework. Lastly, instead of using the engineering contradiction matrix, the study applies the ideal final result (IFR) business contradiction matrix.

Overall, the study combines the perspectives of both consumers and businesses using the TRIZ and AHP methodologies to create the best travel package, as illustrated in Figure 1. The rest of the study is presented as follows: Section 2 explains the methodologies and tools, Section 3 shows the application procedures and results, and Section 4 proposes possible extensions for future research.

Figure 1. Methodology Combination

2. Methodology

The Delphi method is a structured communication technique developed by Norman Dalkey, Olaf Helmer, and Nicholas Rescher as a forecasting method which relies on a panel of experts (Dalkey et al., 1963). The experts answer questionnaires in several rounds. After each round, a facilitator provides a summary of the experts' feedback and the reasons they provided for their judgments (McLaughlin, 1990). The range of answers decreases as the group converges towards the "correct" answer.

2.1 TRIZ

The Russian acronym TRIZ stands for "Teoriya Resheniya Izobreta-telskikh Zadach" or the "theory of the resolution of inventive problems" (Altshuller, 1984). It was developed by Genrich Altshuller in 1946 as a knowledge-based systematic methodology for inventive problem-solving. The main concepts of TRIZ are contradiction, ideality and evolution patterns (Altshuller, 1999).

Contradiction arises in an engineering system if an improvement in one characteristic affects another characteristic to degrade. There are two main types of contradiction: technical and physical contradiction. Technical contradiction arises when an attempt to improve certain attributes of a system leads to the deterioration of other attributes of the system. Physical contradiction arises when there are inconsistent requirements to the physical condition of the same system. A system might have a function that is both beneficial and adverse or unpleasant. These problems are solved by resolving the contradiction.

Ideality occurs when a system or "machine" has all its parts performing at the greatest possible capacity, as introduced by Altshuller. It is a measure of how close a system is to the ideal final result (IFR). The ideality of a system can be expressed as shown in Equation (1).

$$\text{Ideality} = \frac{\text{Benefits}}{\text{Costs Harms}} \qquad (1)$$

The positive benefits are the functions provided by the system, while the harm aspects are its useless output and the waste products of the system. One of the objectives of TRIZ is to increase ideality.

TRIZ tools and techniques include: substance-field analysis, functional analysis, ARIZ, 40 inventive principles, 76 standard solutions, etc. (Zlotin et al., 2014). The study applies the

IFR business contradiction matrix, or "win-win matrix", which uses 31 improving and 31 worsening business-related features (Mann, 2007). The matrix states which of the 40 principles have been used most frequently to solve a problem or a particular contradiction. A portion of this matrix is provided in Figure 2 and some of the 40 inventive principles are discussed in Section 3.

		R&D Spec/Quality/Capability	R&D Cost	R&D Time	R&D Risk	R&D Interfaces
		1	2	3	4	5
1	R&D Spec/Quality/Capability		2,4,15,38	21,38,35, 23,15	3,9,24, 23,36,11	3,13,24, 33,38
2	R&D Cost	2,4,15, 38		26,34,1	27,9,34	13,26,35, 1
3	R&D Time	21,38,35, 23,15	26,34,1		1,29,10, 11	15,25,35, 1
4	R&D Risk	3,9,24, 23,36,11	27,9,34	1,29,10, 11		6,29,15, 14,17
5	R&D Interfaces	3,13,24, 33,38	13,26,35, 1	15,25,35, 1	6,29,15, 14,17	

(Source: Mann, 2007)

Figure 2. Portion of IFR Business Contradiction Matrix

2.2 AHP

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970's, uses a multi-criteria logical thinking approach to solve problems or make decisions (Saaty, 1994). It involves breaking the problem down into finer parts, so that judgment can be made comparing only a pair of issues at a time to derive ratio scales. Then, these ratio scales are synthesized throughout the structure to select the best alternative. Therefore, we must first structure a problem hierarchy. Once we have a structure, it is easier to determine the influences driving the decision. AHP can be implemented using software packages like Expert Choice, Super Decisions software or Decision Lens.

The AHP uses a 1 to 9 ratio scale (see Table 1) to construct a "pairwise comparison" matrix for each level in the hierarchy. Each judgment represents the dominance of an element in the left column over an element in the top row to determine which of the two elements is more important, with respect to a higher-level criterion. If the element on the left is less important than the element on top of the matrix, we enter the reciprocal value in the corresponding position in the matrix. The lesser element should always be used as the unit, and the greater one should be estimated as a multiple of that unit. For a set of "n" elements in a matrix, one needs n (n-1)/2 comparisons because there are "n" 1's on the diagonal for comparing elements with themselves, and of the remaining judgments, half are reciprocals. Thus, we have $(n^2\text{-}n)/2$ judgments. In some problems, one may elicit only the minimum of n-1 judgments (Saaty, 1994). This can be shown using matrix A as follows:

Matrix A **Transposed Form** **Complete Form**

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ \frac{1}{a_{12}} & a_{22} & a_{23} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & a_{33} \end{pmatrix} A = \begin{pmatrix} 1 & a_{12} & a_{13} \\ \frac{1}{a_{12}} & 1 & a_{23} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 \end{pmatrix}$$

Table 1. Importance Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

(Source:Saaty, 1980)

Comparing more than two elements provides greater validity of real-world information. The number of elements compared should not be too large to obtain priorities with admissible consistency. Based on the Perron-Frobenius Theorem, the maximum eigenvalue λmax of a positive reciprocal matrix should equal to the consistency of this matrix (Perron, 1907 and Frobenius, 1912). However, pairwise comparison matrices are not consistent; thus, the consistency index (CI) measures their inconsistency and to what extent the inconsistency could still be considered as acceptable, as shown in Equation (2). The deviation from consistency is represented by the consistency index (CI) and the average of randomly generated pairwise comparison matrix named random index (RI), with the fraction CI divided by RI called the consistency ratio (CR), as shown in Equation (3). Table 2 shows the RI range.

The result may obtain more consistency if λmax is closer to n. A further comparison is made by using the difference λmax − n divided by n − 1, with RI. Then, the estimation of inconsistency ratio (IR) of this arbitrary pairwise comparison decision problem can be obtained.

Consistency Index: $CI = \dfrac{\lambda_{\max} - n}{n-1}$ (2)

Consistency Ratio: $CR = \dfrac{CI}{RI}$ (3)

IR would generally be considered acceptable or good in the Super Decisions software, if it's less than 0.1.

Table 2. Random Index

n	1	2	3	4	5	6	7	8	9	10
Random Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(*Source: Saaty, 1980*)

3. Application

The integrated approach framework with TRIZ, AHP, and the perspective of consumers and businesses is shown in Figure 3 as follows:

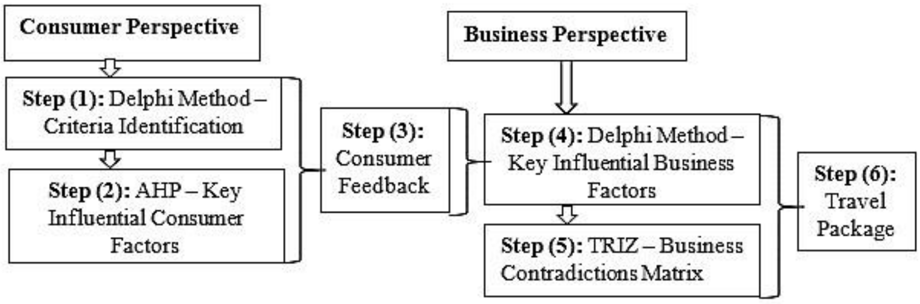

Figure 3. Approach Framework

3.1 Consumer Perspective

The first panel of experts consists of very knowledgeable and experienced individuals who have worked within the Belize tourism industry for many years, including: international peace corps volunteers, archaeologists, and locals. The study uses the following three evaluation rounds:

Round (1): Experts identify which internal, external, positive, and/or negative factors affect visitors' decision to revisit Belize.

Round (2): Experts re-evaluate a new list of only external positive factors and rate their importance.

Round (3): Experts re-rank and do a final approval of the "official" list of factors used to create the criteria and sub-criteria for the main survey questionnaires.

In accordance with the AHP design, the study uses online questionnaires to target a diverse population sample of participants who have been to Belize. Respondents indicate their value, influence, or motivation in terms of importance through the pairwise-comparison method, using the 1-9 Importance Scale (see Table 1). Table 3 shows the criteria and sub-criteria for the main survey questionnaires and Figure 4 shows the AHP hierarchy structure with the goal of determining the key influential consumer factors.

Table 3. Criteria and Sub-Criteria

Criteria	Sub-Criteria
(1) Attractions & Activities	(1) Natural Attractions (2) Built Attractions (3) Private Business Developments (4) Activities
(2) Access & Accommodation	(1) Global Transportation (2) Domestic Transportation (3) Transportation Infrastructure (4) Affordability
(3) Awareness & Attitude	(1) Market Awareness (2) People (3) Service Quality
(4) Amenities	(1) Communication (2) Travel Ease (3) Safety & Security (4) Sanitation

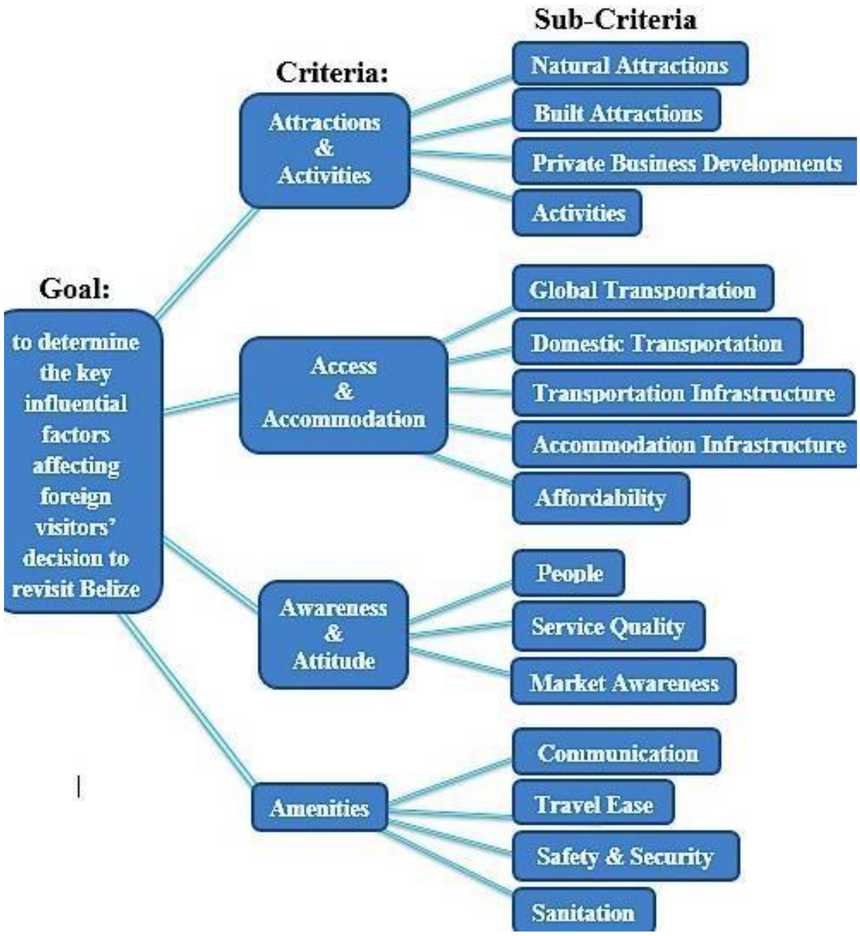

Figure 4. AHP Hierarchy Structure

According to the Super Decisions software results, the most influential criterion is attractions and activities, followed by access and accommodation, amenities, and finally awareness and attitude. Moreover, the most influential sub-criterion for attractions and activities is natural attractions followed by activities, built attractions, and lastly private business developments; for access and accommodation is affordability, followed by accommodation infrastructure, domestic transportation, and lastly a tie between global transportation and transportation infrastructure; for amenities is safety and security, followed by sanitation, travel ease, and lastly communication; and finally, for awareness and attitude is people, followed by service quality and lastly market awareness. Figure 5 shows the limiting importance weights and ideal normalization for each factor by cluster.

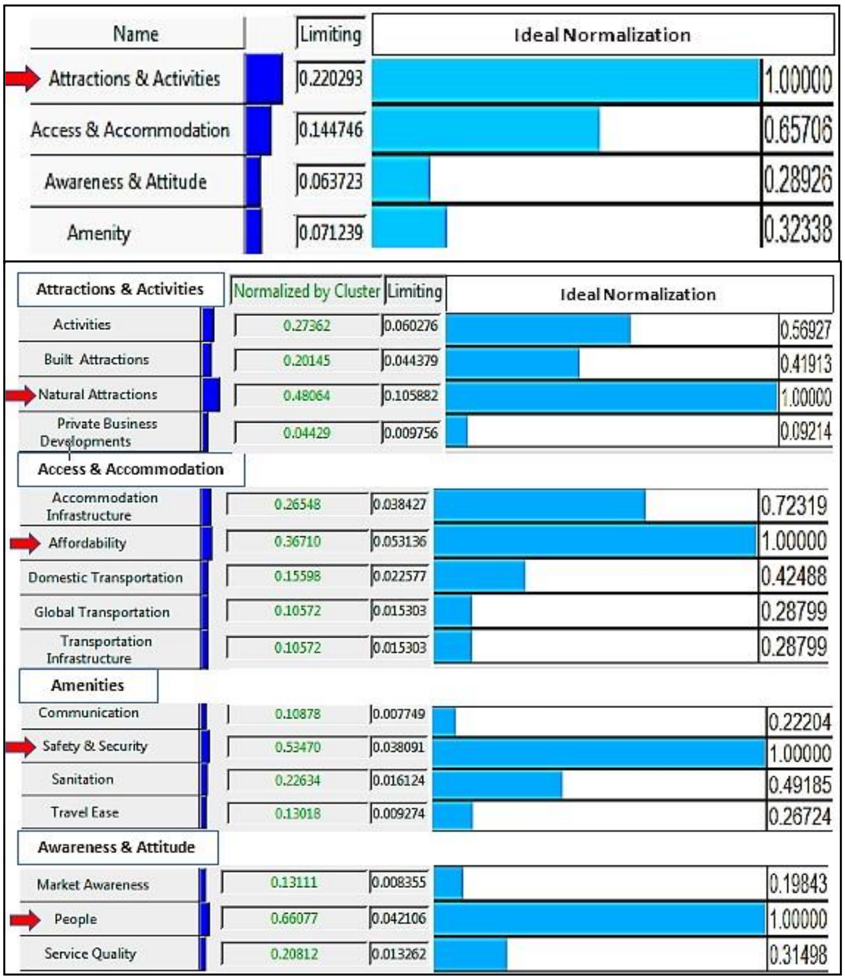

Figure 5. Criteria and Sub-Criteria Priorities

The Super Decisions software also provides the inconsistency ratios for each criteria and sub-criteria, as shown in Table 4.

Table 4. Inconsistency Ratios

		Inconsistency Ratio
Criteria:	(1) Attractions & Activities (2) Access & Accommodation (3) Awareness & Attitude (4) Amenities	**0.04417**
Sub-Criteria: Attractions & Activities	(1) Natural Attractions (2) Built Attractions (3) Private Business Developments (4) Activities	**0.07157**
Access & Accommodation	(1) Global Transportation (2) Domestic Transportation (3) Transportation Infrastructure (4) Affordability	**0.03363**
Awareness & Attitude	(1) Market Awareness (2) People (3) Service Quality	**0.07889**
Amenities	(1) Communication (2) Travel Ease (3) Safety & Security (4) Sanitation	**0.05156**

The inconsistency ratios for each cluster of factors is below the required 0.1 rate for accuracy, validity, and reliability.

3.2 Business Perspective

The second panel of experts includes: travel agents/specialists, philanthropists, and tour guides/operators, who have worked within the industry for five years or more. The study uses the following five evaluation rounds to identify the business factors and contradictions.

Round (1): Experts first review the consumer feedback then list the most influential business factors.

Round (2): Experts re-evaluate a combined list of factors and rate their importance.

Round (3): Experts re-rank and do the final approval of the “official” list of business factors.

Round (4): Experts identify contradictions within the “official” list of factors.

Round (5): The contradictions are plotted in the matrix to identify the corresponding inventive principles.

According to the experts, the most influential business factors are: cost, complexity, risk, feasibility, and satisfaction, and shown in Table 5.

Table 5. Most Influential Business Factors

Factor	Explanation
(1) Cost	Overall cost incurred in organizing package, including: labor cost, transportation cost, research cost, marketing cost, etc.
(2) Complexity	Overall complexity of project, including: selection of sites/activities, scheduling/planning, research, organization, etc.
(3) Risk	Overall uncertainty of project, including: accidents/emergencies, natural disasters, etc. which may increase cost or dissatisfaction
(4) Feasibility	Overall achievability and completion of project
(5) Satisfaction	Overall customer satisfaction with package after experience/service

The study synthesized the list of factors using the IFR business contraction matrix, as shown in Table 6. Cost includes: R&D cost, production cost, supply cost, and support cost; complexity includes: system complexity and control complexity; risk includes: R&D risk, production risk, supply risk, and support risk; and feasibility and satisfaction were equated to "productivity manufacturability" and "product reliability" respectively (Mann, 2007).

Table 6. Factor Equivalence

Factor	Equivalent Factors from IFR Business Contraction Matrix
Cost	#2 R&D Cost, #7 Production Cost, #12 Supply Cost, #17 Support Cost
Complexity	#28 System Complexity, #29 Control Complexity
Risk	#4 R&D Risk, #9 Production Risk, #14 Supply Risk, #19 Support Risk
Feasibility	#6 Productivity Manufacturability
Satisfaction	#16 Product Reliability

The study concludes that agencies want to reduce cost, complexity, and risk, and improve feasibility and satisfaction. Therefore, the suggested contradictions are: (A) feasibility versus cost, (B) feasibility vs complexity, (C) feasibility versus risk, and (D) satisfaction versus risk, as shown in Table 7.

Table 7. Business Contradictions

Contradiction	Improving		Reducing
A	**Feasibility:** #6 Productivity Manufacturability	VS	**Cost:** #2 R&D Cost, #7 Production Cost, #12 Supply Cost, #17 Support Cost
B	**Feasibility:** #6 Productivity Manufacturability	VS	**Complexity:** #28 System Complexity, #29 Control Complexity
C	**Feasibility:** #6 Productivity Manufacturability	VS	**Risk:** #4 R&D Risk, #9 Production Risk, #14 Supply Risk, #19 Support Risk
D	**Satisfaction:** #16 Product Reliability	VS	**Risk:** #4 R&D Risk, #9 Production Risk, #14 Supply Risk, #19 Support Risk

The most influential factors for consumers are: natural attractions, affordability, safety and security, and people (see Figure 5); and the most influential factors for businesses are: cost, complexity, risk, feasibility, and satisfaction (see Table 5). However, these factors are only a general representation consumers' and businesses' perspectives. If visitors require a more customized package, agencies need to reconsider the contradictions, to create the best suitable package.

For example, if a "budget traveler" only cares about affordability, agencies must reduce the price of the package by reducing cost and increasing feasibility (Contradiction A in Table 7). Table 8 shows the plotted contractions in the matrix and the corresponding principles, as conceptual solutions to each contradiction.

Table 8. Corresponding Inventive Principles

	#2	#7	#12	#17
#6	5 2 27 1	15 25 3 10	15 35 13 22	13 10 17 2

The corresponding inventive principles are: merging (5), taking out/separation (2), cheap disposable (27), segmentation (1), dynamization (15), self-service (25), local quality (3), prior action (10), parameter changes (35), "the other way around" (13), "blessing in disguise" (22); and another dimension (17). As an example, agencies may want to focus on #7 (production cost), which includes principles (15), (25), (3), and (10).

Dynamization (15): Agencies can reduce prices during low tourism season (May to October), assign different groups of employees at different locations, or create partnerships with other service providers.

Self-Service (25): Visitors can drive themselves, cook their own meals, and clean their rooms. They can also bring their own equipment for activities like snorkeling/diving, cave-tubing, etc. and explore on their own. Agencies can recycle or reuse materials like towels, napkins, etc. or rent equipment, thus creating a green image.

Local Quality (3): Agencies can provide coupons for local businesses. Resorts can save on electricity by providing open cabins with fresh air or sea breeze. Visitors can stay near a local community or downtown for extra entertainment or exploration. They can meet the local people and learn about the culture, food, etc.

Prior Action (10): Visitors can choose attractions, activities, meal options, etc. before the trip, so that everything is prepared in advance, and agencies can prepare itineraries and backup plans to save time.

These solutions can cut costs and reduce the overall price of the package, thus eliminating Contradiction A. Not every solution may be applicable; therefore, the study recommends an integrated or selective application of the solutions to create the best suitable travel package.

4. Conclusion

This study illustrates the effectiveness of using TRIZ in combination with AHP for multi-criteria decision making within the service industry. TRIZ offers the tools to facilitate concept creation and problem-solving, while AHP is employed as a decision support tool that adequately represents qualitative and subjective assessments under the multiple criteria decision-making environment. The study can be useful to various stakeholders. Tour operators and travel agents can provide more information and develop better destination packages for potential and repeat visitors; foreign visitors in general, especially fist-time visitors, can learn more about Belize and why they should visit; and academics conducting research on this topic, may benefit from the different theories, methodologies, and analysis of empirical data.

Future research may focus on the analysis of direct contradictions between visitors and agencies, instead of solely business contradictions. The TRIZ-AHP hybrid can also be integrated other tools such as Quality Function Deployment (QFD) or Failure Mode and Effect Analysis (FMEA).

References

1. Alshuller, G.S., Creativity as an Exact Science: the Theory of the Solution of Inventive Problems, 1984, Translated by Williams, A. Gordon and Breach Science Publishers Inc.
2. Altshuller, G., The Innovation Algorithm: TRIZ, Systematic Innovation, and Technical Creativity, *Technical Innovation Centre*, 1999, Worcester, MA, USA.
3. Belize Tourism Board, Belize Statistics Digest. Belmopan (BTB), 2012, Available online, https://www.travelbelize.org/, (Accessed on January 1st, 2017).
4. Dalkey, N.; Helmer; and Olaf, An Experimental Application of the Delphi Method to the use of experts, *Management Science*, 1963, **9**(3), 458–467.
5. Frobenius, G., Ueber Matrizen aus nicht negativen Elementen, 1912, *Sitzungsberichte der Koniglich Preussischen Akademie der Wissenschaften,* 456–477.
6. Hsieh, HN.; Chen, JF.; and Quang, HD., Applying TRIZ and Fuzzy AHP Based on Lean Production to Develop an Innovative Design of a New Shape for Machine Tools, *Information,* 2015, *6*, 89-110.

7. Mann, D.L., Hands-On Systematic Innovation for Business and Management, 2nd ed., 2007, (Lazarus Press, UK).

8. McLaughlin, M. W., The Rand Change Agent Study Revisited: Macro Perspectives and micro Realities, 1990, Stanford, CA: Stanford University.

9. Perron, O., Zur Theorie der Matrices, *Mathematische Annalen,* 1907, **64** (2): 248–263.

10. Rosli, M.U.; Ariffin, M.K.A.; Sapuan, S.M.; and Sulaiman, S., Integrated AHP-TRIZ innovation method for automotive door panel design, *Int. J. Eng. Technol,* 2013, *5*, 3158–3167.

11. Saaty, T.L., How to make a decision: the analytic hierarchy process, *Interfaces*, 1994, Vol. 24, No. 6, pp.19–43.

12. Saaty, T.L., The Analytic Hierarchy Process, 1980, New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000), Pittsburgh: RWS Publications.

13. Zlotin, B.; Zusman, A.; Kaplan, L.; Visnepolschi, S.; Proseanic, V.; and Malking, S., TRIZ beyond technology: The theory and practice of applying TRIZ to non-technical areas, 2014, Available online: http://www.trizmantra.com/Learning20%Resource20%files/ TRIZ_Beyond_Technology, (Accessed on January 1st, 2017).

Design and Development of a Novel 3-DOF Pneumatic Automatic Robot for Sewing Production

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Abstract

Because the apparel industry and the footwear manufacturers have the product production automation demands, a novel three dimensional pneumatic automatic sewing machine platform which is designed and developed for the intelligent tailoring production system in this research, can reduce the large manpower costs and time costs in the apparel industry for the footwear manufacturers. The developed three dimensional pneumatic automatic sewing machine platform applied for cotton materials in the automatic tailoring production line can reduce crowded labor force situation immediately and provide a new generation of automatic sewing machine technology. In addition, instead of the traditional tailoring equipment operated electrically, the novel three dimensional pneumatic automatic sewing machine platform actuated by air force is safe and easy to obtain. As a result, the developed three dimensional novel pneumatic automatic sewing machine platform has the structure merits such as cleanness, low cost, high security, high response and energy conservation. The project aims to develop the novel three dimensional pneumatic automatic sewing machine platform for intelligent production. The pneumatic automatic sewing machine platform driven by the nonlinear pneumatic servo system will be proposed and implemented in this study. In detail, the mechanical system and the control system are the primary parts for developing the three dimensional pneumatic automatic sewing machine platform. The D-H notation method is used to resolve the problem of kinematics inclusive of inverse kinematics and forward kinematics in analytical forms for given the end-effector poses, which is used in the path planning of the end effector. In the control system, the control scheme is performed to control pneumatic actuators for following the computed paths that are solved from the target path of the end effector in the path planning. Finally, a three dimensional pneumatic automatic sewing machine platform is established experimentally.

Keywords: Kinematics Analysis, Path Tracking Control, Pneumatic System, Sewing Automation

1. Introduction

In the non-stiffness material-processing industry, such as footwear manufacturers or automobile seat, the automatic process is still low. Because of high manpower costs, most of manufacturers move production lines to low wage countries such as China, Southeast Asia, even in India and Africa for manufacturing. Accordingly, it is necessary to need robots and automatic production system instead of crowded labor force industry. Intelligent robots applied for footwear manufacturers, automobile seat process and apparel industry are more and more popular nowadays. As a result, production costs in Europe and United States greatly reduce, so parts of footwear manufacturers will come back for setting up factories, such as Nike and Adidas. G. T. Zoumponos and N. A. Aspragathos [1] proposed that an innovative fuzzy logic approach for the robotic laying of fabrics on a worktable. Through handling experiments, the solution domain for the path of the robotic gripper is determined, the handling parameters are identified and implicit knowledge is accumulated. Then a proper scheme for the data acquisition is formed and a path-planning algorithm based on fuzzy logic is developed. Due to conflicts and inaccuracies of the acquired data, a subtractive clustering algorithm is used, to identify the proper clusters for the two developed fuzzy systems, with the first employing the clusters as rules and the second a neuro-fuzzy system initialized by the implicit knowledge and trained via back-propagation. Finally, the effectiveness of the two path-planning systems is investigated in an experimental stage where the robot successfully places on a table fabrics of variety of materials and sizes. Panagiotis Koustoumpardis et al. [2] researched that handling of flexible materials is applied for robot manipulators. Besides the difficulties like geometrical uncertainty, obstacle avoidance that emerge when handling rigid materials using robots, flexible materials pose additional problems due to their unpredictable, nonlinear and complex mechanical behavior in conjunction with their high flexibility and high bending deformations. The fact that sewing fabrics is a ‘‘sensitive’’ operation, since fabrics distort and change their shape even under small-imposed forces, poses barrier in the development of automated sewing systems. On the other hand, the need for great flexibility in garment assembly system is really imperative, since cloth manufacturing should cope with fast fashion changes and new materials for fabrics and responding to the consumer demands. Eric Torgerson and Frank W. Paul [3] researched that methods pertaining to the vision-guided robotic control of fabric for performing simulated joining operations for apparel manufacturing. The determination of robot motion paths is based on visual information defining the position of the fabric edges in world coordinates. The usefulness of the shape analysis and motion control algorithms is demonstrated via experimentation with an integrated robot and vision fabric-handling system. Results of these tests show that using machine vision for planning robot motion provides an effective solution for implementing automated robotic fabric manipulation. Xiaoji Liao and Kaiyong Jiang [4] thought that the process of upper sewing is one of the most important steps in the whole shoemaking process, which affects the shoemaking scheme and the appearance of shoes directly. Aiming at improving the automatic level of the uppers sewing process, this paper presented a system which can convert the input of the image of uppers to the output of numerical control code for automatic upper sewing process. The system used a CCD camera to get the image of uppers, and adopted existing image processing technology to carry out noise-removal processing, binarization processing, edge detection, edge thinning, and then the contour of the upper which contains the essential sewing geometric information is extracted from the image. Through vectorization, the contour is approximated to some line and arc segments that can be interpolated on general NC machines. Ryder C. Winck et al. [5] described a novel fabric manipulation method for fabric control during the sewing process. It addressed issues with past attempts concerning fabric position and tension control. The method described involved replacing the current sewing feed mechanism with a servo controlled manipulator to both feed and control the fabric. The manipulator is coupled with a machine vision system that tracks the threads of the fabric to provide real-time position control that is robust with respect to fabric deformations. Robot followed a closed loop trajectory with open loop control while operating in coordination with an industrial sewing machine. The system described also offers a general solution to high accuracy and high acceleration position control systems.

Currently, flourish on high technology industry, the application in semiconductors, manufacturing, biomedical and other related industry are more and more attention in precise position and rapid moving platform. In addition, it is urgent needed to develop the accuracy and high response process device. In recent years, manufacturing industry is developed rapidly, not only enhance the quality production but also emphasize in high accuracy and high efficiency production conditions. Thus, to reach the aim, most of the enterprises have devoted to develop various types of robots instead of traditional man-power. Nowadays, most of the robots work in the industry is driven by motor system which development is more mature. However, the actuators have the limit assembly space, which have to reserve the space for proceeding the multi-axes assembly. Because of pneumatic actuator uses the pressure energy of compressed air as driving force for all types of system. Compared to hydraulic and motor system, the pneumatic actuator system has the advantages like simple structure, cleanness, lightweight, low cost, easy to obtain, high safety in operation, easy maintenance and rapid response. It can be widely applicate in automatic system, semiconductors, photoelectric process devices and medical equipment. Nevertheless, the pneumatic system also has few disadvantages, such as air compressibility, low stiffness, leakage, high nonlinear, sever itself is neutral with no induction area and limited range of motion, lead to the pneumatic system hard to control. The traditional pneumatic system is mostly applied to point and point order control. With a rapid growing of the precise technology, the traditional opened loop control system is gradually unable to satisfied with technological needs. In order to respond the development trend of the precise industry and improve the quality tendency of the medical equipment, it is necessary to integrate sensors into the system and add closed loop control to promote the performance of the pneumatic system. Therefore, it will greatly improve the performance of pneumatic system through detect the measure system and capture a large amount of data to make up a huge database for providing control unit analysis and control.

With the development of technology, many countries such as Europe United States, Japan are started to develop various types of robots to make human life more convenient and have better services. Robots are a self-control mechanical equipment, to achieve self-control behavior by the operation of the programs and internal components. Currently, robots have wide application in auto, mechanical, semiconductors, electronics, food processing and medical industries. The industrial robots can be divided into series robots, parallel robots and multiple series robots. Although, the series robots have widely used in the industry, but the parallel robots are also gradually developed for using in auto, mechanical, models, electronics, semiconductors, panel, photoelectric and other high-technology industries. In spite of parallel robots have many advantages, for example, the cumulative error of each lever link is much smaller, high payload and good stiffness. However, it adopt a closed link design resulting in poor mobility, a narrow work-space and complicated mechanism design. In terms of design and control, it is more difficult and complicated than series robots.

Therefore, with the development of the automatic industries, 4.0 industries and the internet of things, plus the requirement of the apparel automatic sewing machine, and the situation of reducing crowded labor force, a novel three dimensional pneumatic automatic sewing machine platform is developed for the intelligent tailoring production system. Moreover, the developed three dimensional pneumatic automatic sewing machine platform can provide a new generation of automatic sewing machine technology, decrease the large manpower costs and improve the product quality. In this paper, instead of traditional electric sewing equipment, the novel three dimensional pneumatic automatic sewing machine platform is powered by pneumatic system, using compressed air pressure energy as a driven force for pneumatic sewing machine platform. As a result, the developed three dimensional novel pneumatic automatic sewing machine platform bring advantage of the structure merits, cleanness, low cost, high security, high response and energy conservation. Also, in favor of combining with other production devices to achieve the aim of the automation sewing production for the intelligent industry.

2. Design of Three Dimensional Pneumatic Automatic Sewing Machine Platform

In this study, the design of pneumatic sewing machine platform is using closed-chain method. In mechanical part, which includes five pneumatic cylinders of one-dimensional motion. In addition, three dimensional pneumatic automatic sewing machine platform is established. The end point of sewing needle is the three degrees-of-freedom driven to reach automatic sewing fabric surface. The structure of rod-less pneumatic cylinder contains rod-less pneumatic cylinder, actuator and linear encoder, whose detail structure is shown in Figure 1. This study uses the structural characteristics of rod-less pneumatic cylinder and the advantages of easy assembly and design as consider. The combined detail structure of the double pneumatic cylinders is shown in Figure 2. Two rod-less pneumatic cylinders are combined in series. The structure of a three dimensional pneumatic automatic sewing machine platform contains a fixed base, rods and sewing needle, whose structure scheme is shown in Figure 3. Each axis pneumatic cylinder is separated by X axis stroke is 500mm, Y-axis stroke is 200mm and Z axis stroke is 500mm. The main consideration is the design of a three dimensional pneumatic automatic sewing machine platform, which can automatic sewing the general shoe cotton and cloth cotton. In material selection, because of the experimental machine power is pneumatic system. Moreover, it has to consider controlling practically, which the connecting rod must be deformed. Therefore, in order to avoid the influence of weight, which can use lighter material to increase the control error, have the strength of the rod and reach high response, high accuracy characteristics of the design aim.

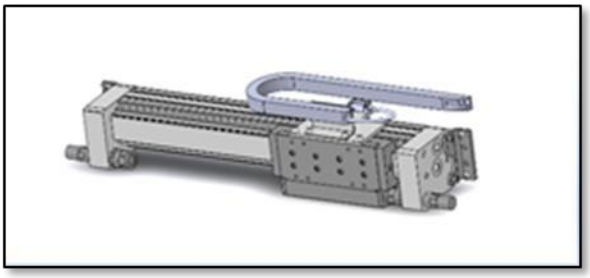

Figure 1. The structure of rod-less pneumatic cylinder.

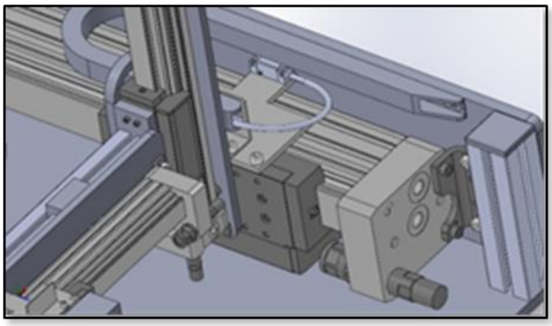

Figure 2. The combined graph of the double pneumatic cylinders.

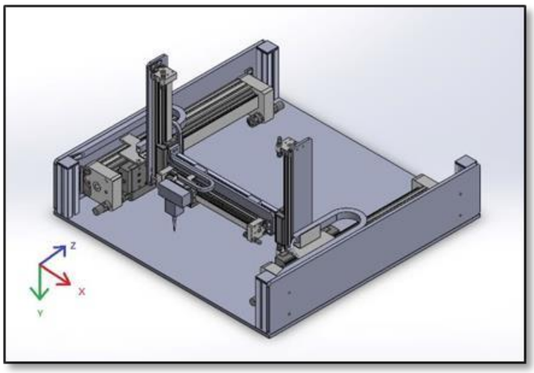

Figure 3. The structure of three dimensional pneumatic sewing machine platform.

3. Degrees of Freedom and Kinematics Analysis of Three Dimensional Pneumatic Automatic Sewing Machine Platform

In this study, a novel three dimensional pneumatic automatic sewing machine platform is developed by the three degrees of freedom mechanical platform for spatial movements. The total degree of freedom of this platform mechanism can be analyzed by the degree of freedom of a mechanism. The mathematic formula can be described as follows:

$$\text{DOF}=\lambda_F \times (n_L - 1) - \sum^{j} c_i \tag{1}$$

where DOF is the mobility (degrees of freedom) of the mechanism. λ_F is total degree of freedom of a mechanism motion space. n_L is number of rods. $\sum_{i=1}^{j} c_i$ is the sum of each joint's individual degrees of freedom, and j is number of total joints.

The mechanism rods in this system includes rod-less pneumatic cylinder, links, sewing needle, which can be obtained degree of freedom as follows:

$$\text{DOF}=6\times(7\text{-}1)\text{-}[(3\times5)+(3\times6)]=3$$

Therefore, the developed three dimensional pneumatic automatic sewing machine platform in this study, the total degree of freedom is three. Because of the movement of the pneumatic sewing platform depends on the position of the slider for rod-less pneumatic cylinder. In other words, in order to obtain the trajectory movement of the pneumatic sewing platform which has to know the position of the slider first. Thus, using the inverse kinematics to reverse the trajectory movement of the pneumatic sewing platform. The inverse kinematics knows the length and the end point of each rod at the position of the workspace, and finds the position of each slider. The inverse kinematics in this system is derived by D-H notation, which solves the kinematic relation. D-H notation method includes four parameters as follow: between the movement of the Z_{i-1} axis and the Z_i axis is d, between the movement of the X_{i-1} axis and the X_i axis is r, between the twist angle of the Z_{i-1} axis and the Z_i axis is θ_i, between the twist angle of the X_{i-1} axis and the X_i axis is α_i.

By means of the four parameters are established and the relationship of the rod notation in this system can be described. The D-H notation is homogeneous transformation matrix between the coordinate system $(XYZ)_{i-1}$ and the coordinate system $(XYZ)_i$. The D-H notation can be written as follows:

$$\begin{aligned} {}^{n-1}T_n &= Rot(z_{n-1},\theta_n)\times Trans(z_{n-1},l_n)\times Trans(x,d_n)\times Rot(x,\alpha_n) \\ &= \begin{bmatrix} \cos\theta_n & -\sin\theta_n\times\cos\alpha_n & \sin\theta_n\times\sin\alpha_n & d_n\times\cos\theta_n \\ \sin\theta_n & \cos\theta_n\times\cos\alpha_n & -\cos\theta_n\times\sin\alpha_n & d_n\times\sin\theta_n \\ 0 & \sin\alpha_n & \cos\alpha_n & l_n \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{aligned} \tag{2}$$

The D-H notation of the three pneumatic automatic sewing machine platform, whose structure scheme is shown in Figure 4. In this study, it establishes eight coordinate planes to analyze the three pneumatic automatic sewing machine platform.

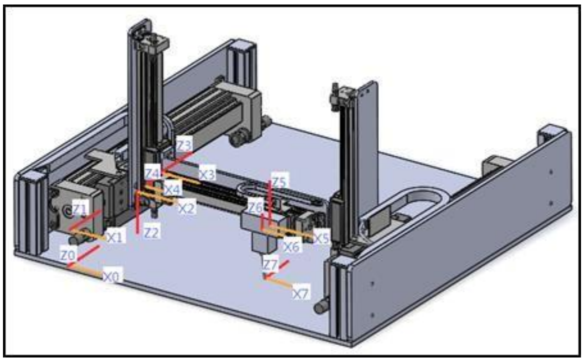

Figure 4. The structure of D-H notation of the three dimensional pneumatic sewing machine platform.

4. Plan and Design of a Novel Integrated Pneumatic Automatic Sewing Machine Platform Experimental System

Figure 5 is architecture diagram of pneumatic sewing machine platform which is integrated sewing equipment. The red part is sewing equipment placement, the left front of the red part is composed by the pneumatic cylinder and axis. In addition, the pneumatic platform can integrate with sewing equipment each other. The mechanism for fixing clothing places on the pneumatic platform, through clothing movement zone to control and sewing zone to control, and with the sewing needle movement to achieve the effective sewing. Therefore, the traditional motor sewing machine is changed to pneumatic sewing machine, and also the characteristics of the pneumatic system like low power consumption, which makes the system have the advantages of energy conservation and environmental protection. Moreover, the bottom design is the position of the control box, which includes the pneumatic value, pneumatic pipeline and controller. The pneumatic sewing machine platform of the integrated sewing equipment adopts light-weight design, which can move the machine, and allow the platform easily to integrate with other systems.

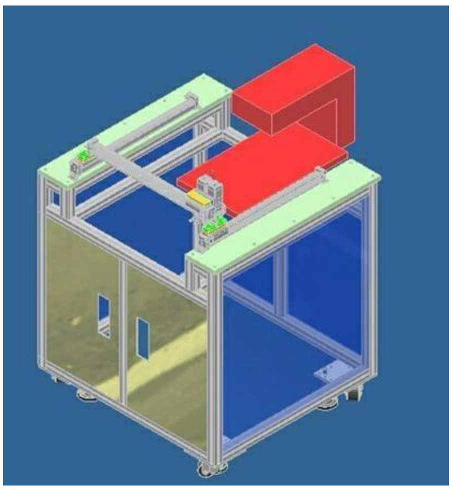

Figure 5. The structure of the integrated pneumatic au-tomatic sewing machine platform (actual sys-tem).

5. Conclusion

The developed 3-DOF pneumatic automatic sewing machine platform is an automatic sewing equipment for the footwear sewing production system in this research. The system will reduce the large manpower costs and time costs in the footwear manufacturers. It is great benefit to introduce full automation in the footwear industries. Be-cause the footwear manufacturers have the product production automation demands, the developed three degrees of freedom pneumatic automatic sewing machine platform applied for shoe materials in the automatic tailoring production line can reduce crowded labor force situation immediately and provide a new generation of automatic sewing ma-chine technology. In addition, instead of the traditional tailoring equipment operated electrically, the novel three dimensional pneumatic automatic sewing machine platform is powered by air force which is safe, easy to obtain and compressibility. As a result, the developed three degrees of freedom pneumatic automatic sewing machine platform has the structure merits, cleanness, low cost, high security, high response and energy conservation. Due to air's advantage such as non-toxic material and easy obtainment, the developed three degrees of freedom novel pneumatic automatic sewing machine platform in this study have the benefits of energy conservation, respond the issues of current environ-mental protection, and reduce harmless to the earth energy.

▪Reference

[1] G.T. Zoumponos and N.A. Aspragathos., Fuzzy logic path planning for the robotic placement of fabrics on a work table. Robotics and Computer-Integrated Man-ufacturing, 2008, 24, 174-186.

[2] Panagiotis Koustoumpardis, Paraskevi Zacharia and Nikos Aspragathos. Intel-ligent Robotic Handling of Fabrics To-wards Sewing. Industrial Robotics: Pro-gramming, Simulation and Applications, 2006.

[3] Eric Torgerson and Frank W. Paul. Vi-sion-Guided Robotic Fabric Manipulation for Apparel Manufacturing. IEEE Control Systems Magazine, 1988, 14–20.

[4] Xiaoji Liao and Kaiyong Jiang. Upper Automatic Sewing Technology Based on Image. Proceedings of the 2008 IEEE In-ternational Conference on Information and Automation, 2008.

[5] Ryder C. Winck, Steve Dickerson, Wayne J. Book and James D. Huggins. A Novel Approach to Fabric Control for Automated Sewing. 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2009, 53-58.

A Study of Using Resources Analysis of TRIZ to Prevent Viper Breeders Been Bitten when Measuring Vipers' Length

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Abstract

Resources analysis solves problems by changing features of the objects around problems. There are three steps in Resources analysis. First, create a checklist of principal demands and requirements to the future solution. Second, create a list of resources and features of resources. Last, decide which resource feature should be changed to generate solutions that can fit principal demands and requirements for the problem. Breeders of the vipers have to measure vipers' length often to keep track with their growth. When measuring, breeders are usually been bitten by vipers. This research tries to use those systematic steps to come up with solutions of the problem. By using resource analysis, we generate some ideas that can improve the situation.

Keywords: Resources analysis, Prevent Viper Breeders Been Bitten

1. Introduction

1.1 Why do we need resource analysis?

Innovation often comes with changes in a currently existing technical system. These changes have to consume resources. Where can we get resources is a big problem.

We must make full use and find out the resources inside the technology system and the environment that could be used in the innovation. We introduce additional resources only when there are really no resources available in the system and the environment. Having the ability to use the limited resources in the technology system and the environment efficiently often plays an important role to a successful innovation.

In the process of solving conflicts and achieving innovation, choosing and using resources appropriately is an important issue. It is an issue that even determines whether the innovation is successful or not.

Being creative when using resources inside and outside the system is an important way to overcome difficulties and to improve the ideality when innovating. Therefore, the choice of the resources is proper or not will determine the success of the innovation.

1.2 Uniqueness of resource analysis

Resource analysis is a method hoping its users improve the system's ideality of the use of resources. That is, increase function, reduce cost, and reduce harmful effects. If users can identify resources and transfer their problem properly, they can find out more ways to solve their problems.

Resource analysis can help users find more resource's dimension. The types of resources include: material, energy field, time, space, etc. The dimensions of time are: past, present, future, or spare, parallel, acceleration, and deceleration. The dimensions of energy field are: Mechanical force, Audible field, Thermal field, Chemical field, Electrical field and Magnetic field. With this systematic analysis, users can find out more possibilities of use of resources. Good identification helps creation. Bad identification holds back creation.

2. Literature Review

Resource analysis is mentioned in some TRIZ books (Genrich Altshuller. 1996, 1999; Gordon Cameron. 2010; Isak Bukhman, 2012; Nikolay Bogatyrev, 2014; Victor Fey 2005). However, there are seldom detailed descriptions in the books. Without detailed descriptions, beginners of Resource analysis may not know how to use resource analysis to help them solve their problems. For this reason, this study arranged the contents, steps and cases of resource analysis of some books, hoping to help beginners understand resource analysis more easily.

3. Methodology

3.1 The choice of resources

The choice of resources needs to be aware of five aspects:

1. We must make full use and find out the resources inside the technology system and the environment that could be used in the innovation. We introduce additional resources only when there are really no resources available in the system. This way, we can simplify the system and reduce costs.

2. Use the same resource in multiple ways.

3. Exploring hidden resources that are not easy to be identify at first sight in the system.

4. Use as much free resources as you can, for example: sunlight, air, wind, temperature.

5. Transform harmful resources into useful resources.

When using the resource can't develop equivalent or higher value of the consumed, the use should be eliminated.

3.2 Kinds of resources

Resources are the sum of substances, field/energy, and information. Under these three kinds, resources can be further classified into 6 categories:

1. Field/Energy resources: gravity field, mechanical field, electrical energy, chemical energy and thermal energy.

2. Information resources: All information which help people make decisions.

3. Structure resources: The form of some shapes or structures can produce beneficial effects or remove harmful effects. We may also add or delete components of the structure to reach some wanted effects.

4. Space resources: Go through all the spaces inside and outside the system and find out idle or spare spaces.

5. Substance resources: Any substance inside and outside the system are resources that can be used, like waste, system components, cheap materials, air, rain, etc.

6. Time resources: Use the time before, during, and after the operation. Reduce time waste.

3.3 Comments for use of resources

Resource Analysis is to list out the system and super system components to decide which component parameter values should be changed for reaching the demand of solving the problem.

Use the problem solution that has the lowest cost and produces least harm.

Use existing resources to create the next generation of the systems or processes.

Through changing the parameter value of the resource, we reach specific requirements of the solution.

Finding the methods to change the parameter values is the way to come up with solutions.

4. The use of resource analysis

There are three steps: clarify requirements, list out resources, and decide how to use resources.

1. Step one: Establish a list of principal requirements to the solution of the problem.

2. Step two: List out resources and identify each parameter of those resources.

3. Step three: Decide which resource parameter value should be changed to reach requirements to the solution of the problem.

The following is the case of how to measure the length of a viper. We use it as an example to illustrate how to use the method.

4.1 step one: Establish a list of principal requirements to the solution of the problem.

4.1.1 Describe the system and problems

a. Describe the problem that needs to be solved.

Breeders of the vipers have to measure vipers' length often to keep track with their growth. When measuring, breeders are usually been bitten by vipers.

b. Draw system structure diagram and label names of the components.

Figure 1. Schematic diagram of measuring the length of a viper

4.1.2 Establish a list of principal requirements to the solution of the problem: Describe the specific requirements that need to be met to solve the problem

1. Need to measure the length of a viper.

2. Measure the viper in its box.

3. Measure at any time we like.

4. People and vipers are all safe.

4.2 step two: List out resources and identify each parameter of those resources.

What is the interaction between resources?

1. Being bitten by a viper, people will be in danger.

2. Vipers will move when being measured.

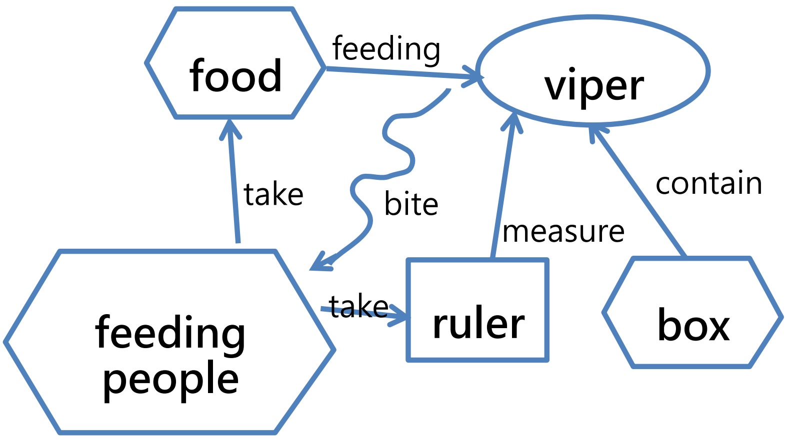

Figure 2. System Context Diagram

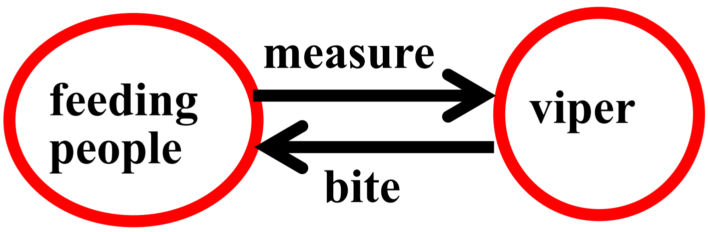

Figure 3. People and viper interactive diagram

4.2.1 List out resources according to the distance and rank of function of the target (object)

Table 1. Resource table inside and outside the system of 'Measuring the length of a viper'

Region	Substances	Fields
in-system resources	viper, box	frictional force
out-of-system resources	people, ruler, food, ground, soil, sunlight, air, rain	gravity, wind, magnetic field

4.2.2 List out resources and identify the name, function, and parameter of resources

Table 2. Resource analysis table inside and outside the system of 'Measuring the length of a viper'

Name	**Function(effect)**	**Parameter(Material, field...)**
Viper	**Target (object)**	Weight, length, temperature (useful & easy to change), age
Ruler	Measuring the length of the viper	Scale, length, hardness
Box	Contain vipers and their food	Weight, length, temperature, material, transparency, shape
Food	Supply nutrition	Weight, volume, alcohol content...
People	Measuring and feeding vipers	Weight, height, temperature, age, immunity

4.3 step three: Decide which resource parameter value should be changed to reach requirements to the solution of the problem.

4.3.1 Choose to change resources and features

Change a characteristic of a resource. As the result, a required function will be reached.

1. Change the characteristics of the viper. As the result, measurement will be done automatically.

2. Change the characteristics of the ruler. As the result, measurement will be done automatically.

3. Change the characteristics of the viper box. As the result, measurement will be done automatically.

4. Change the characteristics of food. As the result, measurement will be done automatically.

5. Change the characteristics of people. As the result, poisoning will be avoided.

4.3.2 The generated solution

1. Put vipers in a freezer. It will make vipers go into hibernation because of the low temperature. Thus, vipers will not move. Measurement of vipers will be easy.

2. Change the shape of the viper box. Design a long, transparent channel with a length scale outside. When a viper moves through the channel, the length of the viper can be measured.

3. Change the degree of alcohol in food. Vipers won't bite people when they're drunk.

4. Inject people with antitoxic serum. People will not be poisoned when they are bitten.

5. Summary and Discussion

Many sources mentioned about Resource Analysis, but when should we use it? The best time for using Resource Analysis is when we know what our key problem is, since the best resources are those that are close to the problem. ARIZ also includes Resource Analysis.

This study attempts to propose a solution to the problem with systematic steps of using resource analysis. By showing the case, we wish it will be easier for beginners to handle resource analysis.

▪Reference

Genrich Altshuller, *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving*, Technical Innovation Center, Inc., 1996. ISBN 978-0964074026

Genrich Altshuller, *The Innovation Algorithm: TRIZ, systematic innovation and technical creativity*, Technical Innovation Center, Inc., 1999. ISBN 978-0964074040

Gordon Cameron, *Trizics: Teach yourself TRIZ, how to invent, innovate and solve 'impossible' technical problems systematically*, CreateSpace Independent Publishing Platform, 2010 .ISBN 978-1456319892

Isak Bukhman, *TRIZ Technology for Innovation*, Cubic Creativity Company, 2012, ISBN: 978-9868563520

Nikolay Bogatyrev, Olga Bogatyreva, *Inventor's Manual*, BioTRIZ, 2014. ISBN 978-1500453657

Victor Fey ,*Innovation on Demand: New Product Development Using TRIZ*, Cambridge University Press, 2005. ISBN 978-0521826204

An Implication of Design Thinking in Culture-based Product Design Process: A Case of Transforming Cultural Features of Vietnamese Traditional Lunar New Year Cuisine to Ceramic Tableware

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Abstract

Tet – Vietnamese Lunar New Year Festival - is considered as the most important festival in Vietnam. During this holiday, Vietnamese traditional cuisines are made to worship their ancestors, and then treated family and friends as one of the main activities in Vietnamese cultural customs. From design point of view, product design with incorporating the cultural features can probably help attract young generations to appreciate the traditionally cultural customs and heritages.

This study, based on Design Thinking initiative, proposes a newly developed culture-based product design process with six phases (i.e., Understand, Observe, Point of View, Ideate, Prototype, and Test) embraced with three levels of culture (i.e., Outer Level, Middle Level, and Inner Level) to promote cultural features in culture-based product design. The process first started with literature research on culture and cultural market survey to understand and observe the target cultural objects resulting in point of view; followed by Affinity Diagram method, Lotus blossom method, and C-Sketch mashed up with three levels of culture to develop as many creative solution concepts as possible; and then scenario building and storytelling with both AEIOU and 5W1H techniques were introduced to help provide distinct perspective and profound knowledge about the solution concepts with target customers. Finally, the chosen solution concept was prototyped and tested. A case with main topic on Vietnamese Lunar New Year Cuisine was demonstrated to present how this newly developed process works.

Keywords: Culture-based Product Design, Design Thinking, Tet – Vietnamese Lunar New Year, Vietnamese Cultures.

1. Introduction

Vietnam is a generally multi-cultural country in which there is a blend of Chinese culture with significant South East Asian influences of Khmer and Japan, and strong Western influences of French and American. Vietnamese cultures have been variously treasured and developed throughout the entire history and geographic expansion of Vietnam, which is one of the factors promoting Vietnam's tourism in addition to natural beauty, geographic and ethnic diversity, fascinating history, political security and low cost (Ashwill & Thai, 2005).

In the "Culture Program's Priorities in Viet Nam (2012-2016)" proposed by United Nations Educational, Scientific and Cultural Organization (UNESCO), culture is also considered as a powerful source of inspiration and unification as well as the national pride to reveal Vietnam and its best to the world. Culture can be the bridge to connect the local identity to the global market. One of three thematic areas UNESCO's Culture Program in Viet Nam also focused on is Cultural Creativity, which enabled transforming cultures into assets, offering new employment opportunities and maximizing Vietnamese's creative expression and enjoyment of diverse cultural goods and services (UNESCO, 2011). In a study on "The Impact of Culture on Creativity" by European Affairs (KEA, 2009), culture-based creativity is also considered as an important feature of a post-industrial economy from developing new products and services, driving technological innovation to inspire people to learn and building communities.

In other perspective, design is another crucial factor, which is believed as the "point where art and technique meet to create another culture," (Flusser, 2002). Design is now everywhere in human's life from public to private spaces. Whatever could be a product could be touched by design. Therefore, designers with culture-based creativity can break the usual way of thinking to acknowledge the evolution of a new vision, an idea or a product (KEA, 2009). However, recently in the contemporary design world, design is no longer limited focusing only on products but more becoming a methodology, which is known as Design Thinking. Design Thinking is a human-centered approach results in innovative impacts on the society development from a large scale of the design industry to a smaller scale of academic environments. Design students have applied design thinking to build up their creative confidence (Brown, 2009). Moreover, Design Thinking also can create a multidisciplinary space in which collaboration will blend the designers' creativity with people's needs and a technological possibility to enable a business strategy to capitalize upon market opportunities (Brown, 2008).

From that point of view, the study focuses on Design Thinking as a crucial platform to build up a culture-based product design process, which can be applied to transform Vietnamese cultural features into modern product design. Moreover, product design with incorporating the cultural features can probably help attract young generations to appreciate the traditionally cultural customs and heritages.

2. Literature Review

▪2.1 Culture-based Creativity

KEA (2009) developed the concept of culture-based creativity, which originated from art and cultural productions or activities "which nurture innovation", not only just "artistic achievements" but also "creative content" for broadband networks, computers and consumer electronic equipments. Moreover, they believed that culture-based creativity could "highlight the elements of culture which trigger creativity". A distinction between culture-based creativity and innovation is also proposed, "to highlight the specific contribution of culture". In order to "characterize" the connection between culture and creativity, the concept of "culture-based creativity" was developed (1) to emphasize the important of creative talents; (2) to recover the meaning of creativity; and (3) to distinguish creativity from innovation (KEA, 2009).

When discussing culture from the perspective of time and space, Xing Liang He (1992) divided "cultural space" into three structural levels: the external, tangible and visible "outer level", the "middle level" of human behavior rites, and regulations in the form of words and language; and the "inner level" of the manifestation of human ideologies. Then more than ten years later in 2003, in a dialogue on culture-based knowledge towards new design thinking and practice, a Hong Kong-based designer Benny Ding Leong mentioned that "spatial perspective of culture" (Figure 2.9) as one of his research tools. He said it was a manageable framework "to visualize and capture the fluid concept of culture", and helped him to identify the research focus. Using that framework could bring him the concentration on to the "inner" level of traditional Chinese culture research (Leong & Clark, 2003).

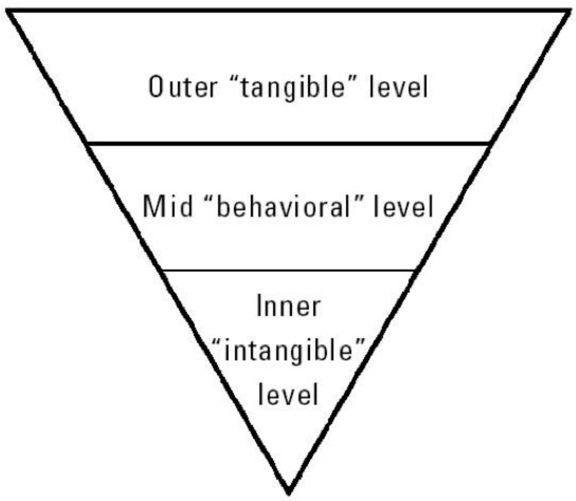

Figure 1. The "spatial perspective" of culture (He, 1992).

Culture-based creativity is a crucial attribute of a post-industrial economy. It can help the development of products and services meet citizens' expectations or create these expectations. It is considered as "fundamental means for industry and policy decision makers" to embrace and implement more the concept of "user-centered strategies" rather than producing things but providing services (KEA, 2009). It also plays a leading role in provoking social innovation by helping "to promote well-being, to create lifestyle, to enrich the act of consumption, to stimulate confidence in communities and social cohesion". Moreover, it makes a big contribution "to product innovation, to branding, to the management of human resources and to communication."

▪2.2 Cultural Design Models

There are various reasons that determined the product consuming, including "practical functions of the product, cultural meanings, aesthetics values, and emotional aspects." Emotional aspects of a product hold an important role in triggering consumers to buy a specific product as it might "evoke effective resonances". One of those might come from the cultural meanings. Every country has its own distinctive and prosperous cultural background, which is always considered as a precious resource of inspiration (Wang et al., 2013). In the 1970s, there was a speedy development in embracing culturally oriented goods and design "as a mean to attract consumers". Therefore "culturally sophisticated products were preferred rather than technological attributes in the 1980s" (Sparke, 2004). Nowadays, culture-based product design is generally mentioned as a creative strategy when some companies and design studios used symbolic value especially national cultural elements in product design to attain a better competitive advantage in the market (Clifton, 2011).

There are many studies revealed that there is an increase in product consuming for symbolic meaning, feelings of pleasure, enjoyed imagery, and aesthetic demand more and more than just for practical or functional needs (Holbrook & Hirschman, 1982; Ravasi et al., 2012; Verganti, 2009). For culture-based branding, Holt (2004) suggested cultural principles for companies, which are aimed "to build up an iconic brand to differentiate themselves to other competitors and also express their identity," (Wang et al., 2013). In the global market, culture-based products guide to make the distinctions instead of uniformity of aesthetic and content (Scott, 2004). Moreover, the intangible value of a product such as emotional arousing, humor, cultural meanings can persuade for the faith of customers to a company (Celaschi et al., 2011; Asokan & Payne, 2008). In summary, transforming cultural features into product design is a potential and future movement in product development, which is also under the impact of culture-based creativity.

▪2.3 Design Thinking Process

Design Thinking process is best described metaphorically as a system of three spaces: Inspiration, Ideation, and Implementation; which separate different sorts of related activities that together might form a continuous sequence of innovation. The Inspiration space is for the circumstances, which might be a problem, an opportunity, or both. It is where the search for solutions gets motivated. The Ideation space is to generate, to develop, and to test ideas that might lead to potential solutions. Finally, the Implementation is "for the charting of a path to market" (Brown, 2008).

With a focus on innovation, creativity, critical thinking, problem solving, communication and collaboration, Design Thinking was taken as learning approach to Schools Research Project to prepare for future students with 21st Century Skills (Carroll et al., 2010). The Design Thinking process includes six key components: Understand, Observe, Point of View, Ideate, Prototype, and Test (Figure 2). The six key components are those developed by the Hasso Plattner Institute for Design in Stanford University, but other design process might have a slight difference.

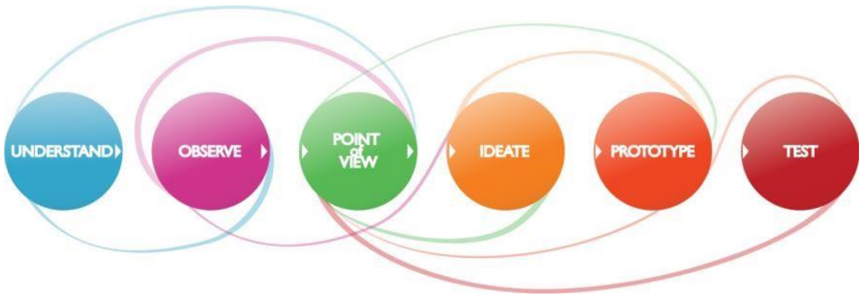

Figure 2. The six key components of the Design Thinking process (Carroll et al., 2010).

3. Methodology

This stage of the research generated three spaces in Design Thinking process (Brown & Wyatt, 2010) (Inspiration, Ideation, and Implementation) with six Design Thinking phases proposed by Carroll et al. (2010) (Understand, Observe, Point of View, Ideate, Prototype, and Test) and Three Levels of Culture Theory (He, 1992; Leong & Clark, 2003) to develop a systematic framework for transforming cultural features of Vietnamese traditional Lunar New Year cuisine to ceramic tableware. There were different creativity activities and tools introduced as hands-on practices in different phases to help participants conduct an implication of design-thinking process and achieve specific tasks in each phase.

In Phase 1 – Understand: participants conducted pre-research on culture with literature review, data collection and group discussion in order to understand the fundamental relevant knowledge on cultural objects. In Phase 2 – Observe: participants were required to do a market survey following the three levels of culture (Outer, Middle and Inner Levels) to comprehend deeper customers' behaviors, needs and insights as well as contemporary technologies and cultural products on the commercial market. In Phase 3 – Point of View: participants with data analyzing figured out the customers' needs as well as narrowing down the design problem, in this case for ceramic tableware. In Phase 4 – Ideate: participants were instructed to use a various collection of hands-on practices with creativity tools such as: Affinity Diagram Method, Lotus Blossom Brainstorming Method, Collaborative Sketching (C-Sketch), AEIOU & 5W1H, Scenario & Storytelling, to diverge, converge and develop conceptual idea solutions. Finally with Phase 5 – Prototype and Phase 6 – Test: participants were required to come out either virtual or physical prototypes (rapid prototypes and then 1:1 scale prototypes) for testing with Value Opportunity Analysis (VOA) to help participants ensure if their design solutions could meet customers' needs. Figure 3 demonstrates the framework of this stage, which is based on three main spaces of Design Thinking with six phases and three levels of culture.

Define design problem

Space 1: Inspiration	Phase 1 **Understand**	Cultural Research	Cultural Object		
	Phase 2 **Observe**	Cultural Market Survey	Outer	Mid	Inner
	Phase 3 **Point of View**	Define Customers' Needs	Product Design (Ceramic Products)		
Space 2: Ideation	Phase 4 **Ideate**	**4.1** Brainstorming & Classification	Affinity Diagram Method		
		4.2 Divergence & Convergence	Lotus Blossom Method		
		4.3 Mashing up with Cultural Levels	Outer	Mid	Inner
		4.4 Group-structured brainstorming	Collaborative Sketching		
		4.5 Scenario Building	AEIOU	Persona	Storyboarding
Space 3: Implementation	Phase 5 **Prototype**	Prototype	Virtual	Rapid	1:1
	Phase 6 **Test**	Test	Test I	Test II	Test III

Figure 3. The systematic framework of the Stage 3: Applying Design Thinking Process with Culture-based Inspiration in Transforming Cultural Features of Vietnamese Traditional Lunar New Year Cuisine to Ceramic Tableware.

▪3.1 Phase 1 – Understand

After the design problem had been designated, participants who attended this design thinking process were required to: (1) carry out a cultural research for foundational comprehension based on three questions: What is the cultural object? How does it influence the customs and daily products? Is there any cultural product design in our daily life? Therefore the participants could get an overall understanding about the cultural object with its background as well as the influenced customs; (2) present the pre-research before teammates which are from cross-disciplines and conduct a group discussion for a more extensive interpretation of the problem.

▪3.2 Phase 2 – Observe

With the foundational comprehension from Phase 1 and followed by three levels of culture (Outer, Middle and Inner Levels), participants carried out a market survey with an online field trip to several commercial websites on ceramic tableware in Vietnam in order to verify if there is any possibility of ceramic tableware with cultural features from Vietnamese traditional Lunar New Year cuisines available on the Vietnamese market. Moreover, they interviewed some prospective customers to understand their behavioral and reflective insights. This was also one of the significant features of Design Thinking: human-centered approach (Brown, 2008).

▪3.3 Phase 3 – Point of View

Participants analyzed the output data from two previous phases to make a narrower focus on the design problem and define the customers' needs.

▪3.4 Phase 4 – Ideate

Step 1: Brainstorming & Classification: Affinity Diagram Method

After conducting the market survey, participants were asked to write down all keywords relating to cultural topic of Vietnamese traditional Lunar New Year cuisines on post-it papers. After that, they categorized them in groups of issues. This activity helped participants focus on the potential group of issues, which could meet the customers' needs and be applied in the real market.

Step 2: Divergence & Convergence: Lotus Blossom Brainstorming Method

Participants set cultural topic in the center of Lotus Blossom Map, and then fill the first layer of boxes with main keywords from the previous step of Affinity Diagram Method. Those main keywords in the first layer of boxes would be set as main topics in the center of the second layer for divergence. Following those new central keywords, participants figured out more keywords to expand the map until it was completed. Finally, the convergence of the Lotus Blossom Map would be started from the outmost layer towards the center. With the central keywords of each layer, two other keywords would be chosen for the idea combinations. There would be 8 idea combinations from the final map. They would be written in the format: "Design topic = Keyword 1 + Keyword 2 + Keyword 3 +…+ Keyword n."

Step 3: Mashing up with Cultural Levels: 3 Levels (Outer, Middle, and Inner)

For the purpose of concentration on cultural topic, each of the idea combination from the previous step of Lotus Blossom Brainstorming Method was mashed up with one cultural level form three levels of culture. For example, a new idea combination would be re-written in the format:

"Design topic A = Keyword A1 + Keyword A2 +…+ Keyword An + Outer Level." The others might be "Design topic B = Keyword B1 + Keyword B2 +…+ Keyword Bn + Middle Level"; "Design topic C = Keyword C1 + Keyword C2 +…+ Keyword Cn + Inner Level."

Step 4: Group-Structured Brainstorming: Collaborative Sketching

From the new idea combinations got in the previous phase of Mashing up with Cultural Levels (Outer, Middle, and Inner) participants would write down that new idea combination on the top of the sketch paper and performed a round of collaborative sketching. They would not have any communication during conducting the Collaborative Sketching. At the end of this activity, they would stick all the sketches on the wall to present about their conceptual sketches and ideas. At this moment, they would discuss more about all the conceptual sketches they got from a round of Collaborative Sketching, and then they would vote for three most potential concepts for next steps of Ideation.

Step 5: Scenario Building: AEIOU & 5W1H, Persona & Storyboarding

From the conceptual idea chosen in the precious step of Collaborative Sketching, participants would use some methods or techniques to build up the scenarios in which the products would meet customers' needs. AEIOU (standing for Activities, Environments, Interactions, Objects, and Users), 5W1H (standing for Who, What, When, Where, Why, and How), Persona (with more detailed characteristics such as: name, gender, occupation, education, hobby, and personality, etc) and Storyboarding (with six panel framework and a brief description based on "who, where, what, when, why, how") are some methods suggested for visually establishing more detailed development for potentially conceptual design solution.

▪3.5 Phase 5 – Prototype

Participants would make: (1) virtual prototypes by detailed sketching or 3D modeling rendered images; (2) rapid prototypes with paper or simple and cheap material to quickly model up a physically prototyped product; (3) a group discussion with virtual prototype and rapid prototype to evaluate and refine for a better solution, after that a 1:1 scaled prototype by 3D printing with refined details and shape for a better image of conceptual solutions for next step of Implementation.

▪3.6 Phase 6 – Test

Following three times of prototyping, participants would make three times of testing: (1) The first time was to check if the conceptual sketches from previous phases could be developed after the group discussion about the possibilities and limitations. (2) Getting feedback form group discussion through rapid prototypes might lead to more ideas for improving or developing the product solutions in the real commercial market. (3) At the final testing, the 3D printed conceptual product at the scale 1:1 with refined details and shape would be used to take a qualitative survey with Value Opportunity Analysis (VOA). An in-depth interview would be conducted with a potential customer for more feedback to enhance the conceptual product in Implementation. This phase is to ensure the possibility of the conceptual product as a culture-based product design.

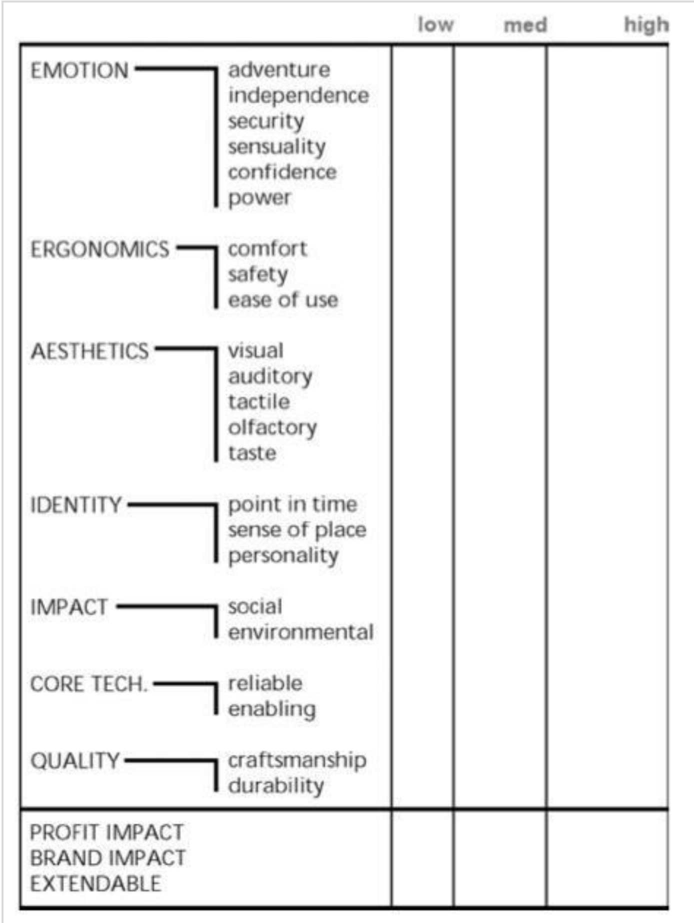

Figure 4. Value Opportunity Chart (Cagan & Vogel, 2002)

Figure 4 shows a Value Opportunity Chart, which would be used to evaluate how product might meet target customers' needs or insights for usefulness, usability, and desirability. The chart lists 7 classes of Value Opportunity with its attributes in a column. The values are measured in a qualitative range and are described as low, medium, and high for each attribute. If a product did not meet any level of that attribute, no line is drawn (Cagan & Vogel, 2003).

4. Results and Discussions

Five Vietnamese graduate students from different departments in Ming Chi University of Technology (New Taipei City, Taiwan) conducted this Stage 3 in one-day mini-workshop on May 5th, 2018. Some parts of the process were conducted after the workshop.

There is a multi-disciplinary collaboration in the group of five participants who joined to demonstrate this implication of design thinking in culture-base product design process. The demographics of this group functionally imitated a "typical company" in its small scale with roles and responsibilities:

- Design Team: including two graduate students from Industrial Design; both of them used to work in Vietnamese companies producing ceramic products. These team members are mainly in charge of designing the products, from the conceptual to developed sketches and models till the sample products.
- Technical Team: including two graduate students. One is from Industrial Engineering and Management; his major is about Ergonomics. The other is from Safety, Health and Environment Engineering. These team members are mainly in charge of technical manufacturing of the products.
- Business Team: including one graduate student from Business Administration. This team member is mainly in charge of business model and profitable abilities of the products.

Moreover, for the culture-based advantages, there is also a multi-regional collaboration in this group. They are from the North of Vietnam (Ha Nam Province), the Middle of Vietnam (the old capital Hue City, the newly developed Da Nang City), the South of Vietnam (Ho Chi Minh City), and one is Guangdong Vietnamese from China Town (Ho Chi Minh City). This interestingly influenced the diversity of the cuisine cultures and customs in the group.

▪4.1 Phase 1 – Understand

The group of five participants conducted a research for fundamental knowledge about Vietnamese cuisine in Tet – the Lunar New Year in Vietnam. Firstly, the team leader presented her pre-research before other team members, based on three questions: What is Vietnamese traditional Lunar New Year cuisine? How does it influence their customs in using ceramic tableware? Is there any daily life ceramic tableware designed with cultural features of those cuisines? After that, the team discussed more on the research to help other teammates understand deeper the reality of Vietnamese cuisine and customs for Tet among different areas in Vietnam, such as: main traditional cuisines, cuisines required for ancestor worship, activities during the time of "eating Tet", eating-style diversity in various regions in Vietnam (the North, the Middle, the South of Vietnam, and in a typical Chinese Vietnamese family), etc.

▪4.2 Phase 2 – Observe

Based on the Understand phase, the group conducted a market survey to learn if there is any application of Vietnamese cuisine to ceramic tableware on the commercial market, especially in export market. With human-centered spirit, they also interviewed potential customers to understand their behaviors in using ceramic tableware, especially Vietnamese ceramic tableware. This observation encourages the group to develop a sense of empathy (Carroll et al., 2010).

▪4.3 Phase 3 – Point of View

After the group learned form Phase 1. Understand and Phase 2. Observe, they developed a Point of View that focused on potential customers' needs and insights (Carroll et al., 2010). In this case with culture-based product design, the design problem was narrowed down through their research: (1) there was a lack of design in Vietnamese ceramic tableware market especially for export purposes, (2) Vietnamese young people prefer second-hand Japanese industrial ceramic tableware for the cheap prices and variety in design, (3) the Vietnamese cultural features were often exploited with very old-fashioned concepts and images.

▪4.4 Phase 4 – Ideate

Step 1: Brainstorming & Classification: Affinity Diagram Method

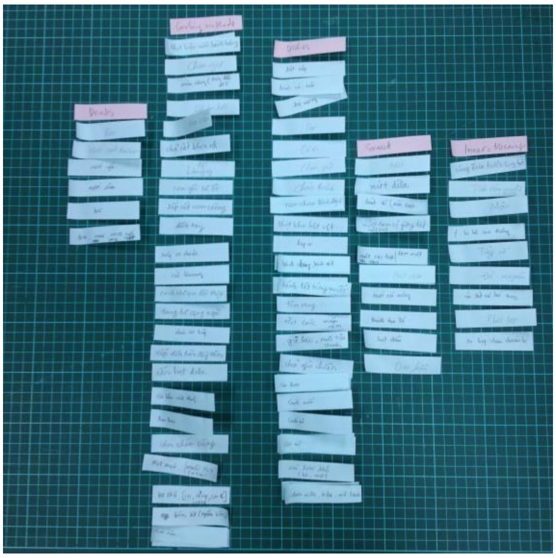

Figure 5. Affinity Diagram Method

With new knowledge after the market survey and defined design problem from previous steps, the five participants in the group wrote down all relevant keywords on post-it papers and categorized into groups. They came out totally 71 keywords and grouped into 5 themes: Traditional dishes, Cooking methods, Drinks, Sweets, Cultural Meanings (Figure 5).

Step 2: Divergence & Convergence: Lotus Blossom Brainstorming Method

The participants set Vietnamese traditional Lunar New Year cuisine (coded "VN Tet cuisine" in short) – the cultural topic – in the central box of Lotus Blossom Map, then fill 5 main keywords from the previous categorized groups. They need 3 more to complete the very first level of the 9-window-map. These 8 keywords would be the central keywords of the second level 9-window-map to be continued for divergence. After fulfilling the whole map of 3 levels of 9-window-map, they came out 8 idea combinations (Figure 6).

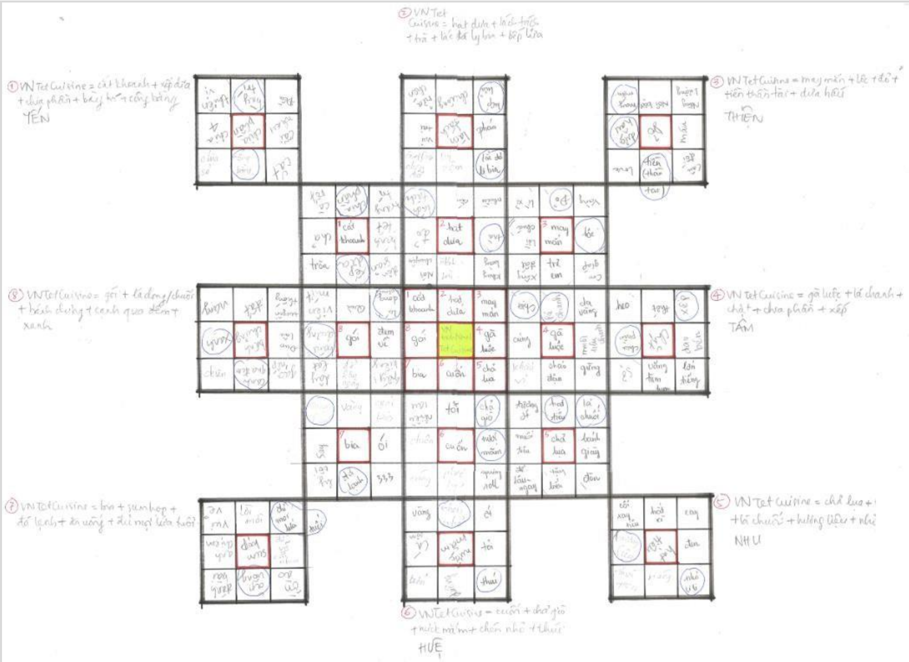

Figure 6. Fulfilling the whole Lotus Blossom Map with the cultural topic: Vietnamese traditional Lunar New year cuisines

Step 3: Mashing up with Cultural Levels: 3 Levels (Outer, Middle, and Inner)

From 8 idea combinations got from the previous phase (Lotus Blossom Brainstorming Method), each participant chose one idea combination and one cultural level to mash up. Therefore, there would be 5 newly culture-based idea combinations (Table 1).

Table 1. Mashing up 5 idea combinations with Cultural Levels

	Idea combinations	**Cultural Levels**
1	VN Tet cuisine = roll + spring rolls + fish sauce + small bowl + smelly	Middle
2	VN Tet cuisine = pork bologna + peppercorn + banana leaf + spice + tiny	Inner
3	VN Tet cuisine = ring cut + arrange plates + partly divide + decorate + equal	Middle
4	VN Tet cuisine = boiled chicken + lemon leaf + chop + partly divide + arrange	Middle
5	VN Tet cuisine = lucky + fortune + red + God-of-Wealth money + watermelon	Inner

Step 4: Group-Structured Brainstorming: Collaborative Sketching

With those 5 newly culture-based idea combinations, participants performed one round collaborative sketching in 25 minutes. After finishing, they came out 25 sketches (5 sketches for each of 5 newly culture-based idea combinations) in which they voted for 3 final conceptual sketches for the next phase of Design Thinking Process (Figure 7).

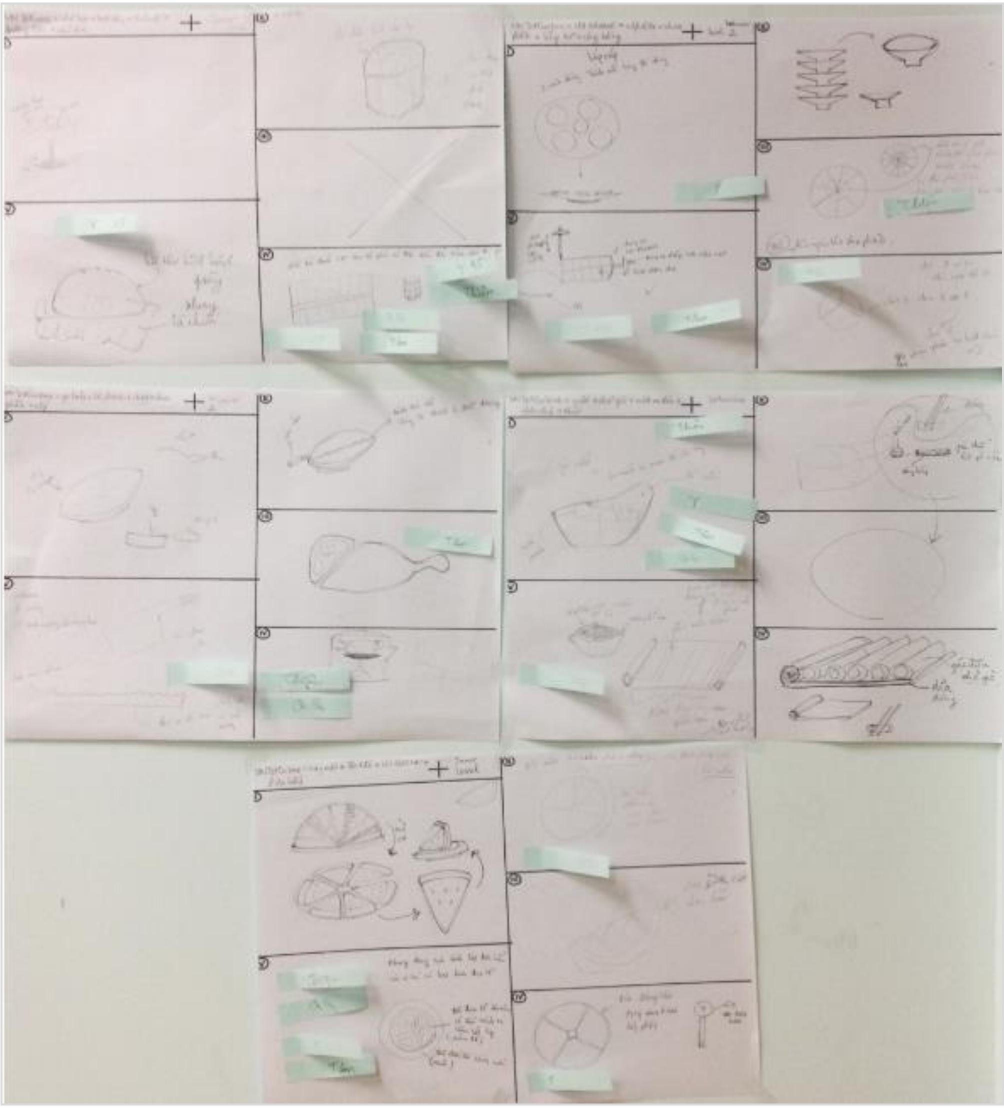

Figure 7. 25 sketches from C-sketch with 5 newly culture-based idea combinations

Step 5: Scenario Building: AEIOU & 5W1H, Persona & Storyboarding

From the final conceptual idea from the collaborative sketching (Step 4), with the case Spring Roll Sauce Bowl, participants used 5W1H & AEIOU to get the detailed and imaginative approach to potential customers who might use the product in some situations. In this case, these methods could help students understand more about the possibility and convenience of using the Spring Roll Sauce Bowl with a purpose of avoiding smelly sauce on hand (Figure 8).

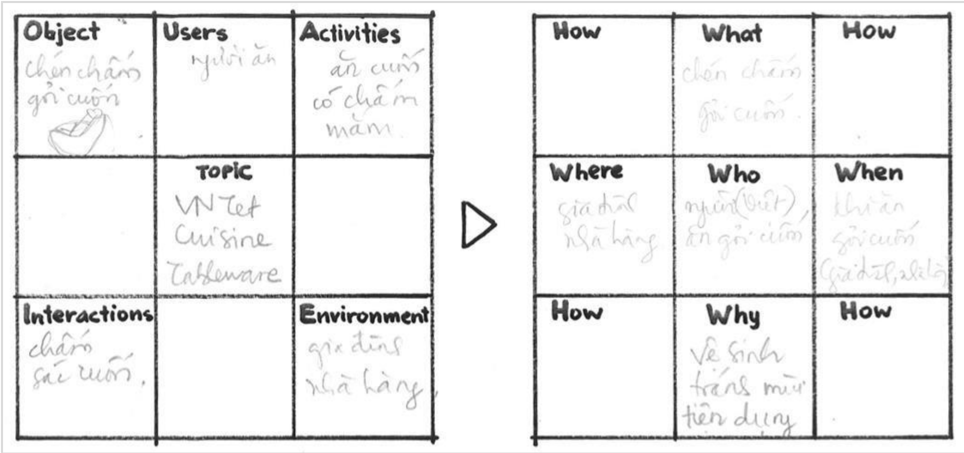

Figure 8. Using 5W1H and AEIOU to approach to potential customers

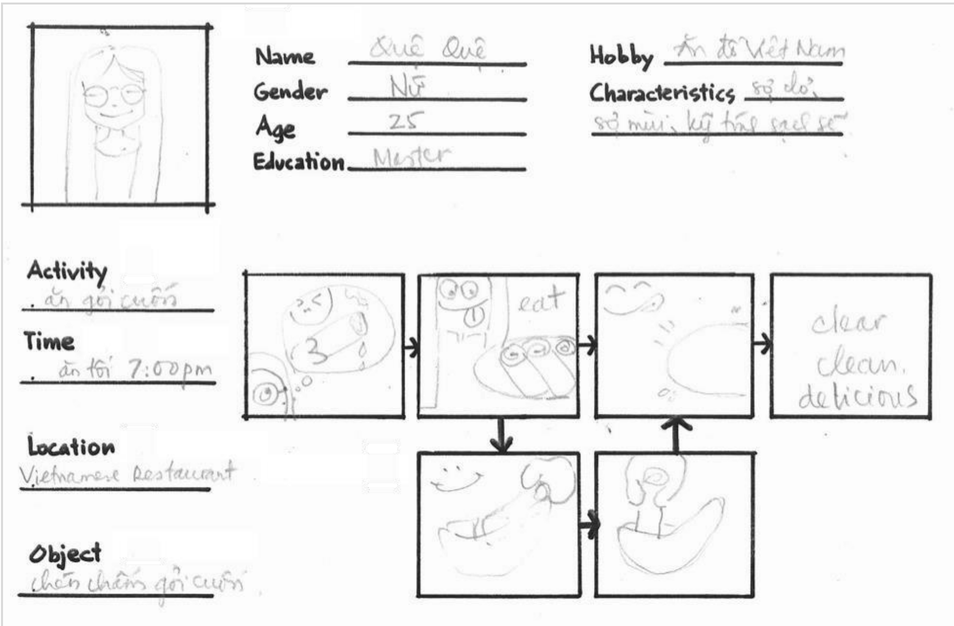

Figure 9. Using Scenario and Storytelling to have a better imagination of potential customers

With detailed and contributive information from 5W1H & AEIOU, participants carved more clearly with the personas that would be potential customers of their product design by developing storyboards visually (Figure 9). In this case with Spring Roll Sauce Bowl, they described the scenario in which a young lady named Que Que (who) wanted to eat spring roll in a Vietnamese restaurant (where) for dinner (when). However she was afraid of smelly sauce on hand when holding and eating the spring roll (why), so she used the Spring Roll Sauce Bowl (what).

▪4.5 Phase 5 – Prototype

Participants in Design Team conducted this phase three times to refine the conceptual product whether it could fulfill the customers' needs or requirements as products of culture-based ceramic tableware which easy to use for daily purpose in family, restaurant, and for tourist souvenir as well. Figure 10 would show more about the Spring Roll Sauce Bowl with virtual, quick and 1:1 prototypes.

Figure 10. Prototypes (virtual, rapid and 1:1 scale) of Spring Roll Sauce Bowl

▪4.6 Phase 6 – Test

Participants in Design Team had team discussions twice with virtual and rapid prototypes before taking target customer test with 1:1 scale prototype and Value Opportunity Analysis. (VOA). This phase is to ensure the possibility of conceptual product Spring Roll Sauce Bowl that was persuaded as a product of culture-base ceramic tableware (Figure 12) compared with other designs in the real market (Figure 11).

The chosen target customer is a Vietnamese female graduate student also from Ming Chi University. She is 23 years old, and from Industrial Engineering and Management department. She is quite introverted and cautious but interested in Vietnamese traditional folk games and cuisines. Figure 12 shows among many specific Value Opportunities, Emotion and Identify are much more value added for the culture-based product rather than the original product. While other Value Opportunity is almost the same between the culture-based product and the existing commercial product. The target customer also shared her belief on the importance and challenge of storytelling in culture-based products for approaching customers as well as educating for the new culture-based impact.

Figure 11. Existing commercial products in the market

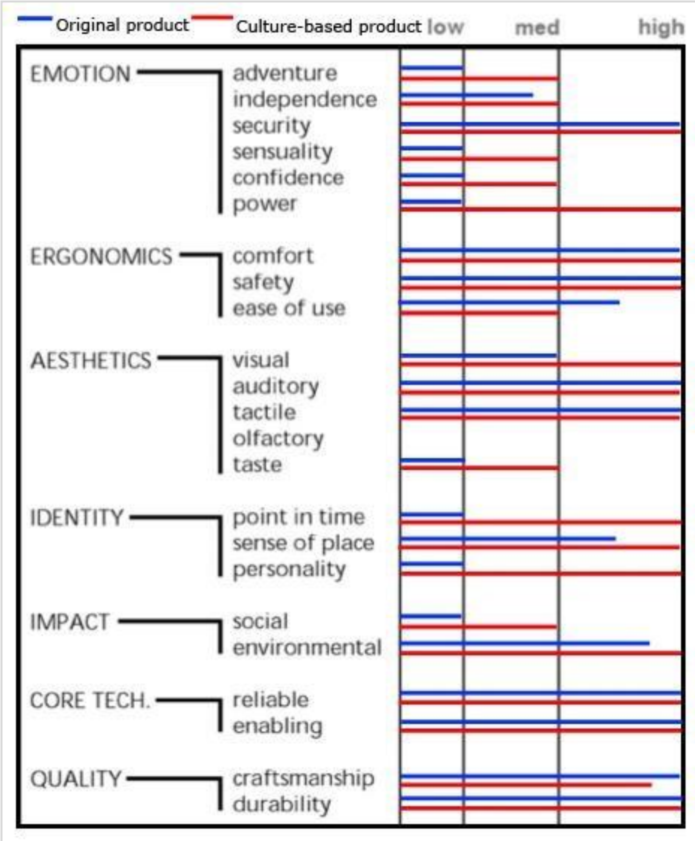

Figure 12. Value Opportunity Analysis for the conceptual product Spring Roll Sauce Bowl

5. Conclusions

This study generated three spaces in Design Thinking process (Brown & Wyatt, 2010) (Inspiration, Ideation, and Implementation) with six Design Thinking phases proposed by Carroll et al. (2010) (Understand, Observe, Point of View, Ideate, Prototype, and Test) and Three Levels of Culture Theory (He, 1992; Leong & Clark, 2003) to develop a systematic framework for transforming cultural features of Vietnamese traditional Lunar New Year cuisine to ceramic tableware. Understand, Observe, and Point of View in the first space (Inspiration) help participants understand the fundamental relevant knowledge on cultural objects, comprehend deeper customers' behaviors, needs and insights as well as contemporary technologies and cultural products on the commercial market, and figured out the customers' needs as well as narrowing down the design problem. In the second space (Ideation), there are many creativity tools such as: Affinity Diagram Method, Lotus Blossom Brainstorming Method, Collaborative Sketching (C-Sketch), AEIOU & 5W1H, Scenario & Storytelling for participants to diverge, converge and develop conceptual idea solutions. Finally in the third space (Implementation), Prototype and Test encourage participants to come out either virtual or physical prototypes (rapid prototypes and then 1:1 scale prototypes) for testing with Value Opportunity Analysis (VOA) to help participants ensure if their design solutions could meet customers' needs.

The implication of Design Thinking to Culture-based Product Design Process is a two-dimension framework combined from three levels of culture as the vertical dimension, and Design Thinking process as horizontal dimension. Therefore, the study might produce a different approach in which cultural features still focusing but keeping as the main and strong target for designers to conduct divergence and convergence in more effective ways.

▪Reference

Ashwill, M. A. and Thai, N. D., Vietnamese Today: A guide to a nation at a crossroads, 2005 (Intercultural Press).

Asokan, A. and Payne, M. J., Local cultures and global corporations, *Design Management Journal*, 2008, **3**(2), 9-20.

Brown, T., Design Thinking, *Harvard Business Review*, 2008, **86**(6), 84-92.

Brown, T., Change by design: how design thinking transforms organizations and inspires innovation, 2009 (Harper Business).

Brown, T. and Wyatt, J., Design thinking for social innovation, *Development Outreach*, 2010, **12**(1), 29-43.

Cagan, J. and Vogel, C. M., Creating Breakthrough Products: Innovation from Product Planning to Program Approval, 2002 (FT Press).

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A. and Hornstein, M., Destination, Imagination and the Fires Within: Design Thinking in a Middle School Classroom, *International Journal of Art & Design Education*, 2010, **29**(1), 37-53.

Celaschi, F., Celi, M. and García, L. M., The extended value of design: an advanced design perspective, *Design Management Journal*, 2011, **6**(1), 6-15.

Clifton, N., Regional culture in the market place: Place branding and product branding as cultural exchange, *European Planning Studies*, 2011, **19**(11), 1973-1994.

Flusser, V., Petite philosophie du design, 2002 (Circé).

He, X. L., The Worship of Chinese Gods of Nature, 1992 (San-Lian Bookstore).

Holbrook, M. B., and Hirschman, E. C., The experiential aspects of consumption: Consumer fantasies, feelings, and fun, *Journal of consumer research*, 1982, **9**(2), 132-140.

Holt, D. B. and Holt, D. B., How brands become icons: The principles of cultural branding, 2004 (Harvard Business Press).

KEA, The impact of culture on creativity, study prepared for the European Commission, *European Commission*, 2009.

Leong, B. D. and Clark, H., Culture-based knowledge towards new design thinking and practice—A dialogue, *Design Issues*, 2003, **19**(3), 48-58.

Ravasi, D., Rindova, V. and Dalpiaz, E., The cultural side of value creation, *Strategic Organization*, 2012, **10**(3), 231-239.

Scott, A. J., Cultural-products industries and urban economic development: prospects for growth and market contestation in global context, *Urban Affairs Review*, 2004, **39**(4), 461-490.

Sparke, P., An Introduction to Design and Culture: 1900 to the Present, 2004 (Oxon).

Verganti, R., Design driven innovation: changing the rules of competition by radically innovating what things mean, 2009 (Harvard Business Press).

UNESCO, The UNESCO's Culture Program's Priorities in Viet Nam (2012-2016), 2011.

Wang, Y. H., Qin, S. F. and Harrison, D., Culture-inspired design principles, methods and tools in current products. *Paper presented at the International Conference: Consilience and Innovation in Design. Tokyo, Japan*, 2013.

Solving the 1D Stock Cutting Problem based on a Simulated Annealing Algorithm

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Abstract

A 1D cutting stock problem is a general issue in many practical fields. The goal of the 1Dimension cutting stock problem is to cut the bars of desired lengths in required quantities from linger bars of given length. To obtain the result needs find an optimal combination of combination set. Because of its NP-hard nature, finding an optimal solution in reasonable time is extremely difficult. To approach an acceptable solution in a short computation time, we used simulated annealing algorithms. In this paper, I proposed a system that use simulated annealing algorithms to find an acceptable solution. The results show that the proposed SA (Simulated Annealing) gives good results and in most cases it can approach the answer under 1 minute.

Keywords: One-dimensional cutting stock problem, Simulated annealing.

1. Introduction

A 1D cutting stock problem is a general issue in many practical fields, such as architecture, steel material. The goal of the 1Dimension cutting stock problem is to cut the bars of desired lengths in required quantities from linear bars of given length. To obtain the result needs find an optimal combination of combination set. Because of its NP (nondeterministic polynomial time)-hard nature, finding an optimal solution in reasonable time is extremely difficult. In this paper, we proposed a system that use simulated annealing algorithms to find an acceptable solution. The results show that the proposed SA gives good results.

2. Simulated annealing algorithms

Simulated annealing (SA) is a method for solving unconstrained and bound-constrained optimization problems(Kirkpatrick, 1983 #1245). SA can get an acceptable solution in a short period especially in the NP-hard solutions. SA models the physical process of heating a material and then slowly lowering the temperature to decrease defects, thus minimizing the system energy. According to statistical thermos dynamics, material under process of annealing can reach the lowest level of energy by itself, Kirkpatrick invented the Simulated Annealing algorithm. It is an adaption of the Monte Carlo method to generate sample sates of thermodynamic system(Metropolis, et al. 1953). Simulated Annealing is a simple algorithm with many advantages. To speed convergence speed, a modified step is introduced to this algorithm.

Table 1 SA algorithm with modified procedure

1. Initialize the system configuration. Randomize $\boldsymbol{x}(0)$.

2. Initialize $\boldsymbol{T}$ with a large value.

3. ***Repeat***: ***Repeat***:
   i. Apply random perturbations to the state $\boldsymbol{x} = \boldsymbol{x} + \Delta\boldsymbol{x}$.
   ii. Evaluate $\Delta\boldsymbol{E}(\boldsymbol{x}) = \boldsymbol{E}(\boldsymbol{x} + \Delta\boldsymbol{x}) - \boldsymbol{E}(\boldsymbol{x})$: ***if*** $\Delta\boldsymbol{E}(\boldsymbol{x}) < 0$,
   keep the new state; ***check If it can reduce line quantity***;
   else accept the new state with probability; $\boldsymbol{P} = \boldsymbol{e}^{-\Delta E/\boldsymbol{T}}$.
   until the number of accepted transitions is below a threshold level. Set $\boldsymbol{T} = \boldsymbol{T} - \Delta\boldsymbol{T}$.

   until $\boldsymbol{T}$ is small enough that we can accept..

The optimization problem can be formulated as a pair of $(\boldsymbol{C},\boldsymbol{f})$, where $\boldsymbol{C}$ describes a discrete set of configurations (i.e. parameter values) and f is the objective function that is to be optimized. The problem is then to find a set $\{\boldsymbol{C}_{opt}\}$ such that $\boldsymbol{f}(\boldsymbol{c} \in \{C_{opt}\})$\$ is optimal.

3. ▪ System Architecture

To approach the answer of 1D stock cutting problem, I used SA algorithm to in steel-cutting planning and develop a system. The input are the needed length and quantity of specific steel bars and those specific lengths of steels bar can be bought on markets. The goal is how to cut the specific lengths bars into desired needed length with fewer loss rates as far as it can be. The system architecture can be divided into those aspects under below:

▪3.1 Energy function

Energy function is also called cost function. It is a measured metric of project goal and it is the baseline of SA algorithm. The energy must weights and measures the needed factors. In this case, loss rates or utilization are the factors needed considering. In equation(1), x means No. of each steel bar. The right part of the equation means its loss rate.

$$Energy(x)=(Steel\ Length-actual\ used\ length)/(Steel\ Length+10000*x) \quad (1)$$

▪3.2 Initial state

The initial state of SA is to randomly allocate each block in a line. Take Figure 1 for example, each block is randomly lined. After the initial state has been constructed, then the following is to permutate this bricks.

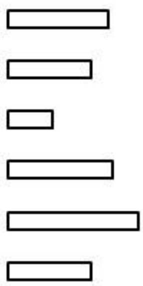

Figure 1 Each piece of bricks are lined randomly.

▪3.3 Permutation

The permutation is to reschedule the order of the bricks. Two types of permutation are defined. One is ***move***($Block_i$, $Stick_j$) which means move ***Block i*** to ***Stick j***. This other is ***swap***($Block_{i1}$, $Stick_{j1}$, $Block_{i2}$, $Stick_{j2}$) which means swap $Block_{i1}$ on $Stick_{j1}$ with $Block_{i2}$ on $Stick_{j2}$. Figure 2 presents the operations of move one brick to another line. Figure 3 presents swap 2 bricks in different lines.

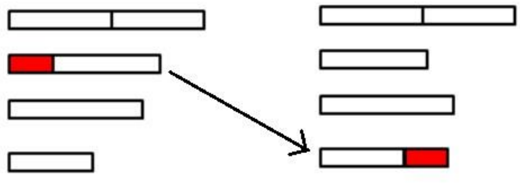

Figure 2 Move of permutation

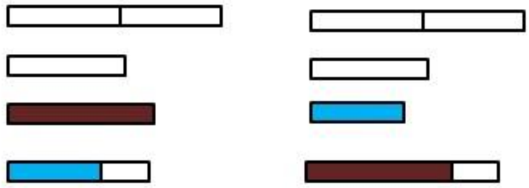

Figure 3 Swap of permutation

▪3.4. Colling

After new state is constructed and its energy is gotten, SA decides if the new state is acceptable. This part tries to get a better state. To break the local optimization, it sometimes accepts worse state. After SA algorithm made its decision, it lowers the temperature to another cycle. Finally, SA will stop at the lowest temperature or acceptable state and get the solution.

4. ▪ Result and Discussion

Figure 4 presents traditional method of getting solutions. It tries to find combination by rules to get its solution. After it get a solution, than it break the set and tries another combination. Figure 5 presents SA method, it first randomly make a set, then it tries to get smaller set by permutation. So, it's faster than traditional methods. The major difference between these two methods is that traditional method is not convergent, however SA method is convergent.

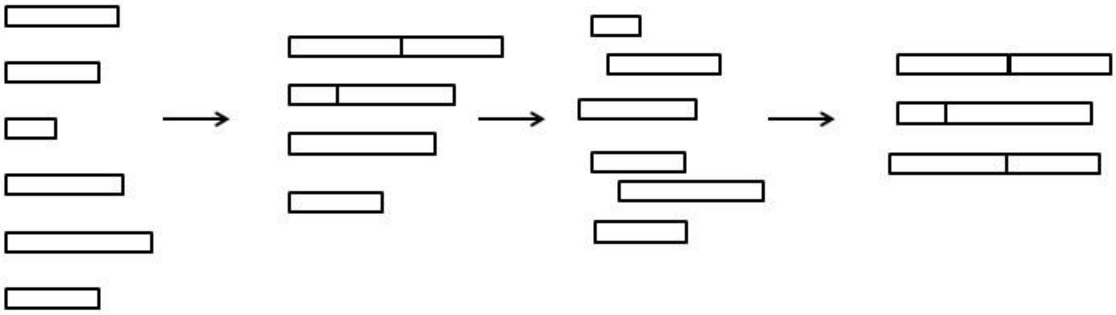

Figure 4 Flows of a traditional method of combination

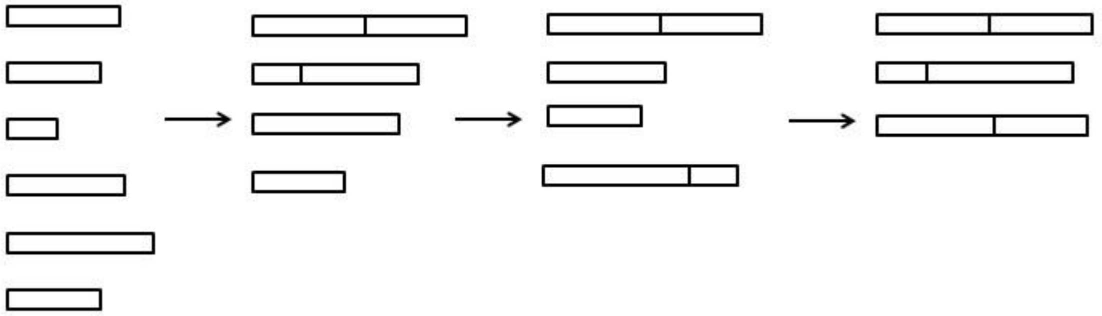

Figure 5 SA method

Figure 6 shows the results of SA algorithm using a practical example. It calculates 5 kinds of steel bars into needed sizes in one minute. The loss rate of this example is 11.471%. The loss rates depends on customers' needed sizes. In this case, the number of long bars is bigger than the number of short bars, so the loss rate is 11.471%. On the other hand, the loss rate is small if the number of short bars is bigger than the number of long bars. The scalability of SA algorithm is also good. The system's scalability is limited by computer memory. The SA algorithm can sassily approach the answer in one minute even over 100 sizes of the bar must be calculated.

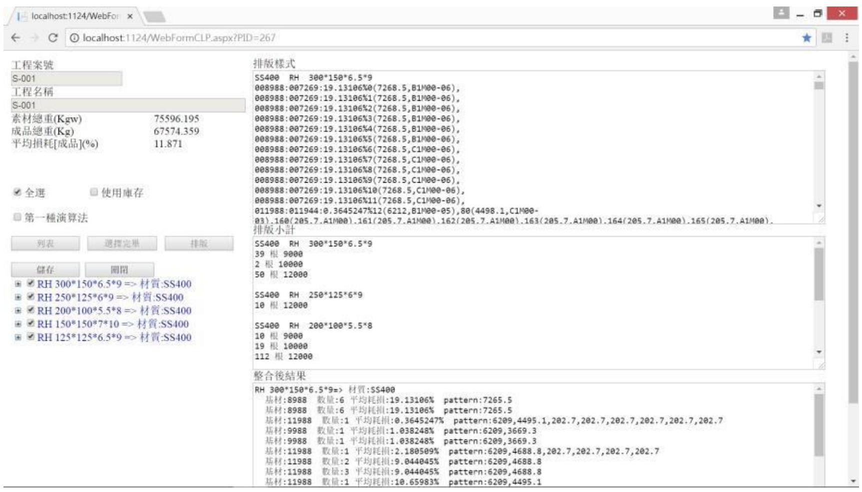

Figure 6 Results by SA algorithm

5. Conclusion

Simulated Annealing in approaching optimal solution is faster than other method, such as Genetic algorithm and other algorithms. 1D stock can be seen as any linear material, including pipes, steel bars. To lessen quantity of the material can reduce costs. And, even more, 1D stock can be expanded into

2D alignment problem which is useful in VLSI layout, cloth cut. The SA algorithm also can be used in these fields.

▪Reference

Kirkpatrick S, Gelatt CD and Vecchi MP. Optimization by Simulated Annealing. Science, 1983, 220(4598): 671-680.

Metropolis N, Rosenbluth AW, Rosenbluth MN, et al. Equation of State Calculations by Fast Computing Machines. Journal of Chemical Physics, 1953, 21(6): 1098.

Application of 40 Inventive Principles in Solving the 1D Stock Cutting Problem

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Abstract

A 1D cutting stock problem is a general issue in many practical fields. The goal of the 1Dimension cutting stock problem is to cut the bars of desired lengths in required quantities from linear bars of given length. To obtain the result needs find an optimal combination of combination set. Because of its NP-hard nature, finding an optimal solution in reasonable time is extremely difficult. TRIZ principles provide many thoughts of inventions. Among these principles, 40 Inventive Principles is easy to utilize. In this paper, 40 inventive principles give insights into this project. This paper proposes the method to solve 1D Stock Cutting Problem under small scalability. The result shows it can get very a small loss rate near-optimal solution.

Keywords: TRIZ, 40 Inventive Principles, 1D stock cutting problem.

1. Introduction

A 1D cutting stock problem is a general issue in many practical fields, such as architecture, steel material. The goal of the 1Dimension cutting stock problem is to cut the bars of desired lengths in required quantities from linear bars of given length(Haessler and Sweeney 1991, Valério de Carvalho 2002). To obtain the result needs find an optimal combination of combination set. Because of its NP (nondeterministic polynomial time)-hard nature, finding an optimal solution in reasonable time is extremely difficult. In this paper, we proposed a system that was developed from the insight origin from TRIZ 40 inventive principles(Altshuller 1997, Zhang, et al. 2003). This proposed utilized combination method to obtain near-optimal solutions. In real cases, it can obtain very good results.

2. Problem Analysis

1D stock cutting has been recognized as a NP(nondeterministic polynomial time)-hard problem which means it is hard to get an optimal solution in a reasonable period. The optimization problem can be formulated as a pair of $(\boldsymbol{C},\boldsymbol{f})$, where C describes a discrete set of configurations (i.e. parameter values) and f is the objective function that is to be optimized. The problem is then to find a set $\{C_{opt}\}$ such that $\boldsymbol{f}(\boldsymbol{c} \in \{C_{\boldsymbol{opt}}\})$ is optimal.

TRIZ has been recognized as a set of powerful tools of systematic innovation. Among the tools of TRIZ, 40 invention principles are the easiest part to get started.

The input is the needed length and quantity of specific steel bars and those specific lengths of steels bar can be bought on markets. The goal is how to cut the specific lengths bars into desired needed length with fewer loss rates as far as it can be.

▪2.1 original thoughts

The original thoughts to this problem are that it is an NP-hard problem, and it indeed is. Therefore to get an optimal problem is nearly impossible. As the types of length increases, the time complexity also increases. So, the nature of NP-hard and time complexity makes this project to get optimal solutions impossible.

▪2.2 insights from TRIZ

40 inventive principles include many useful guidelines for inventive procedures. Principle 10 and principle 22 contribute the most important insights to the problem.

The 1D stock cutting problem is getting more complicated as the types of length increases. It seems that increasing the types of length is a harmful factor which makes the computation more difficult to solve. However, according to principle 22 (Blessing in disguise), it presents that the harmful might achieve a positive effect. After analysis, the types of length can limit the available combination number(DE CARLO, et al. 2012, Domb and Mann 1999).

Common methods to solve the 1D stock cutting problem needs much time to calculate because it repeated to calculate the combinations that have been gotten. So, according to principle 10 (Preliminary action), the method to calculate all available combination in advance. Because the available number of combination is limit by the types of length, to calculate all the combinations become possible.

3. Methodology

This paper proposes a method of combination to get a better result. The first step is to calculate the limits of a number of bricks. The objective of the cutting stock problem (CSP) is to find the minimum number of stock sticks of length $\boldsymbol{L}$ necessary to meet exactly the demands $\boldsymbol{d_i}$ for sticks of shorter lengths $\boldsymbol{a_i}$ for $\boldsymbol{i} = \boldsymbol{1},\ldots,\boldsymbol{n}$. Where $\boldsymbol{di}$ and $\boldsymbol{a_i}$ $\boldsymbol{i} = \boldsymbol{1},\ldots,\boldsymbol{n}$ are integers. These shorter lengths are referred to as items. The problem solution gives the minimum number of rolls necessary to meet the demand and specifies the cutting patterns used to cut the stock sticks into the items(Valério de Carvalho 2002).

$$z = \min \sum_{k=1}^{n} y_k$$

$$\sum_{k=1}^{K} x_{ik} \geq d_i \qquad i=1,\ldots,n$$

$$\sum_{i=1}^{n} a_i x_{ik} \leq L_{yk} \qquad k=1,\ldots,K, \tag{1}$$

$$y_k \in \{0,1\} \quad k=1,\ldots,K,$$

$$x_{i,k} \geq 0 \ \text{ and integer } i=1,\ldots,n;\ k=1,\ldots,M$$

Given that we can buy material of length 9000, 10000. We need to divide them into 4 pieces of 4421.4 and 12 pieces of 4319.8.

▪3.1 step 1

Find numbers of length can divide into need bricks. Like sticks length of 10000 can be divided into 2 pieces of 4421.4 or 2 pieces of 4319.8. Sticks length of 9000 can be divided into 2 pieces of 4421.4 or 2 pieces of 4319.8. Take 319.8 for example, the sticks and be divided into 2 pieces and it needs 12 pieces. We can choose the minimum number of these 2 to reduce the calculation time. So the maximum number array of length 9000 is [2,2] and t the maximum number of length 9000 is [2,2]. And remaining array is [4,12] which means there still have [4,12] pieces to be divided into.

From $Array_{9000}$ = (4,4) and $Array_{remaining}$=(4,12), choose the small number to combine $Maxarray_{9000}$=(2,2), as shown in Table 1. It can be permutated to 6 combinations

Table 1Maximum array of 9000mm

	4421.4mm	4319.8 mm
9000mm	2	2
Remaining(Needed)	4	12
Maximum	=Min(2,4)=2	=Min(2,12)=2

From $Array_{10000}$ = (2,2) and $Array_{remaining}$=(4,12), choose the small number to combine $Maxarray_{10000}$=(2,2), as shown in **Table 2**. This array can be permutated to 25 combinations.

Table 2 Maximum array of 100000mm

	4421.4mm	4319.8 mm

10000mm	2	2
Remaining(Needed)	4	12
Maximum	=Min(2,4)=2	=Min(2,12)=2

▪**3.2 step 2**

To calculate all the combination and loss rate of these 2 lengths and decreasing sorting to an array. Table 3 presents the result of top 6 records.

Table 3 Sorted array

Quantity	Stick Length	Waste length	Loss rate	Quantity of 4421.48	Quantity of 4319.8
1	9000	157.04	1.74	2	0
1	9000	258.72	2.87	1	1
	9000	360.4	4.00	0	2
	10000	1157.04	11.57	2	0
1	10000	1258.72	12.59	1	1
5	10000	1360.4	13.60	0	2
	9000	4578.52	50.87	1	0
	9000	4680.2	52.00	0	1
	10000	5578.52	55.79	1	0
	10000	5680.2	56.80	0	1
	9000	9000	100.0 0	0	0
	10000	10000	100.0 0	0	0

▪**3.2 step 3**

Sort the array by descending. Then we can scan from top to down to collect the combination set

$\sum_{i=1}^{n} a_i x_{ik} \leq L_{yk}$ that $a_j \leq$ remaining array. Repeat the step until all remaining array is 0.

Check columns of the quantity of 4421.48 and 4319.8 that is not greater than $\text{Array}_{\text{remaining}}$ form top row, collect them to answers, and continue collect the remaining result. Then check the second row from the top. Keep the lowest cost solution. And **Table 3 pre**sents the solution shows in gray rows. Then, shift down a row and repeat the process to find if there is another solution. This step is trying to find lower optimal solution.

4. Result and discussion

Figure 1 presents the result of this method. It calculates less than 1 minute. Through many times of experiments compared with another business program, the loss rate is almost the optimal. But it still has a disadvantage. There is a trade-off between saving computing time and saving memory. After types of needed bricks is greater than 12, it computing time increases.

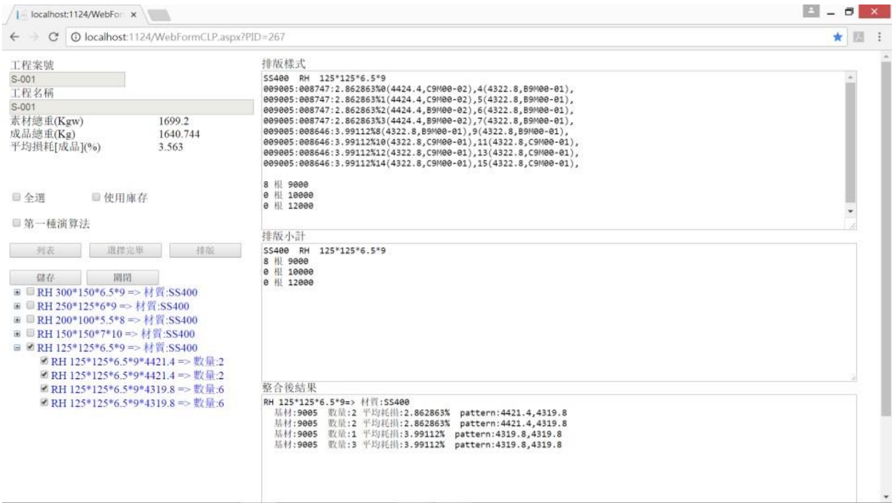

Figure 1 Answer of combination method

5. Conclusion

This method can get near-optimal solution, and it is very important in building industry. Because 2/3 cost of a project is a material fee, use this methodology can save much money. The next step is to fit this methodology in bigger scalability.

Reference

Haessler RW and Sweeney PE. Cutting stock problems and solution procedures. *European Journal of Operational Research*, 1991, **54**(2): 141-150.

Valério de Carvalho JM. LP models for bin packing and cutting stock problems. *European Journal of Operational Research*, 2002, **141**(2): 253-273.

Altshuller G. 40 inventive principles with examples. *The TRIZ Journal Article Archive*, 1997.

Zhang J, Chai K-H and Tan K-C. 40 inventive principles with applications in service operations management. *The TRIZ Journal*, 2003: 1-16.

DE CARLO N, SAMUEL P and SILVERSTEIN D. *The Innovator's Toolkit*. New Jersey: John Wiley & Sons, Inc, 2012.

Domb E and Mann D. 40 Inventive (Business) Principles with Examples. *The TRIZ Journal*, 1999.

The Innovation of Hydrogen-Rich Water Bottle Series Based on TRIZ

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Abstract

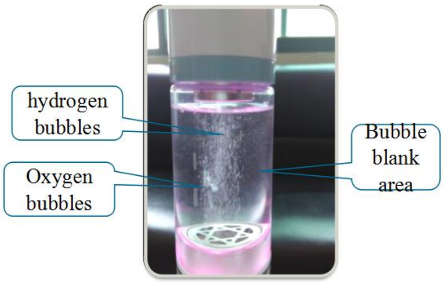
Innovation is the core of a country's development. The ability of product technology innovation and design determines the competitiveness of enterprises and even a country to some extent. Taking the Ospring hydrogen-rich water bottle product as an example, based on the TRIZ method, using space separation, multi-purpose invention and parts of ARIZ-85C solutions, we discussed products design and formed a series of new products technology solutions.Meanwhile, at the stage of applying for patent examination, *Patent Evasion and Regeneration Enhancement method* was applied again to assist in the analysis and defense.

I. Problem Description

Hydrogen-rich water is known as the water with rich hydrogen. Hydrogen has a therapeutic effect on many diseases as a selective antioxidant, which can be applied in a wide range of fields. According to the patent navigation report of hydrogen-rich water and market research, it has been found that the electrolytic hydrogen technology has been used in a considerable proportion for hydrogen-rich water in the domestic market. Common electrolytic hydrogen devices have electrode structures horizontally and vertically arranged. However, there still are shortcomings in such kind of arrangement. When developing prototype, the new product technicians of Ospring found that there emerged oxygen bubbles rising at electrolyzing hydrogen-rich water bottle filled with water, which seriously interfered with the rise of normal hydrogen bubbles, as shown in Figure 1. Does this phenomenon artificially reduce the residence time of hydrogen in the water? Does it involve the solubility of hydrogen in water? This kind of phenomenon that hydrogen interfered with oxygen has also been found in similar products.

(A) Initial state

(B) Electrolysis produces hydrogen bubbles



(C) Hydrogen and oxygen bubbles interfere with each other. There is physical contradiction in the application of TRIZ analysis.
For the same parameter (oxygen), there is an opposite demand (to be on and not on).

Figure 1

II. Solution Process

1. Analysis of Causal Chain

It can be figured out from the phenomena that both hydrogen and oxygen bubbles are contradictorily appearing in the central part of the bottle, rising in the same direction and in the same way. In particular, a small number of oxygen bubbles are in big size with strong lifting force, which crash or advance the smaller hydrogen bubbles, forming distinct areas of mutual interference. Use the causal chain method (Figure 2) to analyze: The bottle uses electrolytic devices that adopt a kind ionic membrane (ion-permeable) which is waterproof and air-proof (over-ion) to divide the cathode and anode into upper and lower level; according to the principle of water electrolysis (method), the upper cathode generates hydrogen and the lower anode generates oxygen so that there is no mutual interference; since there is an oxygen cavity below the anode sheet, only a small port is designed, so that the oxygen can have space and time to remain in oxygen cavities. When the oxygen is emitted, it is blocked by the transmittance circle and rises along the inner peripheral wall of the transmittance circle. Then it is shielded by the gas-collecting hood and rises in the same direction and way as the rising hydrogen. Therefore, oxygen bubbles are risen up by water pressure and larger counter agent due to residence, which collide with the hydrogen bubbles in the same direction and way and interferes with each other. The result is that the hydrogen bubble is promoted faster and easier to release (this is undesirable and the problem pointed out by causal analysis).

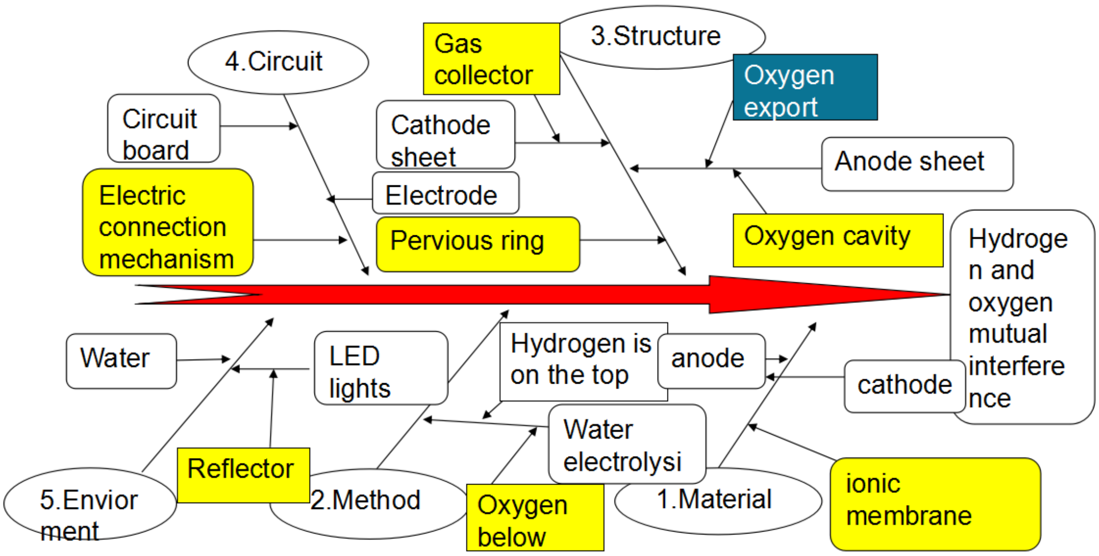


Figure 2

2. Innovative design of hydrogen-rich water bottle in divided-flow

Thus, it illustrates a physical contradiction in the bottle of rising oxygen bubbles and the desire to block them due to mutual interference. In practice, it has been found that there is an area without bubbles at the circumferential edge of the bottle, i.e., a space where the two kinds of bubbles do not interfere with each other. This is why the "spatial separation" can be preferred to use when the physical contradiction is to be solved, and the corresponding invention principle can be preferred. Meanwhile, the multi-purpose invention principle can be used to jointly create an innovative design method for hydrogen-rich water bottle in divided-flow, as shown in Figure 3.

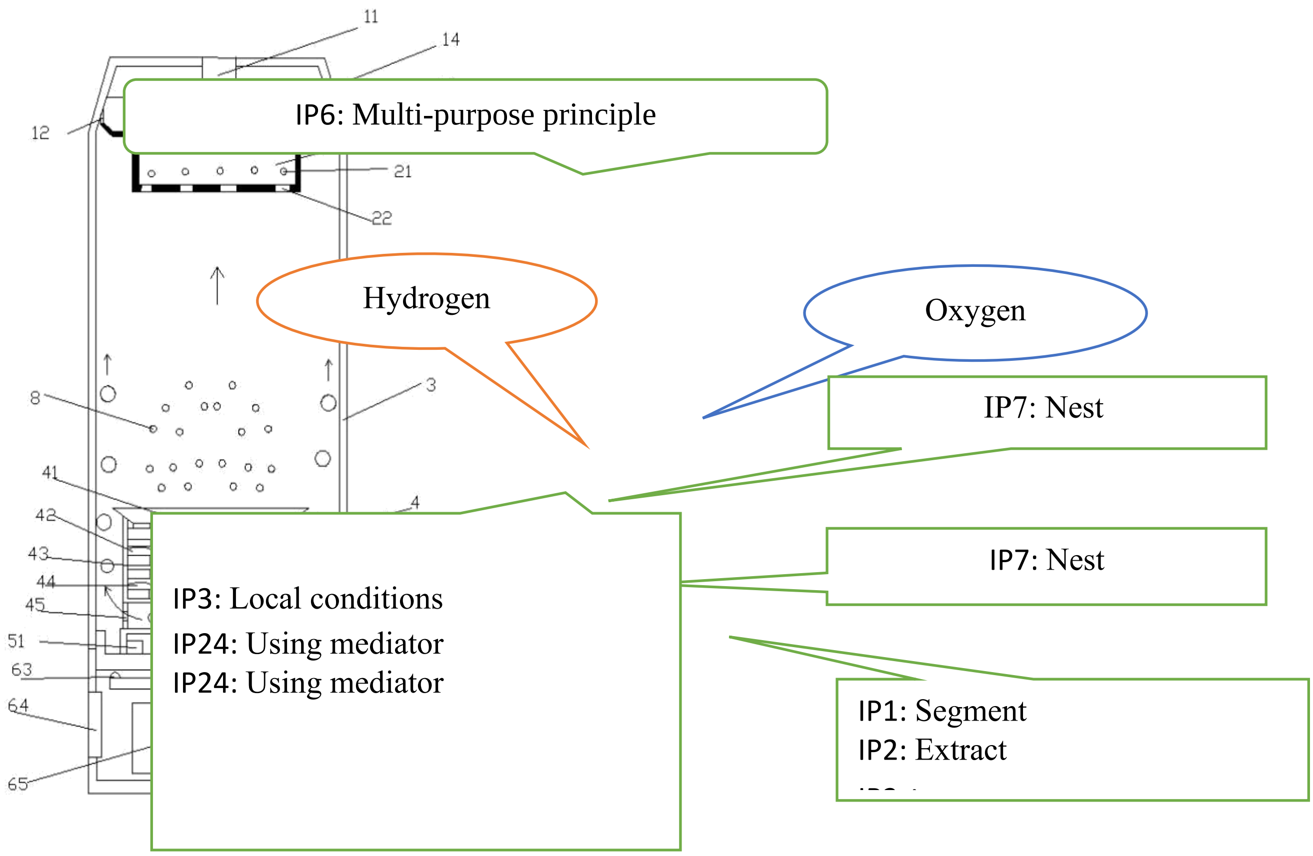


Figure 3 Inventive principle of hydrogen-rich water bottle in divided-flow

For Figure 3, the inscriptions of corresponding inventive principles are as follows:

(1) Dividing and extracting principle: It improves the design on the internal structure of the bottle, which refers to setting vent hole in the lower part of the electrolytic device under the anode plate, as shown in Figure 3--No. 45, allowing oxygen bubbles generated by water electrolysis to rise up through the vent hole by passing the ion membrane.

(2) The principle of using mediators and local quality: it designs a gas-collecting hood with an inverted truncated cone section and puts the hood above the electrolysis device. The oxygen channel is 1/2 of the difference between the upper diameter of the bottle and the inner diameter of the bottle, which will promote oxygen bubbles to rise up close to the inner periphery of the bottle, as shown in Figure 3--No. 41, the left and right channels.

(3) Nesting principle: according to the above improvement, in the process of hydrogen production by water electrolysis, it will produce hydrogen bubbles to embed in the oxygen bubbles, and then the two kinds of bubbles will be enclosed in the bottle. Finally the three are nested in coordination; in the device, there are electrolysis device, which is set with the cathode, the ion membrane, and the anode from the top to the bottom, and nesting coordination is applied again.

(4) The principle of multi-purpose can be used to make an object have multiple functions. There are 2 to 6 LED lights distributed in a circle at a suitable position in the bottle (Figure 3 - No. 63), with three functions of notification, aesthetic and electrolytic display; a multi-function filter element is designed on the cover (Figure 3 - No. 21), with three functions of mineralization, electrolyte increase, and magnesium metal increase in water.

Finally, a hydrogen-rich water bottle with divided-flow is designed as shown in Figure 4.

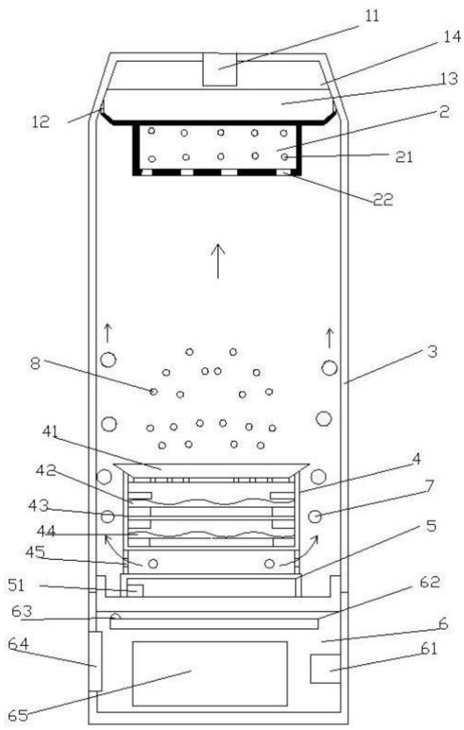


Figure 4 Hydrogen-rich water bottle with divided-flow

3. Innovative design of layered hydrogen-rich water bottle

In the above example, a conceptual solution was formed in the innovation process of "spatial separation". What would be the result if "space" were made to be "separated" a bit more? (According to analysis in "asymmetry principle", it may have "a greater degree of asymmetry")? However, there is no such thing of the degree of spatial separation in the TRIZ theory. Can people reuse these principles of invention? According to the concept of magnifying innovation, the hydrogen and oxygen are further separated, and multiple invention principles are repeatedly applied. The hydrogen and oxygen bubbles are divided into inner and outer layers, respectively rising up. As shown in Figure 5, the innovative design of a layered hydrogen-rich water bottle is produced.

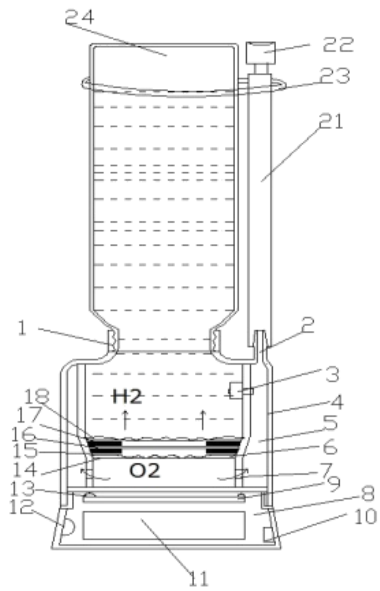


Figure 5 A portable hydrogen-rich water generator

4. Innovative design of fission hydrogen-rich water bottle

What will happen if “space” is to be “separated” to a greater extent? The hydrogen will be left in the main body, and the oxygen bubbles will be branched out, as shown in Figure 6. The oxygen bubbles will flow away from the pot, and the hydrogen and oxygen will rise up respectively. Multiple inventive principles will be used, of which “mediators”--- refers to the application of check valve in Figure 6-61, snuffle valve 6-62. Finally, an innovative design of the fission hydrogen-rich water kettle with the filter element as Figure 6 is formed.

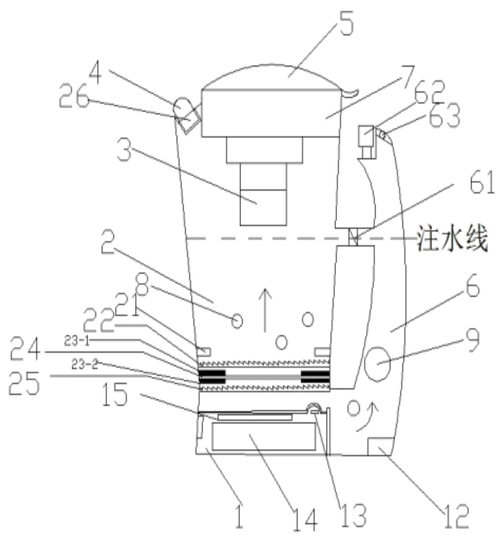


Figure 6 Multi-purpose hydrogen-rich water kettle with the filter element

5. Application of object-field analysis

Object-field analysis is an important problem description and analysis tool in TRIZ theory, which can be used to solve other problems beyond physical contradictions. In the process of solving technical problems, it is equivalent to the fourth step of ARIZ-85C, which means to establish an object-field model and introduce it to the second or third object. The specific procedure is to introduce the object-field concept as appropriate in each of the above three separation plans. For example, the introduction of the second field can be: the pressure field, the third object: pressing device; the second field can be: the ultrasonic field, the third object: the atomization sheet 3; the second field can be: the thermal field, the third object: the electrical heating sheet 4; the second field can be: the radiation field, the third object: the far-infrared emitting device, etc..

6. Program Evaluation

The method of space separation above is involving at least 5-6 invention principles, which better solves the physical contradictions described in this paper. Oxygen becomes easy to control in the new system, for which a new channel is formed through the vent hole, the gas-collecting hood, and the circumference of the bottle (outside the bottle and the kettle), generating hydrogen, oxygen to rise up with divided-flow, different layers and fissions, as well as mutual interference. Meanwhile, it also applies the principles of multi-purpose inventions to collaboratively form conceptual solution of three innovative products.

The solution to this project is similar to the 7th step of ARIZ-85C.

(1) Search, analyze and evaluate the patented technology information.

The same problems and solutions of this project have not yet been found, but related technical methods in the same technical field have been found. From another view, it can be used to confirm the correctness and creativity of the TRIZ method used to resolve the physical contradiction of the project. For example:

① As shown in Figure 7: China Patent *Fission Hydrogen and Oxygen Separation Electrolysis Devices and Methods* (Application No. 201510995475.3). In order to avoid mutual interference between hydrogen and oxygen, the electrolytic device of the invention is tilted with the cathode facing upwards, as well as the oxygen generated; with the anode facing down, the generated oxygen is directed to the outside of the container sidewall (see arrow in Figure 7).

② As shown in Figure 8: Chinese Patent *A Bottle Container for Preparing Hydrogen-Rich Fluid Sub-bottle* (Application No. 201510586311.5). In order to avoid mutual interference between hydrogen and oxygen, the electrolytic device of the invention is set with the cathode facing upwards, as well as the oxygen generated; with the anode facing down, an oxygen vent is provided on the side wall of the bottle body to emit oxygen (see Figure 8--0132).

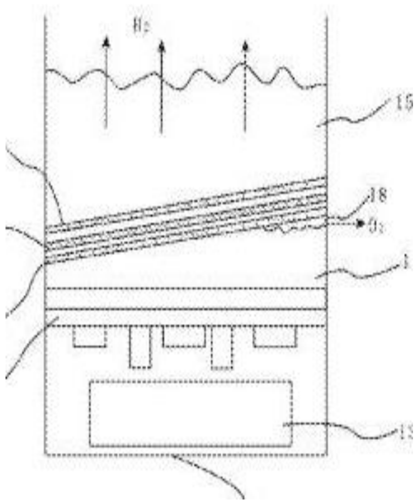


Figure 7 Fission hydrogen and oxygen separation electrolysis devices

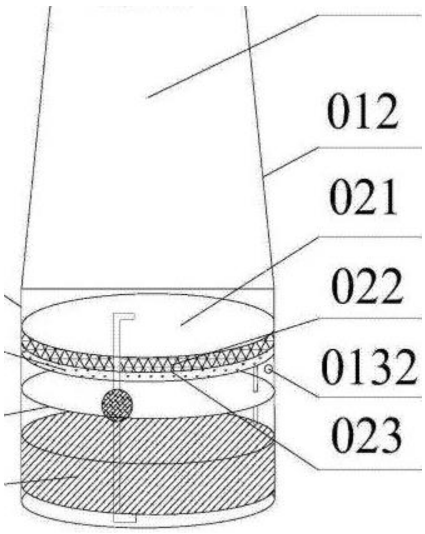


Figure 8 Hydrogen-rich fluid sub-bottle

Compare Figure 3 of this program with Figure 7 and 8 of other programs:

Advantages of this program: as for separation of hydrogen and oxygen, the excess hydrogen and oxygen are collected in the cavity between the lid of the bottle and the surface of the water in the bottle. Then the gas pressure will rise if there is more gas, which can be emitted from snuffle valve on the lid (Figure 3--11). It's much easier for this patented program to be productization. For other programs, as shown in Fig. 7--Arrows, Fig. 8--0132, the oxygen can be emitted from the wall of the bottle, which can be a patented solution. But if it is made into a product, it must leak air in the water. The leakage prevention measures are quite complicated.

(2) System predicting and improvement: according to the principle of subsystem imbalance evolution, on the premise that the separation of hydrogen and oxygen has been solved, attention shall be paid to the innovation of subsystems, such as the lid, in which the design of the snuffle valve of different forms and structures is the unique and only technical feature of similar products in the domestic market; as well as the application of electrolytic devices, bottle OLED and so on.

7. Continuous Innovation

Once the innovative concept of separating hydrogen and oxygen has formed, external enhancements and expansion of different usages shall be carried out focusing on its core technologies. In the process of implementing this project, the patent navigation of hydrogen-rich water technology is also carried out. The achievement of patent navigation is merged with TRIZ applications and the development of hydrogen-rich water technology. The patent navigation helps us understand the development trend of patent technology, technical route and opponents in the same field at home and abroad, of which the technical route refers to the direction of technology application to follow-up innovation. Meanwhile, in order to solve similar problems, the principles of the invention can be reused; for example, the eighth step of the ARIZ-85C is adopted to maximize the above concepts. The innovative program will be gradually expanded, with the application of “sub-airflow”, “layer”, and “fission”, supplemented by changes in structure, shape, function, and usage. Finally, four kinds of sub-airflow innovation programs such as those shown in Figures 9-12 have been produced.

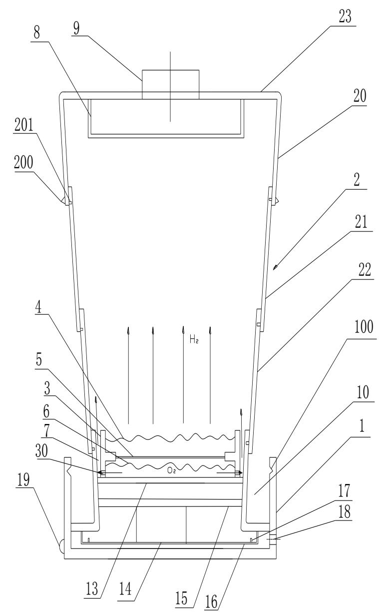


Figure 9 Portable nested hydrogen-rich water bottle

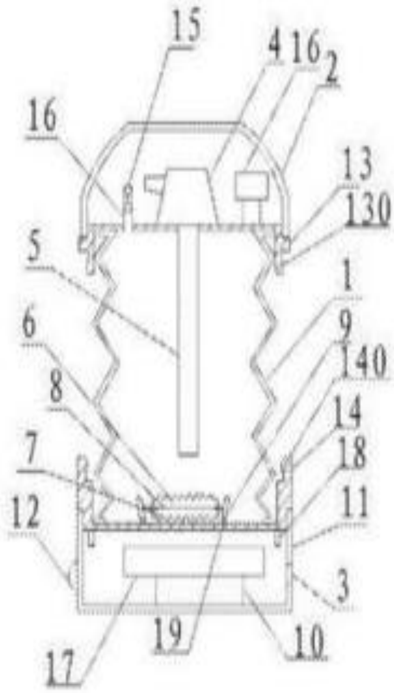


Figure 10 Portable elastic hydrogen-rich water bottle

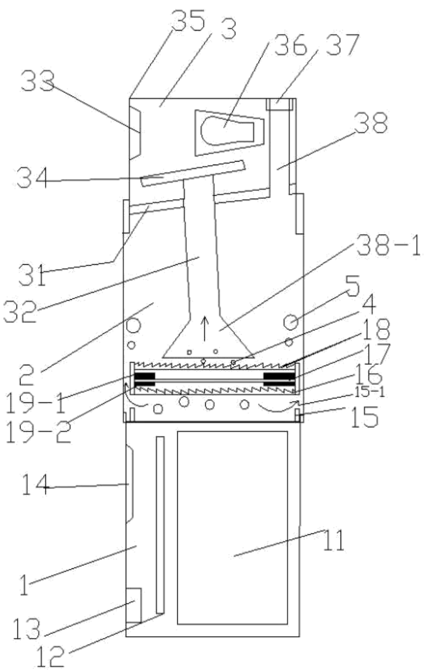


Figure 11 Cosmetic hydrogen-rich water steamer

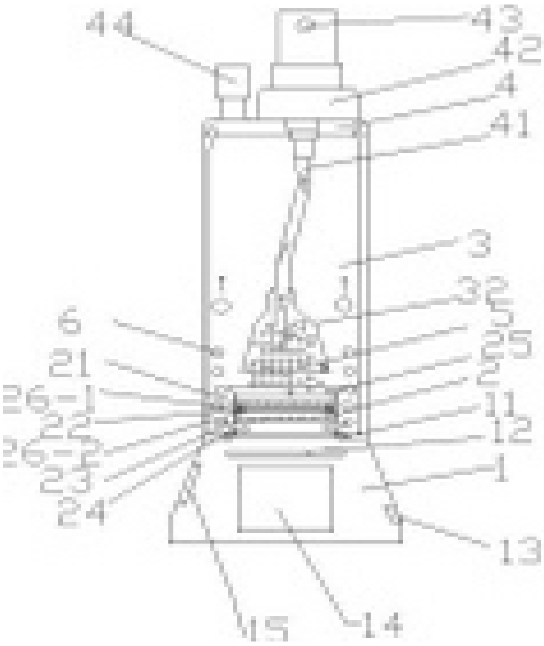


Figure 12 Portable dual-purpose hydrogen-rich water bottle

Another kind of layered innovative program as shown in Figure 13 is produced.

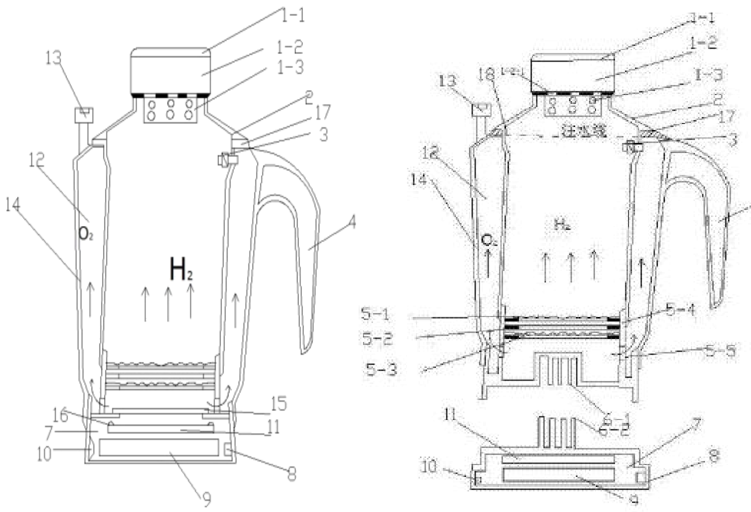


Figure 13 Layered hydrogen-rich water bottle with filter element

Four kinds of innovative programs have also been produced as shown in Figure 14-17.

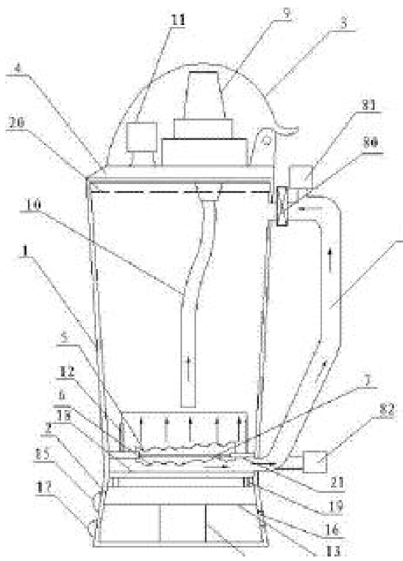


Figure 14 Multi-purpose hydrogen-rich water bottle

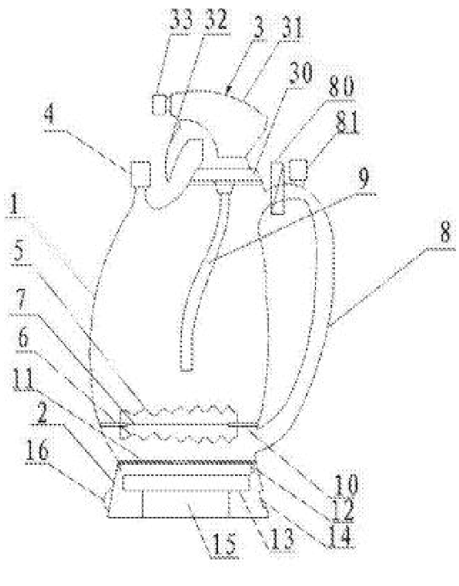


Figure 15 Hydrogen-rich water atomizer

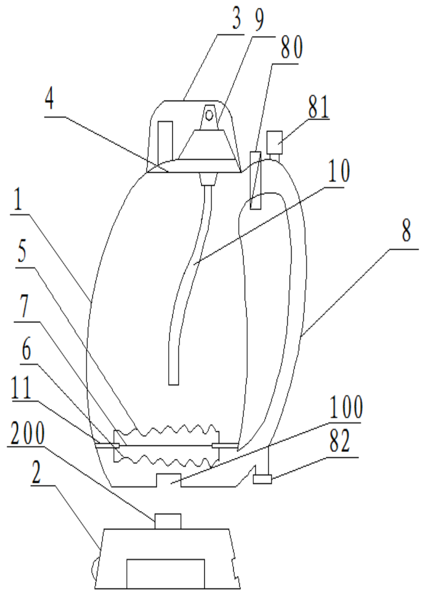


Figure 16 Separated multi-purpose hydrogen-rich water kettle

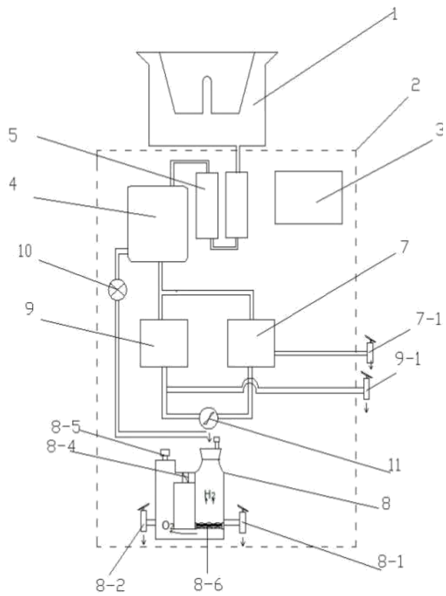


Figure 17 An antimicrobial mineralized hydrogen-rich water dispenser

In the above solutions, about 6 to7 principles of TRIZ are applied several times to design a total of 12 kinds of structures or devices to separate hydrogen and oxygen for three products. With increasing spatial separation, the contradiction of hydrogen and oxygen bubbles rising up in the same way is solved. The object-field analysis is conducted to introduce the second field and third object. Meanwhile, the solution is expanded, which highlights the multi-purpose and multi-function. This highlights the innovative features and facilitates the creation of patents. (A total of 26 patent applications are formed), which will help realize various solutions for product development.

III. Patent Application and Essential Examination

Since the beginning of 2016, this project has started to be developed, together with the creation and application of patents in the development process, which has lasted more than one year. Finally, there are more than 40 applications for inventions by the end of 2016. This process can be described as: engineering problems --- TRIZ applications --- patent applications. The applications for inventions disclosed at this stage have gradually entered the stage of essential examination, that is, the examiner puts forward: the review opinions—listing the comparative patents—require a reply with sufficient reasons. As the examiner has given "comparative patents", this will be the “target patent” from the view of TRIZ. To this end, it can use the *Patent Evasion and Regeneration Enhancement Method* to analyze. Examples are as follows.

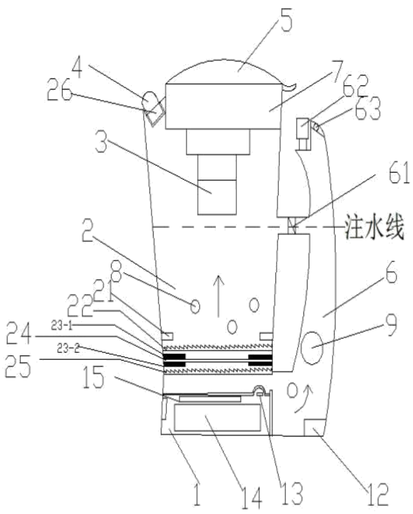


Figure 6 A Multi-purpose hydrogen-rich kettle bottle with filter element

Application No.: 201610745903.1

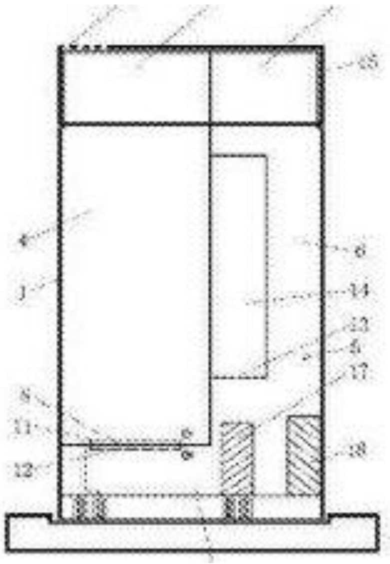


Figure 18 Integrated hydrogen-rich water production device

Application No.:201510538253.9

When the *A Multi-purpose Hydrogen-rich Water Kettle with Filter Element* of Figure 6 entered the first review, the examiner gave a comparative patent (1) of Figure 18 *Integrated Hydrogen-rich Water Production Device*. In the process of replying, the *Functional Analysis for Patent Analysis* was adopted, especially the "Patent Cutting Rule C" was applied several times as follows:

Current function provider	Function	Target	Cutting rule	New function provider	Cutting question	Cutting method
Second water inlet	Add pure water	Pure water	Rule E (new providers perform better functions)	One-way valve water flows from the first cavity (kettle body) through the one-way valve into the second cavity (kettle handle), only in not back.	How does Rule C find the system or peripheral components to perform this function?	Cut the assembly of the second water inlet, then the target water will not exist, and its function of detecting the water level disappears. Finally, the sensor is naturally eliminated.

Exchange ion to resin	Provide positive ion	Positive ion	Rule E (new providers can perform better functions and improve performance)	Filter elements contains chlorine removal, mineralization, and purification, which can not only purify water, but also increase the electrolyte, that is, producing positive ions.	How does Rule C find system components to perform better functions?	Cut ion to exchange for resin. Then PP cotton, as the filter function provider, doesn't need to exist. The positive ions increased to promote the electrolytic efficiency will be replaced by the combined filter elements that perform better functions, and the specific position is set at the inlet.
Air hole	Emit oxygen	Oxygen	Rule E (new providers can perform better functions and improve performance)	Snuffle valve (at the top of the handle)	How does Rule C find system components to perform better functions?	After cutting the air holes, there is no need for an automatic opening and closing leak-proof device (a total of 4 components such as a sealing bezel will be eliminated).

After cutting pattern analysis, comparing it with patent (1), it shows that in the main/feature function, one technical principle has been changed, three feature functions have been improved, and a total of nine components have been cut. The invention only applies for adding 2 components. In addition, there is also a mouthpiece that is shared, thus illustrating that there are many innovations in the present application, and thus it is also believed that the present invention has obvious substantive features and significant progress, and thus accords with paragraph 3 *Creativity* of the *Patent Law Article 22*. It's subject to be approved whether this reply can be accepted by the examiner or whether the reasons for the statement are fully expressed.

IV. Innovation Experience Based on TRIZ

Through the above-mentioned plant-wide innovations based on TRIZ, technical problems of the system can be discovered at the pre-development stage of the project, and the classic TRIZ method can be used to solve these problems. In responding to the review reply, the patented invention applied has adopted the *Functional Analysis for Patent Analysis* belonging to the modern TRIZ theory, which helps the series of innovations to be more perfect, and at the same time the application of the TRIZ theory method contributes to the creation of high-quality patents. This will help to form a reasonable lineup of enhancements around the core patented technologies and create a relatively large patent layout.

Reference

English Reference:

[1] G.Maarten Bonnema. TRIZ for systems architecting[J].Procedia Engineering, 2011（9）.

[2] John, Terninko. The QFD，TRIZ and Taguchi method Connection[J] .TRIZ Journal,1998（1）.

[3] Simona-Mariana Cretu.TRIZ method introduced to the calculation field[J]. Procedia Engineering, 2011（9）.

[4] Zhan Runhua. TRIZ and Applications：The process and methods of technological innovation[M]. Beijing： Higher Education Press，2010.

Chinese Reference:

[1] TRIZ--打开创新之门的金钥匙 孙永伟 [美]谢尔盖.伊克万科 编著（4）

[2] TRIZ 创新理论与应用原理 王亮申 孙峰华 等编著（10）

[3]陈德金，林继扬.创新方法区域工作实施路径与策略研究——以福建为例[J].中国培训，2017（10）.

[4]许栋梁.系统化专利回避再生与强化[M].台湾：亚卓国际顾问股份有限公司，2017（7）.

[5]张兵.基于 QFD 及 TRIZ 的院前急救输液泵创新设计与开发[D]，第二军医大学，2015（5）.

[6]张娜.基于 TRIZ 创新理论的工程机械自动变速方法的研究[D]，吉林大学，2011（5）.

[7]曾献智.基于 TRIZ 理论的 Z 公司轴承产品创新方法研究[D]，河南科技大学，2015（6）.

Constructing A Design Thinking Curriculum for First-Year College Students

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Abstract

To nurture students with creative problem solving and cross-domain integration capabilities through innovative curriculum activities is considered as one of the most important issues to help companies, societies, and even countries achieve sustainable development in today's highly competitive world. Design Thinking (DT) from Stanford University's d.school is an effective training tool to promote systematic and creative thinking. With three creative spaces (Inspiration, Ideation, and Implementation), DT goes through a creative process with continuous interactions between divergent thinking and convergent thinking, resulting in innovative solutions that meet people's needs. An innovative curriculum for first-year college students, based on the initiatives of DT, was developed to integrate a version of DT process with six stages (i.e., understand, observe, point of view, ideate, prototype, and test) and Scenario-based Design method to help students develop their cross-domain innovative talents at school in addition to their professional talents.

Keywords: Design Thinking, Scenario-based Design, Innovative Curriculum

1. Introduction

The McKinsey Quarterly pointed out in "The War for Talent" report in 1998 that competition for talent would be a major issue in the 21st century. It seems the competition for talent has continued to intensify with the spread of globalization and high-level skills. This same report ranked "talent competition and internationalization" among the ten major trends impacting business operations. These developments have brought the immense challenge to education systems of cultivating talent among students to fill the needs of business and society.

However, today's mainstream education system continues to place emphasis on content specialization and individual achievement training. It promotes a "one-way knowledge transfer" form of education and uses extrinsic motivators, like grades and rewards, to encourage students to learn (Wagner & Compton, 2015). In this type of system, students must embrace rote learning to achieve high academic performance, which ultimately inhibits the development of critical-thinking skills and self-exploration. Furthermore, the knowledge they acquire in this type of education system lacks applicability, which leads to the gradual erosion of their natural propensity towards curiosity (Wagner et al., 2015). Thus the system stands in dire need of an innovative educational environment and pedagogy.

An innovative educational environment should foster a student's ability to explore and collaborate with others across domains. Such learning environments often integrate games into the learning process to generate interest in order to stimulate intrinsic motivation. In addition, games provide students with the opportunity to hone their problem-solving skills through trial and error (Wagner et al., 2015). Well-known innovative educational environments include Carnegie Mellon University's Entertainment Technology Center, Franklin W. Olin College of Engineering, IDEO, and MIT Media Lab (Wagner et al., 2015). Interest in these types of educational centers has grown in Taiwan. The Ministry of Education has spearheaded a student-centered higher-education enhancement project in order to "strengthen the link between industry and practice, and promote a 're-cultivation' model of education" that supports the application of knowledge gained through learning. The goal of the project is to foster skills that students will need for the future by helping students "become rooted in their profession and by strengthening their problem-solving skills, ability to work across domains, and ability to learn independently." Other similar projects include the Smart Aging Alliance, the cross-tech scientific personnel training program, National Taiwan University's Interdisciplinary Integration and Innovation Executive Masters of Science (EMS) program, the NTU Design Thinking Club, National Tsing Hua University's House of Strange Science, and Tunghai University's liberal arts education program.

The Hasso Plattner Institute of Design (also known as the d.school), which was established by the founder of IDEO Tom Kelly at Stanford University in 2005, presents a viable model for talent cultivation (Wagner et al., 2015). With the assistance of teachers from various fields, the d.school mentors inter-disciplinary design teams as they design products or services that meet the real-world needs of society and consumers by mining a series of extractions and reorganization (Brown, 2008; Brown & Wyatt, 2010; Wagner et al., 2015). Scenario-based design (Scenario Based Design) delineates the goals, environment, and behavior from the target customer's perspective through extraction and reorganization, which helps designers explore issues under real conditions to find solutions (Nardi, 1992; Fulton & Marsh , 2000; Rosson & Carroll, 2002). Presenting these elements in a visual format facilitates communication between members of cross-domain teams and helps establish team consensus.

This study integrated design thinking with Scenario Based Design to construct a series of mini-courses. Different areas of expertise, data clarification and problem-solving skills, and cross-domain collaboration training were outlined in practical courses to help students develop innovative and people-oriented solutions to problems. These courses are aimed at helping students blossom into well-rounded talents who possess the necessary professional acumen and experience, design-thinking skills, and innovativeness to succeed in their careers.

2. Literature Review

▪2.1 Design Thinking

The concept underlying “design thinking” can be traced back to the books *Sciences of the Artificial* by Herbert A. Simon published in 1969 and *Experiences in Visual Thinking* by Robert McKim published in 1972. The former argues that design thinking is human-centered, mindful of the process, and action-oriented, and that using this process can help change the world by producing realistic and creative solutions.

The concept of design thinking was first formally defined in Bryan Lawson's book *How Designers Think*. Nigel Cross and Peter Rowe applied this concept to general education and architecture. Eventually, Professor Rolf Faste established a course on design thinking at Stanford University. David M. Kelley imported design thinking into the fields of management and commercial design, leading eventually to the founding of the d.school. Today, design thinking is a topic of interest around the world.

Design thinking can be considered a discipline (Brown, 2008). It emphasizes that designers need to abandon preconceived and intuitive thinking patterns to become innovative. Designers need to explore issues via the designer's own observations and empathy while at the same time taking into account the user’s needs and behaviors and the market feasibility of products and services (Brown, 2008/2009). This is nonlinear process that involving the 3I’s of the iterative exploration process: Inspiration, Ideation, and Implementation (Brown, 2009).

Stanford University's d.school (Kang & Liu, 2017) is the most prominent developer of cross-disciplinary talent. The cultivation of design thinking at the school comprises two dimensions: “problem definition” and “problem solving”. These aspects are the basis of problem-based learning (PBL) (Kang et al., 2017). The program has five key features: (1) project-oriented learning; (2) dual-teaching and dual-domain; (3) real situations and problems; (4) cross-domain grouping of learners; and (5) high efficiency.

Tim Brown (2009) believes that the following three elements are necessary for the mining of problems: (1) insight: using consumer behaviors as clues to identify unmet needs; (2) observation: analyzing data collected from observations of consumer behavior; (3) empathy: understanding both consumer experiences and consumer emotions to unearth their current and potential needs.

Generally speaking, there are no specific or defined processes and tools in the design process (Brown, 2008, Brown et al., 2010). However, if a designer does not apply a structured framework in the process of defining a problem, his/her personal biases are more likely to affect his/her interpretation of the problem (Thomsen, 2013). In the concept development stage, if there are no helpful tools available, the process could be subject to many constraints. Scenario-based design is a kind of visualization process (Nardi, 1992; Huang, 2001) that chronologically describes personal, situational, temporal, geographic, and material design methods (Campball, 1992; Tang & Lin 2011). Through extraction and reorganization of these elements, Scenario Based Design can be used as a tool for problem definition (Fulton et al., 2000; Nardi, 1992) and as the foundation for problem solving. It can also be used as a method for communication in a cross-domain team.

2.2 Scenario-based Design

Scenario-based design is a visual design method for delineating prospective designs (Nardi, 1992; Huang, L., 2001). Scenario Based Design conveys the agent or actor through oral or textual narratives. In a sequence of events, the objective is to connect disparate elements into a story in order to present the context and underlying meaning of the behavior (Carroll, 2000; Rosson et al., 2007; China Productivity Center, 2013; Yu, Lin, & Wang, 2001).

The user-oriented innovative scenario experience design method developed by Liang is loosely based on the User-Oriented Innovative Design. The latter was developed by the product design company IDEO. It also draws on the innovative cross-domain collaborative method developed by Stanford University's Institute of Design (or d. school), as well as the user-oriented cross-domain integrative new product development model (i-NPD) developed by Carnegie Mellon University. Liang's innovative user-oriented scenario experience design method is used in integrative industry-academia workshop-type settings. It provides a framework for cross-disciplinary teams as they simulate scenarios, define problems, and generate possible solutions from the target customer's perspective.

The advantage of Scenario Based Design lies in its holistic representation of user behaviors and activities through the delineation of social, resource, and user goals (Nardi, 1992). Scenario Based Design also allows for the exploration of the problem on various levels (Rosson et al., 2007; Huang, 2002). Scenario Based Design can be either used as a concrete or flexible framework. It can help the designer evaluate and manage the design process and reduce the influence of external restrictions and risks (Rosson et al., 2007). The Scenario Based Design process is not affected by technical and financial considerations (Moggridge, 1993), which facilitates communication with people in different domains (Yu et al., 2001; Tang et al., 2011; Su, 1994).

The disadvantage of Scenario Based Design is that it can be misleading if social behavior and cognitive elements are absent from the data collection process (Rosson et al., 2007; Yu et al., 2001). Moreover, if the scenario development process is not done systematically, it may result in confusion which may lead to pointless scenarios or inapplicable concepts (Yu et al., 2001). In the assessment stage, when there is a lack of data or expert input, the outcome may be unrealistic scenarios or designs (Tang et al., 2011).

3. Design-Thinking Curriculum

This study established a process for training cross-disciplinary design talents based on the 3I's of design thinking. This study provides contexts for users to follow based on the scenario design process and tools proposed by Liang Youzhao (Huang, 2002; Li, 2015; Yang, Kao, Liu, Lee, & Zheng, 2016). These contexts serve as reference for facilitators of cross-domain learning. The following lays out our research methodology.

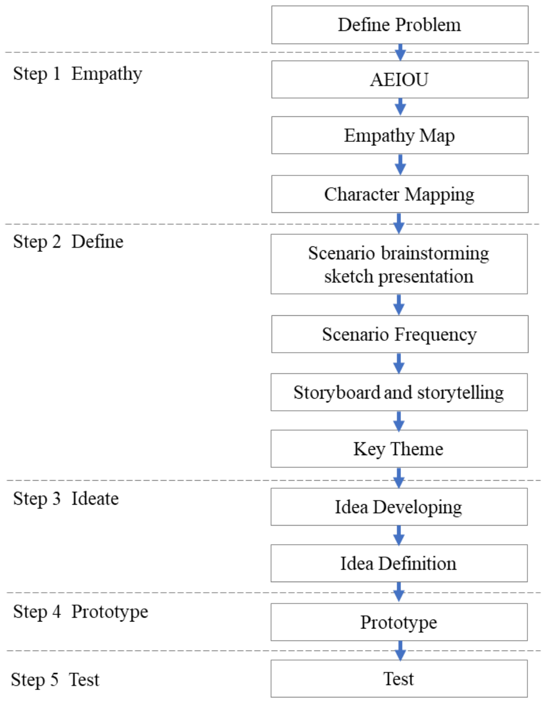

Figure 1 Structure of Design-Thinking Curriculum

▪3.1 Design Thinking Process

Step 1 Empathy

Step 1-1 AEIOU: After determining the design issues, learners in each professional field record their observations based on the following: activities (e.g. events, processes, and models); environment (e.g. the surrounding environment's function, characteristics, and atmosphere); interface (e.g. person-to-person, person-to-object, and person-to-space interactions); object (e.g. objects in the environment); and user (e.g. the roles played by those in the environment, their relationships, and the differences between their needs). Afterwards, learners gather within their discussion groups to extract key information or crucial elements.

Step 1-2 Empathy Map: This step is divided into two phases: (1) After defining the single or multiple target customers according to the design issue, categorize the elements extracted in Step 1-1 into the following four dimensions: think and feel (e.g. ideas, attitudes, positions, and viewpoints); see (e.g. behavior, affairs, and environment); hear (e.g. people in the environment and the environment itself); say and do (e.g. public attitudes, visible expressions, and behavior towards others). At the same time, the learners continue coming up with ideas based on the definition of the target customer. (2) Elements are further categorized into two types: pain (e.g. fear, frustration, and obstacles) or gain (e.g. expectations, needs, and achievements).

Step 1-3 Character Mapping: Multiple representative persons and their characteristics (e.g. age, gender, education level) are then specified based on the target consumer defined in Step 1-2. Learners then fill out characteristics of these representative persons on the provided form in a systematic fashion. For example, if the ages of the representative persons are 10, 8, and 16, the ages should be written in chronological order (8, 10, and 16). Use this information to create a coherent consumer profile.

Step 2 Define

Step 2-1 Scenario Brainstorming Sketch Presentation: Learners write down the target customer that was defined in Step 1-3 (Who) and their characteristics onto the form. Then, one or more pain or gain points (What) are selected and summarized in Step 1-2. Finally, learners describe the motivation behind development of the product or service (Why) based on the consumer's pain or gain points. Further describe the macro context of these pain or gain points (When and Where).

Step 2-2 Scenario Frequency: Transcribe Who, Where, What, Why, and When from Step 2-1. Then, learners draw a scenario process map of the macro-context narrative using keywords. The design problems are then imported into each process grid.

Step 2-3 Storyboard and storytelling: From the scenario process structure created in Step 2-2, learners select several of the storyboards and delineate the theme (scenario), location, and time based on the keywords in the scenario process structure. Learners then describe the critical issues that may occur as well as solutions for those issues. Lastly, the learners illustrate the scenario using images to help learners across various professional fields discuss and pinpoint the scenario’s issue; the images also optimize the conceptualization and serves as a draft for reference.

Step 2-4 Top-10 Key Themes: Share the written content from Step 2-3 in group discussions. The listeners should listen for key points (e.g. the problem or solution) and write them down on post-it notes. Then, the post-it notes are pasted into the corresponding grid. Finally, everyone votes on the most crucial issues and prioritize them by importance.

Step 3 Ideate

Step 3-1 Idea Development: Each team member selects a key theme from Step 2-4, and lists the problem points for the target customer according to the content. Lastly, learners use the text or image to describe the conceptualization of the solution. The best ideas or solutions are then selected through group discussions.

Step 3-2 Idea Definition: Based on the design concept selected in Step 3-1, learners write down the combination of concept elements (i.e. essential concept factors) on the form. Then, they describe what kinds of problems can be solved and what goals can be reached by using these elements. Lastly, they name the product or service to help clarify the design issues and concretize the design concepts for learners across domains.

Step 4 Prototype

The results of the design concept optimization are then integrated with the prototype construction of each stage to help the design team check whether the design meets the target customer's needs during the production process. Learners should check whether there is anything that needs to be modified or optimized during usage.

Step 5 Test

Experts and target customers are invited to perform concept-testing to further refine the concept solution and confirm that the concept meets the market and customer needs, and whether it is effective during use.

▪3.2 Questionnaire

In order to understand the impact of cross-domain learning on students taking the micro-courses, we used a quantitative questionnaire to survey the participants post-course. The quantitative questionnaire references the Ministry of Education's design-thinking program. Questionnaire items (shown in the appendix) are aimed at gauging the subject's thoughts on cross-disciplinary cooperation, problem mining and identification, and problem-solving training in the course curriculum. Items 4, 5, and 7 are reverse-coded items. Respondents were asked to rate the items along a five-point Likert scale where “1” indicates “strongly disagree” and “5” indicates “strongly agree”. After all questionnaires were submitted, SPSS statistical software was used to analyze the data for the means and standard deviations. The statistical results were used for the pilot study, analysis, and discussion.

4. Results and Discussion

Freshman attending private universities in northern Taiwan during the 2017 - 2018 academic year were selected to participate in this study. The participants were observed in one of the required courses of “2017 Design Thinking Cross-Domain Talent Training Program”. This was a project-oriented course focusing on patient safety, specifically “Innovative Designs for Patient Fall Prevention". The two-day course was held on the weekend of 2017/10/14 -2017/10/15 for a total of 18 hours and 1 credit.

The learners in this study came from three colleges (College of Environment Resources, College of Engineering, and College of Management and Design); three departments (Department of Electrical Engineering, Department of Industrial Engineering, and Management, and Department of Chemical Engineering); six classes (two classes in each department); and a total of 303 people. Mojibake grouping was used to split up the participants. There was a total of 52 groups of 5 to 6 people. There were 9 instructors in total (6 from design fields and 3 from medical and nursing fields) and 4 teachers from outside the school. The total number of teaching assistants was 26 (18 in design fields and 8 in medical fields).

▪3.2 Quantitative Research Results

A total of 303 questionnaires were sent out; 283 were submitted of which 216 were viable and 67 nonviable. Participants come from three departments: 37% from EE; 31% from IEM; 32% from CE (Table 1). Cronbach's Alpha was used to test for reliability which came up with an alpha value of 0.764, which is within the acceptable range for reliability.

Table 1 Basic Data for Research Participants

Item	Department	Number of People	Ratio
Department	Electrical Engineering (EE)	80	37%
	Industrial Engineering and Management (IEM)	66	31%
	Chemical Engineering (CE)	69	32%

*Department of Electrical Engineering；EE, Department of Industrial Engineering and Management；IEM, Department of Chemical Engineering；CE
Source: compiled by this study

Exploratory factor analysis (EFA) was conducted. It comprised the varimax method of the rotation method. Only items above the 0.5 threshold were retained, though no items were deleted. Confirmation of KMO showed a KMO value of 0.879 and the Bartlett's Sphericity Test resulted in a significant result (alpha <0.05). This validated the data for factor analysis (results shown in the following table).

Table 2 Validation Results

Component	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	0.842	0.793	0.820			0.693		0.813	0.836	0.822
2				0.699	0.772		0.671			

Source: compiled by this study

After the preliminary analysis, it was found that the participants had positive replies for each item. During the course, the participants indicated that (Q1) they were able to learn observation skills (M ≥ 3.55); (Q2) they gained problem-mining skills (M ≥ 3.71); (Q7) they were able to understand what empathy is (M) ≥ 3.62); and (Q3) they were able to use user experience to clarify the context of the industry problem (M ≥ 3.46). In comparison to the traditional curriculum, participants indicated that (Q9) they could more effectively clarify the context of an industrial problem (M ≥ 3.56) and (Q8) understand what cross-domain learning is (M ≥ 3.62) (details shown in Table 3).

However, during the process, participants experienced criticism and interference from other team members (Q4) (M ≥ 2.86, SD ≥ 1.003). Finally, participants felt that when a concept is conceived, it is important to (Q5) prototype the mental concept (M ≥ 3.37) and (Q6) test and observe users in real situations (Table 3).

After running the course and conducting discussions with the participating teachers and teaching assistants, we discovered that the participants who were exposed to the creative-thinking tools provided in the design thinking workshops for the first time experienced the following problems: (1) learners thought that there was a high level of similarity between execution and the contexts of macro and micro scenarios; (2) learners experienced operational difficulties in defining personal characteristics when delineating the roles of ethnic groups; (3) learners felt that the concept development phase was too restrictive.

Based on this feedback, the following revisions were made to the process: (1) we removed Steps 1- 4 regarding macro scenarios and brainstorming; (2) when defining personal characteristics, learners were asked to place the definitions directly below the person instead of "connecting the dots"; (3) we selected three important topics, and used forced association to develop and name concepts.

Table 3 Quantitative Analysis Results

		Overall	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean
Total	M	3.57	3.72	3.81	3.64	2.94	3.35	3.96	3.70	3.60	3.62	3.33	
	SD	.940	.818	.779	.750	1.003	1.082	.825	1.102	1.066	.992	0.987	
EE	M	3.70	3.91	3.97	3.82	3.06	3.27	4.00	3.83	3.85	3.73	3.52	
	SD	.931	.808	.775	.836	1.088	1.053	.738	1.048	.975	.954	1.041	
IEM	M	3.55	3.70	3.78	3.64	2.86	3.36	3.95	3.66	3.55	3.56	3.39	
	SD												

		.854	.696	.764	.802	1.094	1.046	.679	.954	.728	.814	.965
CE	M	3.47	3.55	3.71	3.46	2.93	3.42	3.93	3.62	3.42	3.58	3.10
	SD	.976	.867	.769	.933	1.180	1.035	.693	1.072	1.035	1.035	1.139

*1=Strongly Disagree, 2=Disagree, 3=Don't Know, 4=Agree, 5=Strongly Agree

*Department of Electrical Engineering；EE, Department of Industrial Engineering and Management；IEM, Department of Chemical Engineering；CE

*Source: compiled by this study

5. Conclusions

This study used design thinking to integrate Scenario Based Design to build a set of cross-domain mini-courses. Using AEIOU and empathy-map extraction elements as the basis for the development of scenarios, the issues, users, design goals, and prospective concept designs for possible solutions were delineated. This assisted learners across different domains to produce design concepts that meet the needs of the target customer. The findings from this pilot study are as follows:

1. This cross-domain learning micro-course can help learners acquire skills in observation, problem mining, empathy, cross-domain learning, and clarification of the context of industry issues via user experience.
2. During the process of the study, cross-domain cooperation may generate criticism and interference. Further study is required for understanding the exact kind of interference and determining a means of adjusting for it to minimize related issues.
3. After design conception, it is important to prototype the mental concept and test it and observe users in real situations.
4. The results of this study serve as a reference for various professional fields for facilitation of the systematic defining and solving of problems.

In future research, we to focus on these issues and conduct qualitative and quantitative studies to understand the participants' experiences and engage in deeper analysis.

▪Reference

Brown, T. & Wyatt, J. (2010) Design Thinking for Social Innovation, *Stanford Social Innovation Review, 12(1)*, 29-43.

Brown, T. (2008, June) Design Thinking, *Harvard Business Review, 86*, 84-92.

Brown, T. (2009). *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*. Harper Business.

Brown, T. (2009). Designers – think big!. Retrieved from TED Talks: https://www.ted.com/talks/tim_brown_urges_designers_to_think_big/transcript

Campbell, R.L. (1992). Will the real scenario please stand up? *SIGCHI Bulletin, 24* (2), 6-8.

Carroll, J. M. (2000). Five reasons for scenario-based design. *Interacting with computers, 13*(1), 43-60.

China Productivity Center (2013). *User Experience Innovative Design Handbook: From Insight to Value*. New Taipei City: China Productivity Center.

Fulton, S. J., & Marsh, M. (2000). Scenario building as an ergonomics method in consumer product design. *Applied Ergonomics, 31(*2), 151-157.

Huang, L. F. (2002). A Study on Scenario Approach in Product Innovation Design and Teaching (Master's thesis, National Taipei University of Technology). Retrieved from https://ndltd.ncl.edu.tw/cgi-bin/gs32/gsweb.cgi?o=dnclcdr&s=id=%22090TIT00719003%22.& searchmode=basic

Kang, S. C., & Liu, P. L. (2017). *Educating the Talent of the Future: T-Shaped Talent Workshop*. Taiwan: Airiti Press Inc.

Lee, Y. L. (2015). *A User-Centered, Innovative NPD with Integration of Scenario-based Design and TRIZ* (Master's thesis, Ming Chi University of Technology). Retrieved from https://etds.ncl.edu.tw/cgi-bin/gs32/gsweb.cgi/ccd=DAWnqu/record?r1=1&h1=1 McKim, R. H. (1972). *Experiences in visual thinking*.

Moggridge, B. (1993). Design by story-telling. *Applied Ergonomics, 24*(1), 15-18.

Nardi, B. A. (1992). The use of scenarios in design. *ACM SIGCHI Bulletin, 24*(4), 13-14.

Rosson, M. B., & Carroll, J. M. (2007). Scenario-Based Design. In A. Sears & J. A. Jacko (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications* (pp. 1041-1060): CRC Press.

Simon, H. A. (1996). *The Sciences of the Artificial*. London, England: MIT press.

Su, C. B. (1994). *Theories and Applications of Scenario in Human-Computer Interaction ---- A Case of Interactive TV ProgramGuide* (Master's thesis, National Chiao Tung University). Retrieved from https://ndltd.ncl.edu.tw/cgi-bin/gs32/gsweb.cgi?o=dnclcdr&s=id=%22082NCTU0374004%22. &searchmode=basic

Tang, H. H., & Lin, Y. C. (2011). The Influence and Problems of Scenario Design Approach on Multi-disciplinary Collaboration Design. *Journal of Design. 16* (3), 21-44.

Thomsen, D. (2013). *Why Human-Centered Design Matters*. Retrieved from WIRED: https://www.wired.com/insights/2013/12/human-centered-design-matters/

Wagner, T., & Compton, R. A. (2015). *Creating innovators: The making of young people who will change the world*. Simon and Schuster.

Yang, C. M., Kao, C. H., Liu, T. H., Lee, Y. L., & Zheng, Y. Y. (2016, December). *A User-Centered, Innovative NPD with Integration of Scenario-based Design and TRIZ.* Proceedings of the 17th Asia Pacific Industrial Engineering and Management Systems Conference, Taipei, Taiwan. Yu, D. J., Lin, W. C., & Wang, J. C. (2003). Scenario-O*riented Design.* Taipei：Garden City Publishers.

Using Quantitative Measures in Effect Identification and Prioritization for Problem Solving

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Abstract

This research proposed a mathematical method to identify TRIZ solution models to given problems based on similarity measures. Quantitative methods were used to allow the users quickly and objectively obtaining solution models to a problem with priority based on existing effects and solved effect case base which is the accumulation of many expert knowledge and experiences instead of individual expert's knowledge. Similarity concept was used to determine the relevant effects and related solved cases as solution models. A total of 210 known cases and 70 effects from scientific website/knowledge database are verified with the author's research team for solution generation. By conducting a 3-fold verification of the 210 cases, the ten highest similarity solution models provided a hit rate exceeding 87.6% coverage of original solutions. This substantially exceeded the 23.8% hit rate of ten randomly selected solutions covering original solutions. The ten worst similarity solution only provided 0% hit rate.

This provides a paradigm shift in research direction for TRIZ-based research from logical reasoning to quantitative calculations contributing to TRIZ recognition in scientific fields. The contributions of this study include: 1) Using the problem characteristics array and solution characteristics array based on technical effects to enable mathematical computations for prioritized effect solutions instead of traditional qualitative reasoning and non-prioritized excessively large number of suggestions. 2) Providing a means to continually accumulate expert knowledge and experience by integrating more expert-solved cases to provide users a rapid, objective, and effective problem-solving system. This implies a continuous learning system which uses cumulative knowledge from many experts objectively instead of otherwise knowledge from individual experts. 3) Enhancing existing 39 parameters to 78 parameters and increasing existing 36 functions to 61 functions to cover more problem solving situations.

Keywords: Theory of inventive problem solving (TRIZ), Systematic Innovation, Problem/Solution Similarity, Effect Knowledge Database, Computer-aided problem solving.

1. Introduction

TRIZ is the Russian acronym of theory of inventive problem solving. The use of technical Database is one of TRIZ's most important solution approaches (Alushuller, 1984). The current database searching method consists in identifying needed functions or needed attribute changes as searching conditions to find related effects or resources for trigger solutions. Presently, Goldfire Innovator, Oxford effect database, and Pro/Solutions (Pro-Innovator) database, are commonly used technical databases. Although these databases can provide effects for problem solving, the number of recommended solutions often are excessively large and without priority making them hard to use.
For example, searching for "Move Solid" on (Oxford Creativity, 2017) generates 230 suggestions, most of which are not relevant to particular conditions of a specific problem. For problem-solving effectiveness, it is important to prioritize those suggestions for any specific problem. This is one of the main themes of this paper.

The other drawback with using effect database is that it identifies relevant effects only by using a single needed function or single needed parameter change to solve a problem. However, when dealing with real-world problems, constraints on multiple parameter characteristics and/or multiple function characteristics may be relevant or even required. For example, one may need to move a solid in low temperature and extremely high-pressure environment such as those conditions in deep seas. Effects that only match "Move Solid" may not be viable in those extreme conditions.

Addressing the above two issues, this paper proposed a theoretical base and quantitative approach to map from problems characteristic array to solution array in terms of applicable effects to solve problems using effect database and case base.

2. Literature Review

2.1 Scientific Effect Databases

Scientific effect database, or database of working principles, is one of important problem solving tools in the systematic process of systematic innovation (Sheu & Lee, 2011). It is also one of the important steps of ARIZ (Algorithm for Inventive-Problem Solving) solution process (Altshuller, 1999; Shen, et al., 2012). Originally, TRIZ only had 30 function groups (Lee, & Han, 2010), which represent a portion of the physical phenomenon and effects database in TRIZ (Altshuller, 1984). Inventions were often a direct result of the application of scientific effects and phenomena. However, a single inventor usually only is well versed in a single discipline and has only limited knowledge and experience in others (Martin, 2005). To effectively support complex product design, effect model in TRIZ was extended, and E-FBS (Extended-effect driven Function-Behavior-Structure) model was proposed (Cao, et al., 2009.)

Some improvement opportunities for existing effect databases are summarized below: (CREAX, 2011; Goldfire, 2017; Oxford Creativity; 2017. Pro/Solutions KB, 2009).

1. There is no suggested priority for reference effects. Current databases have a common disadvantage that is they don't prioritize potential effects for problem solving. The number of possible effects to solve a function-based or parameter-based search range from tens to hundreds. Going through hundreds of effects to locate a right one for solution is very time consuming. Usually, only a small number of effects, among the large number of listed ones, are relevant for any given problem as the problem related surrounding/situation parameters may be very different from those of the listed effects capable of generating a similar function.
2. The Goldfire effect database has a large number of effects but they are not organized in an easy-to-use way. Same function requirements are listed in several different ways such as in different fields and usage situations making it difficult to search.
3. The number of parameters and functions available in the existing effect databases is insufficient. For example, Oxford Creativity effect database only have 37 parameters and 35 functions to locate effects for problem solving. Often times, the needed function or parameter change to solve a specific problem are not on the listed function or parameter lists.

This research addressed the above-mentioned first issue and alleviate third issue by adding the number of parameters (attributes) from 39 to 78 and the number of functions from 36 to 61 (Mann, 2007; Sheu, & Chiu, 2017.) Please see Appendix A. The principle to prioritize applicable effects is based on TRIZ theorem "Similar Problem, Similar Solutions" for problem solving. The ideal of effect database allows user to leverage effects used in own or other industries to solve similar problems.

2.2 Similarity Comparisons

Over the past few decades, researchers of similarity theory have come up with hundreds of formulations. De Baets et al. proposed a parametric family of cardinality-based similarity measures. Choi et al. arranged 76 methods for similarity and distance calculations and used Hierarchical Clustering Method to compare the relationship between these methods. Jimenez et al. enhanced Jaccard, Dice and cosine similarity measures to generalize an analysis of its boundaries, monotonicity property, and a method for constructing similarity functions.

In order to define the similarity of any two elements, I and J, they can be represented as arrays of the same kind. Dunn and Everitt (1982) listed a binary variable paired observation table as shown in Table 1. i and j are two variables in corresponding columns of I and J to be compared. They represent the same attribute column of the two arrays I and J. An array variable that equals to one in that column represents that an observed value of the attribute indicated by that column exhibits certain defined characteristics. An array variable that equals to zero represents that the observed value does not exhibit the defined characteristics with respect to the corresponding attribute indicated by that column. In

Table 1, *a* represents the number of attributes in which observed values in *i* and *j* are both equal to one, which results in successful **positive matches** between the corresponding columns of Array *I* and Array *J*. *b* represents the number of attributes in which observed values *i* and *j* are respectively (0, 1), which represents that *i* does not exhibit the defined characteristics while *j* exhibits the defined characteristics and thus matching is unsuccessful. *c* represents the number of attributes in which observed values *i* and *j* are respectively (1, 0), which represents that *j* does not exhibit the defined characteristics while *i* does. Again, the match is unsuccessful in this case. Lastly, *d* represents the number of attributes in which *i* and *j* are both zero, which means that neither exhibit the corresponding defined characteristics, thereby resulting in a successful **negative matches**. Numerous similarity measurement methods exist to indicate the similarity between *I* and *J* (Choi, Cha, & Tappert, 2010; Donald, Keith, & Harold, 1989; Jackson, Somers, & Harvey, 1989; and Meyer, Garcai, Souza, & Souza, 2004).

Table 1. Binary Variable Paired Observation Table

i / *j*	1*(Presence)*	0*(Absence)*
1*(Presence)*	*a*	*b*
0*(Absence)*	*c*	*d*

3. Methodology

This section explains the methods developed for mathematical approaches to identify solution effects from effect database with priorities. Section 3.1 explains the foundation concepts for this study. Section 3.2 explains the modeling approaches for the problems, effects, and cases. Section 3.3 explains the method of identifying effect solutions using similarity measures. Section 3.4 explains the overall tasks of identifying effect solutions. The computational details of how to identify the solutions in section 3.5.

3.1 Solution model and foundation concepts

TRIZ problem solving process, embodied in Effect and Resource databases, are shown in Figure 1. This work focused on improving the encircled process step of converting from a problem model to solution models, or trigger solutions, using effect database. A future work will concentrate on using Resource database in a similar fashion. However, the process of matching problem models to their corresponding solution models by using TRIZ problem-solving tools has been reliant on expert experiences and judgments. Not only different experts may identify different solutions, the traditional methods may also obtain different solutions at different times even for the same person.

The lack of repeatability and mathematical/quantitative contents contributed to the lower-than-deserve acceptance of TRIZ research work by rigorous scientific journals.

This research addressed the above-mentioned problems in TRIZ identification of solution models in terms of effects. By using quantitative measures the goals of solution priority, objectivity, repeatability, modeling rigor, and the speed of obtaining solution models, can be achieved. In the meantime, the system design allows for problem solving based on the integral results of continual accumulation of many experts' knowledge/experiences embedded in many expert-solved cases instead of knowledge/experience of an individual expert.

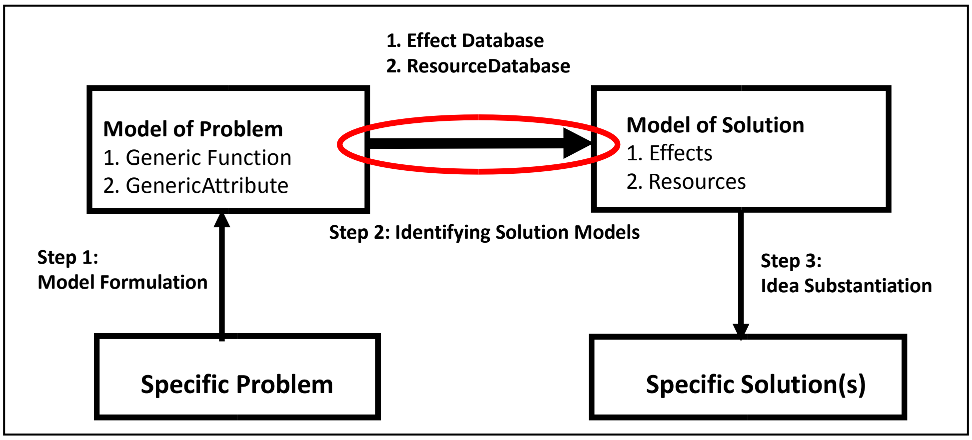

Figure 1. TRIZ Model of Problem Solving Embodied in Effect and Resource Databases

Figure 2 illustrates the relationships among the attribute, function, effect and resource. For example, functions from different industries/applications have their terms and these are industry or application specific functions. By extracting the fundamental aspects of similar "Specific Functions", one can identify "Generic Function" for a group of Specific functions. For example, hammer hits nail, wheel drives conveyer belt, and pitcher throws ball, are all application specific functions. Their generic function, move solid, represents the common fundamental aspect of their specific functions. Similar situation holds for attributes. The application specific attributes such as length, height, depth, width, et al., all represent different perspectives of a same fundamental attribute of "length" and can all be converted into their generic attribute of length. Therefore, we could transform the specific functions and specific attributes into corresponding generic functions and generic attributes. We can then use the generic function and generic attribute to search effect database for trigger solutions. The effect database contains the various effects, or working principles, which can be used to achieve the corresponding generic function. Oxford creativity effect database also contains various resources, components and physical systems, which can be used to achieve the corresponding function. This paper focus on the prioritization of effects. Future work will focus on the prioritization of resources.

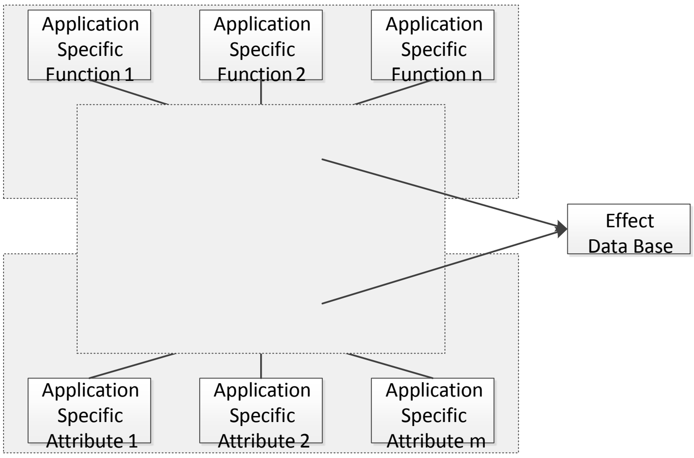

Figure 2. The Relationship among Attribute, Function, and Effect

Two scenarios were used to identify relevant effects for solution models based on similarity measures:

a. If the model of a problem to be solved is similar to the model of a solved case, then the solution model of the given problem will be similar to the solution model of the solved case. If the similarity index is higher than a pre-determined threshold, we can use the solution of the solved problem weighted with the similarity to form the solution model of the problem to be solved.
b. The characteristic attributes of the to-be-solved problem and needed functions to solve the problem are identified. If relevant attributes which are conducive for the effect to occur is similar to the characteristic attributes of the to-be-solved problem and the functions which can be provided by the effect is similar to the needed functions to solve the problem, we consider the likelihood for this effect to solve the problem is high. The similarity between the function provided by this effect and the needed function to solve the problem and the similarity between the relevant attributes of the problem and relevant attributes of the effect can be used as the weigh factors for priority calculation.

3.2 Modeling of the problems, effects, and cases

In order to calculate the various similarities, the research developed below arrays to fully represent problem to be solved, effects, and cases using attribute and function elements.

Problem Characteristic Array (PCA): PCA is the standardized problem model. It models a problem to be solved with functions and attributes characteristics of that problem.

Effect Characteristic Array (ECA): ECA is the standardized characteristics of an effect. It characterizes an effect with the environmental attributes which are conducive for the effect to occur and the functions/attribute-changes the effect is able to provide if it occurs.

Case Characteristic Case Array (CCA): CCA is the standardized Case model. It models a solved case including two parts. The first part of the CCA is its Problem Characteristic Array (PCA) with functions and attributes characteristics of that problem. The second part of the CCA is the Solution Array (SA). It indicates which effects have been or can be used to solve this problem.

3.2.1 Modeling of a problem, PCA

Figure 3 shows the bit array representation of a PCA. A PCA contains an attribute part and a function part. Since function can also be represented as change or maintain the attribute(s) of an object, the function part of a PCA are further divided into attribute subsection and function subsection to fully represent a function. For convenience, the authors denote the attribute part of the function as indirect functions and the function part as direct functions. When using the PCA, the user needs to identify the correct phase for the subject problem system, which could be solid, liquid, gas, or field. In the attribute array, a "1" in a cell value indicates that the corresponding attribute is one of the characteristic attributes of the current problem. A "0" in an attribute cell indicates that the corresponding attribute is irrelevant to the problem. The characteristic attributes of the problem PCA can be considered as characterizing system or environmental attributes which is relevant to the problem situation. For example, to fix a problem for submarine outer shell in the deep sea, one of its characteristic attributes would be extreme low temperature and very high pressure. So, temperature and pressure are the characteristic (relevant) attributes of the problem among others.

On the attribute subsection of the function array, a "1" in the cell indicates that to solve this problem some change/maintenance of this parameter is needed. A "0" in the cell location indicating that this attribute is irrelevant to the problem solving. On the function subsection of the function array, a "1" in the cell indicates that achieving the corresponding function can solve this problem. A "0" in the cell indicates that the corresponding function is irrelevant to problem solving.

A PCA fully models a problem.

Attribute Array			Function Array					
			Attribute Subsection			Function Subsection		
A_1	…	A_M	A_1	…	A_M	F_1	…	F_N

Needed functions to solve the problem.

Needed attributes change/maintenance to solve the problem.

Characteristic attributes of the problem.

Figure 3. Problem Characteristic Array (PCA)

3.2.2 Modeling of an effect, ECA

Figure 4 shows the effect characteristic array (ECA). The attribute/function sets of the ECA are similar to that of the PCA used with respect to the problem-solving effect. The first part of ECA is attribute array. The characteristic attributes of the attribute array are the attributes, which are relevant to this effect or conducive for the effect to occur. A "1" in a cell value indicates that the corresponding attribute is one of the characteristic attributes of the current effect. A "0" in an attribute cell indicates that the corresponding attribute is irrelevant to the effect. The second part of the ECA is the function array. This part, in turn, includes indirect function sub-section (change/maintenance attributes) and the (direct) functions sub-section. A "1" in a function field of the effect indicates that a function or attribute change can be achieved with this effect. A "0" indicates that the corresponding function(s) are irrelevant to this effect. The ECA itself can be considered as a solution to a problem of certain attribute/function characteristics. In this sense, an effect by itself can be considered as another form of a case. Therefore, they can be added to the database for the solution process.

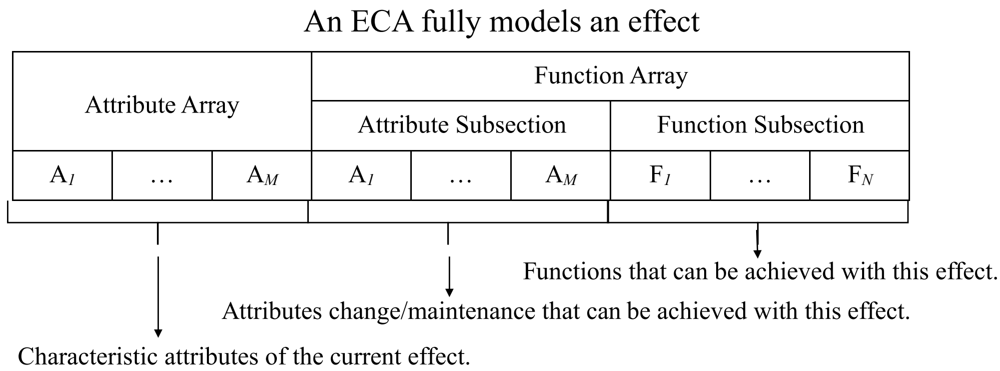

Figure 4. Effect Characteristic Array (ECA)

3.2.3 Modeling of a case, CCA

Refer to Figure 5. A CCA is defined as the direct compilation of PCA and solution array (SA) to be the model of the case. The first part is the problem characteristics array (PCA), same as defined before. The second part is the solution array. The solution array of CCA is an effect array representing which effect(s) could be used to solve the problem. In the solution array, a "1" in a cell means that the corresponding effect can be or has been used to solve the problem or the kind of problem characterized by its PCA. A "0" in the cell indicating that this effect is irrelevant to solving this problem.

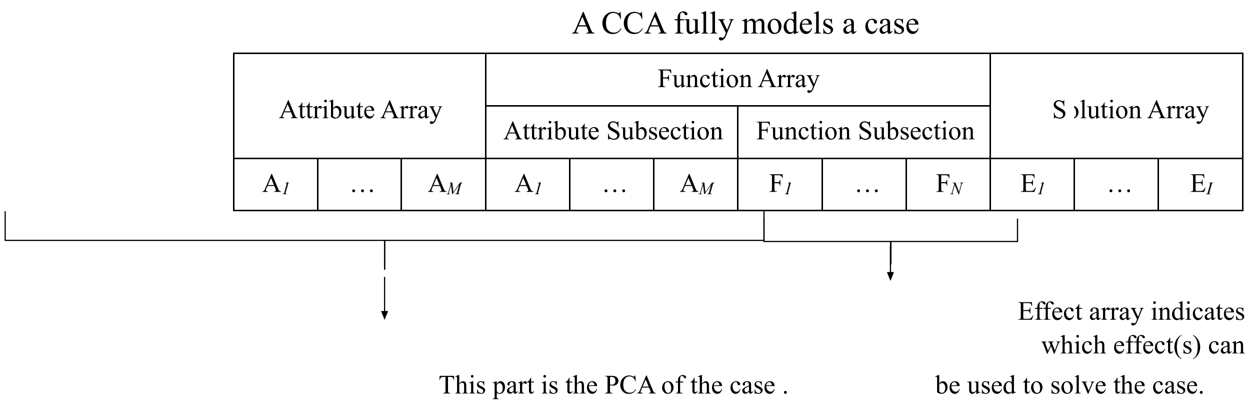

Figure 5. Case Characteristic Array (CCA)

3.3 Identifying Effect Solutions Using Similarity Measures

This research provides two ways of using similarity to locate appropriate effects and cases for prioritized effect solutions. (1) Based on comparison of problem PCA with ECA in effect database directly; (2) Based on comparison of problem PCA with PCA part of solved cases in case database. The detail steps of similarity comparisons are explained in sections 3.4 and 3.5.

3.3.1 Identifying solutions by similarity comparison with effects

Figure 6 shows the concept of identifying effect for model of solution. Three steps are used. (1) Characteristic function array of the problem PCA to be solved is compared against the function arrays of an effect ECA. (2) If the similarity measure is higher than certain threshold 1, the characteristic attribute array of the PCA is compared to characteristic attribute array of the effect ECA. If the similarity is higher than certain threshold 2, it indicates that this effect may solve the problem. Then, (3) the corresponding effect identification is recorded as a solution model of the problem.

The similarities between the PCA of the case to be solved and the Attribute/Function arrays of the ECA are then converted to be a weigh factor for the identified problem-solving effects.

3.3.2 Identifying solutions by similarity comparison with cases

Identifying effect solutions from solved case database also has three steps as shown in Figure 7. (1) Characteristic function array of the problem PCA to be solved is compared against the function array of a case CCA. (2) If the similarity measure is higher than certain threshold 1, the characteristic attribute array of the PCA is compared to characteristic attribute array of the case CCA. If the similarity is higher than certain threshold 2, it indicates the effects used to solve this case may solve the problem. Then, (3) the relevant problem solving effect(s) on the SA of the solved case are recorded as eligible problem solving effects for the case to be solved. The similarities between the PCA of the solved case and PCA of the case to be solved are then converted to be weigh factor for the identified problem-solving effects. The weigh factor for this PCA-CCA comparison and the counter-part weigh factor for the same effect from the PCA-ECA comparison, as stated in previous section, are combined to form the priority index for that effect toward solving the problem.

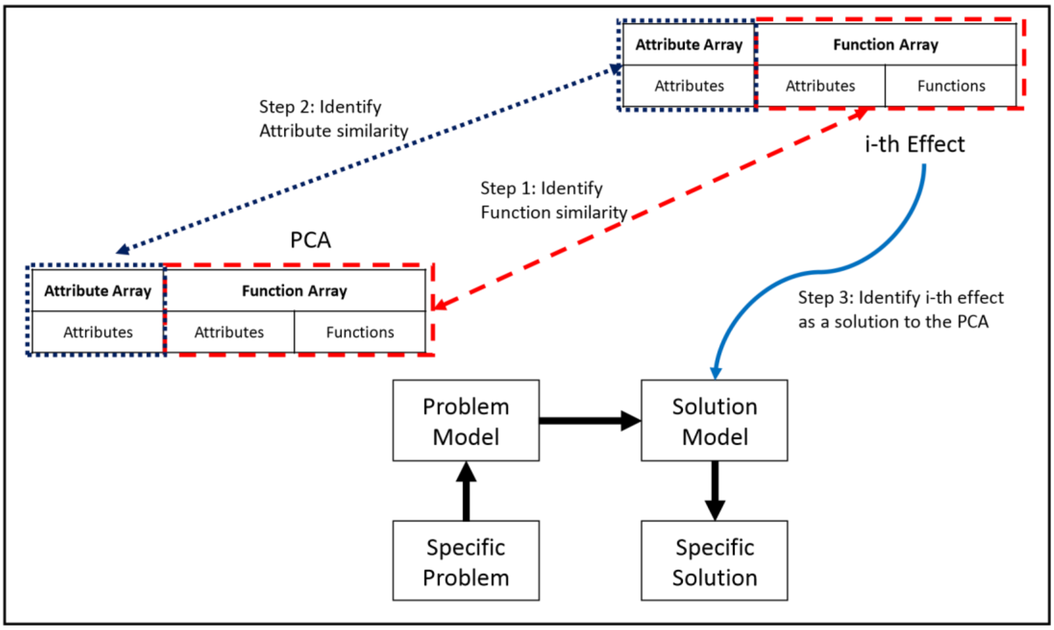

Figure 6. Process of Identifying Solutions by Similarity Comparison with Effects

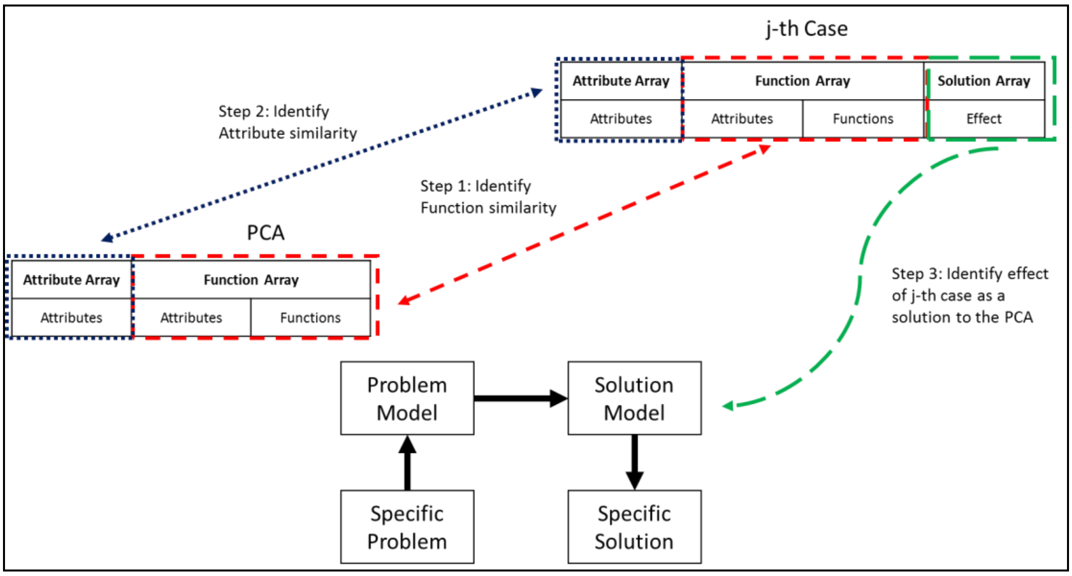

Figure 7. Process of Identifying Solutions by Similarity Comparison with Cases

3.4 Identifying Overall Tasks of This Study

The overall tasks of this research and their process sequence are illustrated in Figure 8 and briefed below:

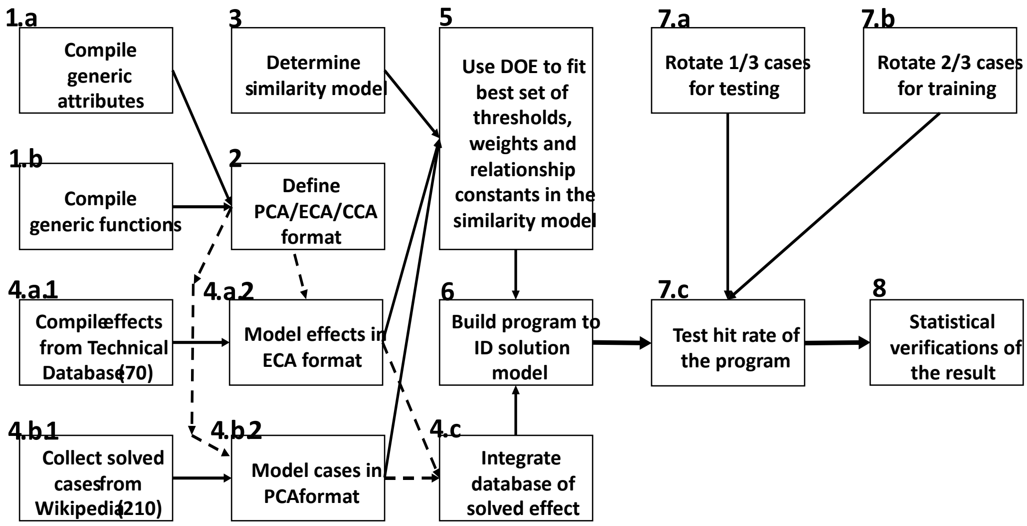

Figure 8. Overall Tasks of the Research

Step 1: Compile generic attributes and functions

This step is to standardize and summarize the attributes and functions form other knowledge database and to integrate some additional ones from author's team to form a list of generic functions and generic attributes.

Step 2: Define the Formats of PCA/ECA/CCA

The definitions of PCA/ECA/CCA in bit-array format allow us to calculate the similarities between problems/effects/cases enabling the objective identification of effect solutions to a problem. Methods of using PCA-ECA comparisons and PCA-CCA comparisons to identify effect solution models with priority are described in Section 3.2. See Section 3.5 for more details.

Step 3: Determine Similarity Models

The commonly used Jaccard and Dice similarity indices (Choi, Cha, & Tappert, 2010; Donald, Keith, & Harold, 1989; Jackson, Somers, & Harvey, 1989; and Meyer, Garcai, Souza, & Souza, 2004) were modified to become generalized Dice indices to form Eqs. 1 and 2 below.

a) Similarity formulae for matching the corresponding array between PCA and ECA:

$$^{k}Sim_{i}(PCA,ECA)=\frac{{}_{E}^{k}\alpha\cdot{}_{E}^{k}a+{}_{E}^{k}\beta\cdot{}_{E}^{k}b}{({}_{E}^{k}\alpha\cdot{}_{E}^{k}a+{}_{E}^{k}\beta\cdot{}_{E}^{k}b)+{}_{E}^{k}c},0\leq{}^{k}Sim_{i}(PCA,ECA)\leq1 \qquad (1)$$

Symbol definitions:

(1) ${}^{k}Sim_{i}(PCA,ECA)$ represents the similarity coefficient for matching the arrays between the PCA and $i\text{-}th$ ECA.

(2) ${}_{E}^{k}a$ represents the number of positive matches (1–1) in the same environmental phase in the corresponding array matches between the PCA and $i\text{-}th$ ECA.

(3) ${}_{E}^{k}b$ represents the number of positive matches (1–1) in different environmental phases in the corresponding array matches between the PCA and $i\text{-}th$ ECA.

Note that attributes and functions may exist in different environmental phases which include solid, liquid, gas, or field. The degree of similarity has different weights between different phases. For example, if "Clean" is a needed function to solve the problem with "Solid" phase, an effect which can provide the function as "Clean" in "Solid" phase will have a perfect match , the weigh factor can be "1". However, if an effect provides the same "Clean" function but in a different phase, such as liquid, the similarity shall be counted less significant and the weight will be between 1 and 0.

(4) ${}_{E}^{k}\alpha$ and ${}_{E}^{k}\beta$ are weigh factors for ${}_{E}^{k}a$ and ${}_{E}^{k}\beta$ respectively.

(5) ${}_{E}^{k}c$ represents the number of non-matches (1–0 or 0–1) and negative matches (0–0) in the corresponding array matches between the PCA and $i\text{-}th$ ECA.

(6) If $\begin{cases} k = A: \text{ represents that this array is the attribute array} \\ k = F_a: \text{ represents that this array is the attribute subsection of the function array} \\ k = F_f: \text{ represents that this array is the function subsection of the function array} \end{cases}$

b) Similarity Formulae for matching the corresponding array between PCA and CCA

$$ {}^{k}Sim_{j}(PCA,CCA) = \frac{{}_{C}^{k}\alpha \cdot {}_{C}^{k}a + {}_{C}^{k}\beta \cdot {}_{C}^{k}b}{({}_{C}^{k}\alpha \cdot {}_{C}^{k}a + {}_{C}^{k}\beta \cdot {}_{C}^{k}b) + {}_{C}^{k}c}, 0 \le {}^{k}Sim_{j}(PCA,CCA) \le 1 \qquad (2) $$

Symbol definitions:

(1) ${}^{k}Sim_{j}(PCA,ECCA)$ represents the similarity coefficient for matching the arrays between PCA and $j\text{-}th$ CCA.

(2) ${}_{C}^{k}a$ represents the number of positive matches (1–1) in the same environmental phase in the corresponding array matches between the PCA and $j\text{-}th$ CCA.

${}_{C}^{k}b$

(3) represents the number of positive matches (1–1) in different environmental phases in the corresponding array matches between the PCA and $j\text{-}th$ CCA.

(4) ${}^k_c\alpha$ and ${}^k_c\beta$ are weigh factors for ${}^k_c\alpha$ and ${}^k_c\beta$ respectively.

(5) ${}^k_c c$ represents the number of non-matches (1–0 or 0–1) and negative matches (0–0) in the corresponding array matches between the PCA and $j\text{-}th$ CCA.

(6) If $\begin{cases} k = A: \text{ represents that this array is the attribute array} \\ k = F_a: \text{ represents that this array is the attribute subsection of the function array} \\ k = F_f: \text{ represents that this array is the function subsection of the function array} \end{cases}$

Step 4: Collecting Cases and Establishing the Case Database

This is steps 4.b.1 in Figure 8. It includes two parts: Effect-as-cases and Solved cases primarily extracted from Wikipedia web site.

Step 4.a.1: Compile effects from Technical Database

70 commonly used effects were collected from Oxford Effect Database.

Step 4.a.2: Model effects in ECA

This step defines attributes and functions in phases of ECA according to ECA definition stated before. The characteristic attributes and desirable functions are identifies based on discussions by author's research team. The discerning criteria are based on the below questions:

On the attribute array:

If the change or maintaining of the subject attribute can cause the effect or can influence the effect to occur, the attribute can be considered as relevant to the effect in the attribute field.

On the attribute subsection of function array:

If the occurrence of the effect can help to change or maintain the subject attribute, the subject attribute is considered relevant to the effect. Otherwise, the subject attribute is irrelevant to the effect.

On the function subsection of function array:

If the occurrence of the effect can help to achieve the subject function, the subject function is considered as relevant function to this effect. Otherwise, the subject function is considered irrelevant to this effect.

Step 4.b.1: Collect solved cases from website

210 cases of solved problems were collected from Wikipedia website and other scientific websites such as OxfordCreativity (www.triz.co.uk). Three cases are selected from each of the 70 effects thus generating 210 cases.

Step 4.b.2: Model cases in CCA

The identification of characteristic attributes and desirable functions are based on discussions by author's research team. The discerning criteria are based on the below questions: **On the Attribute Array:**

If the attribute is a characteristic feature of the problem, the attribute can be considered as relevant to the problem. Otherwise, the attribute is considered as irrelevant to the problem.

On the attribute subsection of function array:

If change or maintaining the subject attribute can help to solve the problem of this case, the subject attribute is considered as relevant indirect function of the problem. Otherwise, the subject attribute is irrelevant to the problem solving.

On the function subsection of function array:

If the achievement of the subject function can contribute to solving the problem of this case, the subject function is considered as relevant function to this problem. Otherwise, the subject function is considered irrelevant to the problem.

On the effect array:

If using the subject effect can help to solve the problem of this case, the subject effect is considered as relevant effect solution of the problem. Otherwise, the subject effect is irrelevant to the problem solving.

It is clear that most attributes or functions are not characteristic or relevant attributes or functions of the characteristic array thus easily screening out most attributes. They can be easily identified as “0” in the phase. Usually, only a small number of attributes or functions are clearly characteristic or relevant attributes or functions of the characteristic array. They can be easily identified as “1” in the phase. Small number of attributes and functions may have unclear relevancy to the problem characteristics depending on different person’s opinions. Discussions for consensus were used to determine if the value of those fields to be “1” or “0”. In the future, certain fuzzy value may be assigned for this case based on some discussion or voting scheme. Identification of the relevant functions to solve the problem is straightforward and only a very small number of functions can help to solve the problem.

Step 4.c: Integrate database of solved effect

Altogether, there were 70 effect-as-cases and 210 solved cases in the database for problem solving.

Step 5: Using DOE to set parameter values

DOE (Design of Experiment) method was used to determine the best threshold levels, weight between ECA and CCA, and various parameters in the similarity equations, Eq. 1 and Eq. 2. The Taguchi method was used in the setting of these parameters to objectively obtain the optimal parameter combinations using the 70 effects and 210 solved cases.

The process for parameters setting is as follows:

- Setting factor standards for a total of 8 factor parameter sets including 28 factor parameter of which are independent.
  (1) ${}^{F}_{E}\delta$ represents the threshold for function array similarity between PCA and ECA.
  (2) ${}^{F}_{C}\delta$ represents the threshold for function array similarity between PCA and CCA.
  (3) ${}_{E}\delta$ represents the threshold for total array similarity between PCA and ECA.
  (4) ${}_{C}\delta$ represents the threshold for total array similarity between PCA and CCA.
  (5) ${}^{A}_{E}\alpha, {}^{A}_{E}\beta, {}^{F_a}_{E}\alpha, {}^{F_a}_{E}\beta, {}^{F_f}_{E}\alpha, {}^{F_f}_{E}\beta$ are the weigh factors in Eq. 1.
  (6) ${}^{A}_{C}\alpha, {}^{A}_{C}\beta, {}^{F_a}_{C}\alpha, {}^{F_a}_{C}\beta, {}^{F_f}_{C}\alpha, {}^{F_f}_{C}\beta$ are the weigh factors in Eq. 2.
  (7) ${}^{F_a}_{E}\omega, {}^{F_f}_{E}\omega$ represent the weights for attribute subsection and function subsection of ECA function array. Where ${}^{F_a}_{E}\omega + {}^{F_f}_{E}\omega = 1$.
  (8) ${}^{F_a}_{C}\omega, {}^{F_f}_{C}\omega$ represent the weights for attribute subsection and function subsection of CCA function array. Where ${}^{F_a}_{C}\omega + {}^{F_f}_{C}\omega = 1$.
  (9) ${}^{A}_{E}\omega, {}^{F}_{E}\omega$ represent the weights for attribute array and function array of ECA. Where ${}^{A}_{E}\omega + {}^{F}_{E}\omega = 1$.
  (10) ${}^{A}_{C}\omega, {}^{F}_{C}\omega$ represent the weights for attribute array and function array of CCA. Where ${}^{F}_{C}\omega + {}^{F}_{C}\omega = 1$.
  (11) ${}_{E}\omega, {}_{C}\omega$ represent the weights of effect solutions for effect-as-case and solved case. Where ${}_{E}\omega + {}_{C}\omega = 1$.
- Proceed to conducting a Taguchi experiment with the parameters as inputs and the target of optimization is to maximize the case solution hit rates. The combination of parameter sets and the optimal parameter value sets is thus obtained in Table 2 below.

Table 2. Parameter Value Set Derived from Design of Experiments

Parameter Set	$({}_{E}\omega, {}_{C}\omega)$	$({}^{F_a}_{E}\alpha, {}^{F_a}_{E}\beta)$ &) $({}^{F_a}_{C}\alpha, {}^{F_a}_{C}\beta)$	$({}^{F_f}_{E}\alpha, {}^{F_f}_{E}\beta)$ & $({}^{F_f}_{C}\alpha, {}^{F_f}_{C}\beta)$	$({}^{F_a}_{E}\omega, {}^{F_f}_{E}\omega)$ & $({}^{F_a}_{C}\omega, {}^{F_f}_{C}\omega)$	${}^{F}_{E}\delta$ & ${}^{F}_{C}\delta$	$({}^{A}_{E}\alpha, {}^{A}_{E}\beta)$ & $({}^{A}_{C}\alpha, {}^{A}_{C}\beta)$	$({}^{A}_{E}\omega, {}^{F}_{E}\omega)$ & $({}^{A}_{C}\omega, {}^{F}_{C}\omega)$	${}_{E}\delta$ & ${}_{C}\delta$
Parameter Value	(0.8, 0.2)	(50, 15)	(50, 15)	(0.8, 0.2)	0.6	(50, 15)	(0.5, 0.5)	0.6

Step 6: Build program to ID solution model

The detail algorithm and processes of the program is explained in Section 3.5

Step 7: Test hit rate of the program

The 210 cases from case database were divided into 3 groups evenly and approximately randomly with the constraint that cases of the same effect are distributed as evenly as possible to each of the 3 groups in a round-ribbon manner. This is to make sure that each group has a good representation of the various effect solutions. A K-Fold Cross-Validation method, as shown in the Section 5, was used to test the program and calculate the hit rate of the program. The hit rate of the experiment is defined as the percentage when the proposed solution set is able to contain the original solution used in each case.

Step 8: Statistical Verifications of the Results

Statistical verifications were given in Section 5 below.

3.5 The detail algorithm and processes of the program

3.5.1 Overall process of the similarity comparisons

The overall process of the identifying solution model is given in Figure 9. It includes 1) the identification of relevant effects with priorities from the comparison between the problem PCA and the ECAs, and 2) the identification of relevant effects with priorities from the comparisons between the problem PCA and the CCAs. The solutions from both parts are cumulated and prioritized based on the final similarity measures.

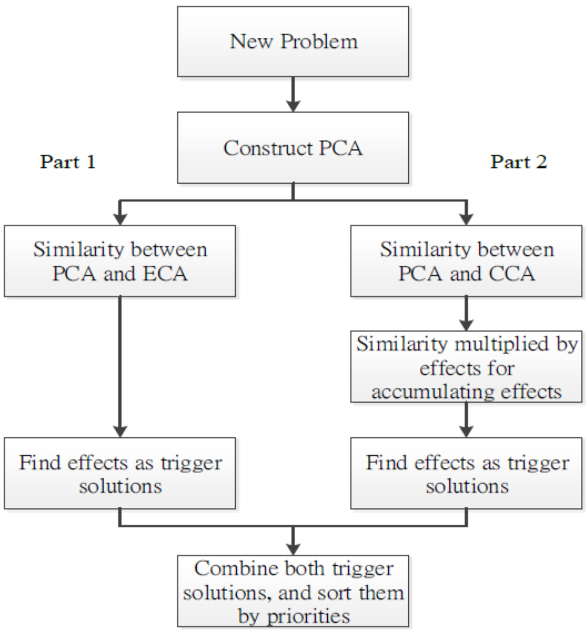

Figure 9. Overall Process of Similarity Comparison

3.5.2 Part 1: Elaboration on the first part of Figure 9:

Similarity comparison process for the PCA to be solved and effects (ECAs). Refer to Figure 10.

Step 1: Set initial values

Set $i = 1$ representing calculation of the attribute and function similarities for the first effect.

Step 2: Determine whether $i \leq I(70)$

Where $I(70)$ is the total number of effects under test. Proceed to Step 7 to prioritize and output the solutions.

Step 3: Calculate ${}^{F}Sim_i(PCA, ECA)$ and determine if ${}^{F}Sim_i(PCA, ECA)$ passed the threshold of ${}^{F}_{E}\delta$

${}^{F}Sim_i(PCA, ECA)$ represents the function similarity between the problem and an effect defined as ${}^{F}Sim_i(PCA, ECA) = {}^{F_a}_{E}\omega \cdot {}^{F_a}Sim_i(PCA, ECA) + {}^{F_f}_{E}\omega \cdot {}^{F_f}Sim_i(PCA, ECA)$. The function array is more important than the attribute array, so it is calculated first as the first screening.

${}^{F}_{E}\delta$ is the threshold for function array similarity. If ${}^{F}Sim_i(PCA, ECA) \geq {}^{F}_{E}\delta$, calculations proceed to Step 4, otherwise $i = i + 1$ and calculations returns to Step 2 for the next effect.

Step 4: Calculate $Sim_i(PCA, ECA)$ and determine if $Sim_i(PCA, ECA)$ passed the threshold of ${}_{E}\delta$

$Sim_i(PCA, ECA)$, the similarity between a problem and an effect, is defined as $Sim_i(PCA, ECA) = {}^{A}_{E}\omega \cdot {}^{A}Sim_i(PCA, ECA) + {}^{F}_{E}\omega \cdot {}^{F}Sim_i(PCA, ECA)$. ${}_{E}\delta$ is the threshold for the total ECA similarity. If $Sim_i(PCA, ECA) \geq {}_{E}\delta$, the effect may be a possible solution, and calculations proceed to next step. Otherwise $i = i + 1$ and calculations returns to Step 2 for the next effect.

Step 5: Compile the solution models

When the similarity calculations for all effects are completed, the effects whose similarity measures passed both the function thresholds and attribute thresholds as mentioned in the previous steps can be listed as feasible effects to solve the problem. These effects can be combined with the feasible effects obtained from next section, Part 2 of Figure 9, to form the full set of effects for solving the subject problem. The similarities values for all feasible effects from ECA comparison and from PCA comparison will be normalized and cumulated within the same effect to determine the final priority of the effect. The normalized similarity value of $i\text{-}th$ effect from ECA database is represented as ${}_{E}Norm_i$.

3.5.3 Part 2: Elaboration on the Second part of Figure 9:

Refer to Figure 10 for similarity comparison process between problem PCA and solved cases (CCAs)..

Step 1: Setting initial values

Set $j = 1$ representing calculation of the attribute and function similarities from the first case.

Step 2: Determine whether $j \leq J(210)$

$J(210)$ indicates that the model contains 210 solved cases. When the current case j is less

than or equal to J, calculations proceed to Step 3. Otherwise, all cases have completed the similarity calculations. Then, proceed to Step 7 to compile the solution models for outputs.

Step 3: Calculate ${}^{F}Sim_j(PCA, CCA)$ and determine if ${}^{F}Sim_j(PCA, CCA)$ passed the threshold of

${}^{F}_{C}\delta$

${}^{F}Sim_j(PCA, CCA)$ represents the function similarity between the problem PCA and the

PCA of the current case and is defined as
${}^{F}Sim_j(PCA, CCA) = {}^{F_a}_{C}\omega \cdot {}^{F_a}Sim_j(PCA, CCA) + {}^{F_f}_{C}\omega \cdot {}^{F_f}Sim_j(PCA, CCA)$. ${}^{F}_{C}\delta$ represents the threshold

for function array similarity. Similarities between the problem PCA and past cases must be greater than or equal to the corresponding threshold, ${}^{F}_{C}\delta$. If ${}^{F}Sim_j(PCA, CCA) \geq {}^{F}_{C}\delta$, calculations proceed

to Step 5, otherwise $j = j + 1$ and calculations to Step 2 for next case.

Step 4: Calculate $Sim_j(PCA, CCA)$ and determine if $Sim_j(PCA, CCA)$ passed the threshold of ${}_C\delta$

$Sim_j(PCA, CCA)$ represents the similarity between the problem and the current case and is defined as $Sim_j(PCA, CCA) = {}^A_C\omega \cdot {}^A Sim_j(PCA, CCA) + {}^F_C\omega \cdot {}^F Sim_j(PCA, CCA)$. ${}_C\delta$ represents the threshold for the total CCA similarity.

If $Sim_j(PCA, CCA) \geq {}_C\delta$, the solved case is considered sufficiently similar to the problem to be solved. The effects that are used to solve the case are feasible effects for the problem. The corresponding similarity measure, $Sim_j(PCA, CCA)$, is noted as the constituent similarity for these feasible effects. Further normalization and integration of $Sim_j(PCA, CCA)$ and $Sim_i(PCA, ECA)$ for the same feasible effect will be used to determine the priorities for all feasible effects. If $Sim_j(PCA, CCA)$ is less than the threshold, discard this case.

If $j \geq J$, calculations proceed to next step. Otherwise, let $j = j + 1$ return to Step 2 for next case.

Step 5: Normalize and integrate the similarities of individual feasible effects to form the priority indices for the various effects

This step integrates similarity values for each passing effect from PCA/ECA comparison and from PCA/CCA comparison to form the final similarity value for each effect as the priority index for the effect. The higher the final similarity index the higher the corresponding effect is considered more likely to solve the subject problem.

Similarity value for each effect from PCA/CCA comparison:

The similarity values from all passed cases are assigned to the solving effects which are used to solve the case to indicate the problem solving relevance for each effect in each case for the subject problem. The problem solving relevance for the effects which are not used in solving a case are assigned zero problem solving relevance with respect to that solved case. The problem solving relevance for each effect across all solved cases are added to indicate its relevance to solve the subject problem to be solved. To prevent any accumulated problem solving relevance for an effect to be greater than one. The accumulated problem solving relevance of each effect are then normalized by dividing it by the largest problem solving relevance of all effects to form the normalized similarity value of that effect from the PCA/CCA comparison. The normalized similarity value of $i\text{-}th$ effect from PCA/CCA comparison is denoted as ${}_{C}Norm_i$.

The similarity value for each effect from PCA/ECA comparison was obtained from Part 1 Step 5 previously.

When similarities for each effect from both PCA/ECA comparison and PCA/CCA comparison are weighed and added based on the below equation to form the final similarity measure for the effect:

$$Sim_i = {}_{E}\omega \cdot {}_{E}Norm_i + {}_{C}\omega \cdot {}_{C}Norm_i$$

Where:

Sim_i : The final problem solving relevance for the effect *i* to solve the subject problem represented by the final similarity index to solve the problem. The higher the Sim_i, the higher the priority of the effect *i* is recommended to solve the problem as a trigger solution.

i : the index identification for the effect *i*.

${}_{E}\omega$: The weight for the normalized similarity between the PCA and ECA comparison.

${}_{C}\omega$: The weight for the normalized similarity between the PCA and CCA comparison.

Lastly, the prioritized effects are used, according to their priority sequence, as trigger solutions for problem solving by human operations.

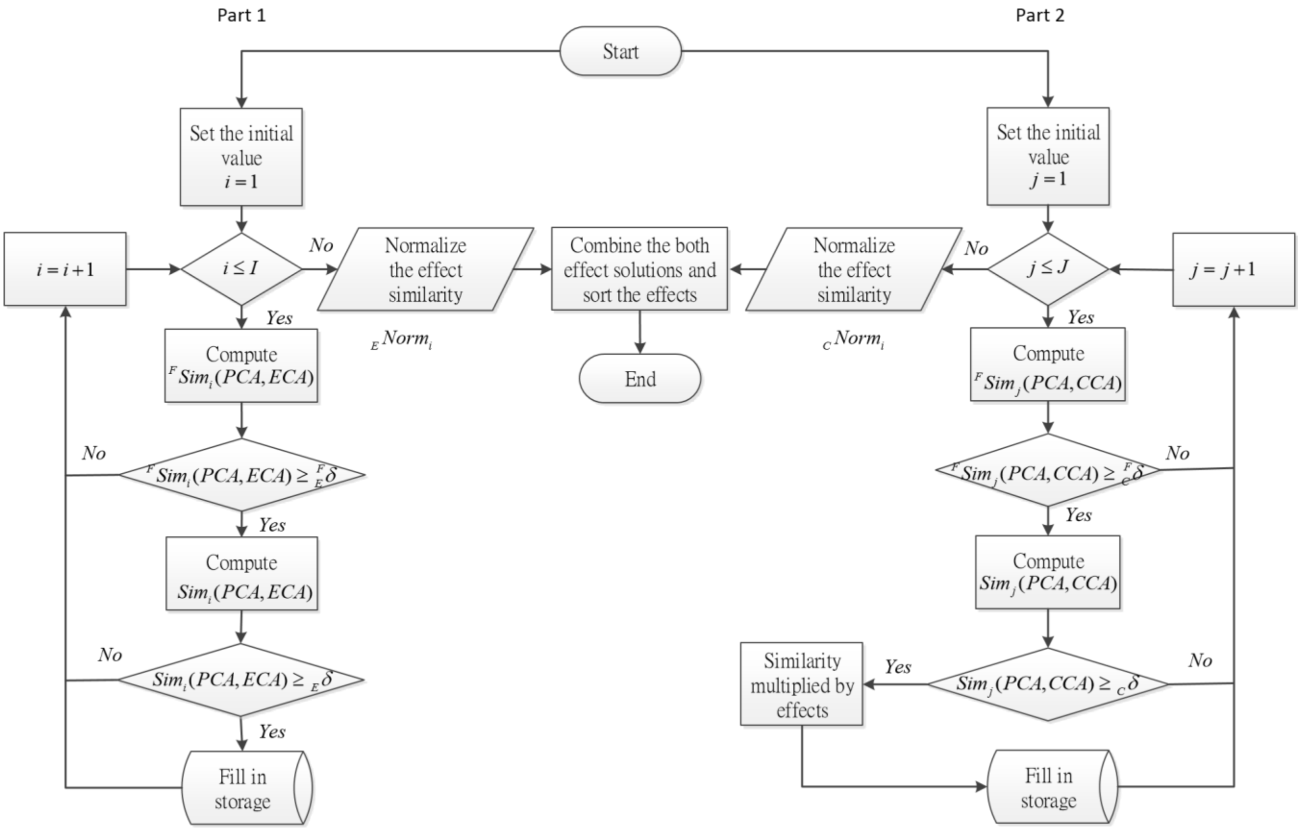

Figure 10. Similarity Comparison Process for PCA to ECA and CCA

4. Results and Case Verifications

A simple operating interface for the mathematical problem-solving tool in this study was constructed using Visual Basic for Applications (VBA) of Excel. Details of the software interface are omitted to reduce the space of this paper and can be found in (Hong, J. 2017).

4.1 K-Fold Cross-Validation

To make a sound experiment, the K-fold (K=3) cross-validation process was used to rotate test sets. The 210 solved cases were divided equally into 3 data sets. The 3 groups of data sets take turns to serve as test set of 70 problems each with the other 2 data sets of 140 cases plus 70 effects as the training set for experiments. The results showed consistent good prediction of existing solutions regardless of which data set is used as test set. The concept of K-fold validation is illustrated in Figure 11.

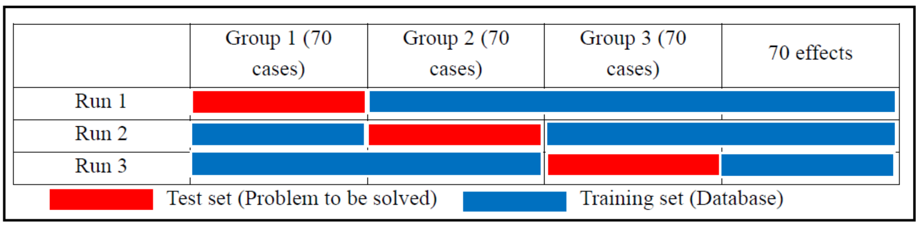

Figure 11. The Process of K-Fold Cross Validation

The best, random, and worst output trigger solutions, were used to determine the effectiveness of the prioritization method proposed. By selecting the 10 highest priority solutions for each "unsolved" problem, the system was able to have 87.6% hit rate while random selection of solution models can only have 23.8% hit rate. It is noted that the worst 10 solutions based on similarity measures result only 0% hit rate. This verifies the validity of the prioritization method. Details of the test results are given in Tale 3.

Table 3. The Overall Performance on Hit Rate

	1st-fold	2nd-fold	3rd-fold	overall average
Best 10 solutions	0.9	0.886	0.843	0.876
Random 10 solutions	0.143	0.286	0.286	0.238
Worst 10 solutions	0	0	0	0

To clearly verify the significant differences between best set, random set, and worst set of given number of trigger solutions, hypothesis testing was applied to the results in Table 9 and statistics results were shown in Figure 12.

(1) Comparison between 10 highest (best) prioritized effect solutions and 10 randomly selected effect solutions:

$$H_0: \mu_{10\_Best} \leq \mu_{10\_Random}$$

$$H_1: \mu_{10\_Best} > \mu_{10\_Random}$$

Paired-Sample *t* test and confidence interval: Ten best and ten random solutions (Pair 1 result)

Using IBM SPSS software, the analysis results showed that $p/2 = .0045 <\ \ = .05$. Therefore, H_0 was rejected, which verified that the hit rate of the ten best effect solutions were statistically and significantly higher than that of the randomly selected effect solutions.

(2) Comparison between 10 highest (best) prioritized effect solutions and 10 lowest (worst) prioritized effect solutions:

$$H_0: \mu_{10\_Best} \leq \mu_{10\_Worst}$$

$$H_1: \mu_{10\_Best} > \mu_{10\_worst}$$

Output results from the IBM SPSS software:

Paired-Sample *t* test and confidence interval: Ten best and ten worst solutions (Pair 2 result)

The results showed that when = .05, $p = .000$, thus $p/2 <$ which represents that H_0 was rejected. This proved that the hit rate of the ten best effect solutions were statistically and significantly higher than that of the ten worst effect solutions.

(3) Summary

Based on all the above statistical verifications of a two-tailed *t* test, it is clear that the solving power of the ten highest similarities effects was superior to the those of ten either randomly selected effects of lowest similarity effects.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Best	.87633	3	.029704	.017150
	Random	.23833	3	.082561	.047667
Pair 2	Best	.87633	3	.029704	.017150
	Worst	.00000	3	.000000	.000000

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Best & Random	3	-.690	.515
Pair 2	Best & Worst	3	.	.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Best - Random	.638000	.105276	.060781	.376480	.899520	10.497	2	.009
Pair 2	Best - Worst	.876333	.029704	.017150	.802544	.950122	51.099	2	.000

Figure 12. The Results of Hypothesis Test using IBM SPSS

4.2 Sensitivity analysis with respect to the number of output solutions selected

The results of the sensitivity analysis are shown in Figure 13. The solution hit rates is positively correlated with number of effect selected for problem solving. With 3 best similarity solutions, the hit rate is already over 80%. Outputting the six most similar effect solutions resulted in 88% hit rate.

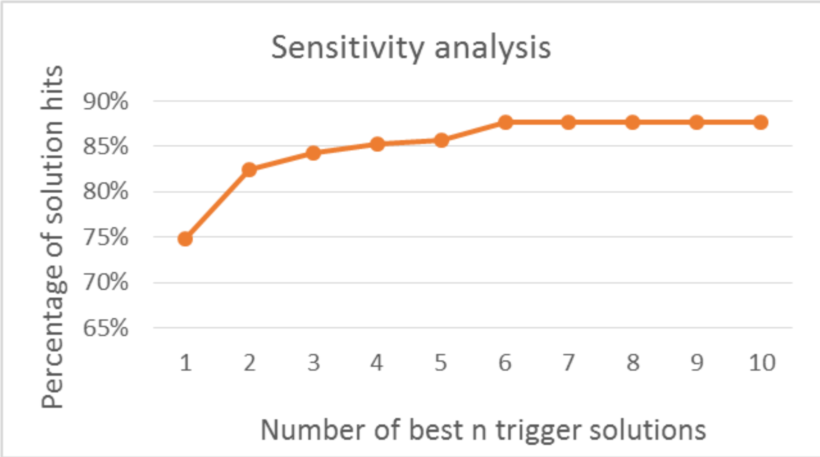

Figure 13. Sensitivity Analysis on the Number of Trigger Solutions

5. Summary and Conclusions

This research proposed a mathematical/quantitative approach to prioritize relevant effects for problem solving using similarity measures. The results showed that the prioritized effects provides substantially higher hit rate to solve problems successfully compared with the same number of either randomly selected effects or lesser similarity effects. Thus, the method was certainly effective in relevant effects identification for problem solving compared to random selections of effects.

A computer-aided effect identification system was constructed to prevent laborious manual calculation processes. The significance of this work compared with traditional expert identification of solution models in using effect database are given below:

- Unlike traditional TRIZ methods, which are primarily based on qualitative reasoning, a new class of using quantitative/mathematical methods such as similarity measures was proposed. This represents a paradigm shift from the traditional TRIZ research using qualitative methods for problem solving and opens up a new research direction of using quantitative measures for TRIZ problem solving.
- With more quantitative and objective accumulation of expert knowledge in terms of solved cases, the proposed method is able to achieve the below advantages:
    - To the best of the author's knowledge, no sense of priorities has been enabled in current TRIZ Effect database. As some solution models are more relevant than others to each problem, sense of priority becomes important when there are many solution models to choose from. The system is able to propose priorities for problem solving based on the principle of "Similar problems have similar solutions".
    - The system's database cases can be extendable by adding more expert solved cases to the system. The process knowledge is based on the accumulation and integration of many

expert solved problems instead of individual experts' problem solving. As the number of verified cases grows, the robustness of the system to identify prioritized solution models is expected to increase.

- Models of solution are repeatable by objective calculations during the process of problem model to solution model. This is contrasted to traditional TRIZ problem solving which is highly expert dependent.
- When there are many possible solution effects to choose from, the expert examination of many solution models will be very time consuming. The computer aided system can calculate through all possible solutions quickly and reliably, and with priorities in terms of likelihood for problem solving. This can save a lot of time in solution searching.

The contributions of this paper include:

1. By way of using function-attribute based arrays to fully characterize problems, solutions, and cases, this method enables the ability to use quantitative computations for identification of prioritized effect solutions, and other types of TRIZ solutions, instead of traditional qualitative reasoning and non-prioritized excessively large number of suggestions. With the function-attribute-solution array modeling approach, in the future, many other mathematical classification tools can also be used to identify and prioritize TRIZ solutions such as Effects, Trends, et al. This opens up a new area of research in integrating quantitative/mathematical computations and TRIZ logical reasoning for problem solving.

2. Providing a means to continually accumulate expert knowledge and experience by integrating more expert-solved cases to provide users a rapid, objective, and effective problem-solving system. This implies a continuous learning system which uses cumulative knowledge from many experts objectively instead of otherwise knowledge from individual experts.

3. Enhancing existing 39 parameters to 78 parameters for generic attributes and increasing existing 36 functions to 61 functions to cover more problem solving situations.

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▪Reference

Altshuller G., Creativity as an exact science. Gordon and Branch Publishers (1984).

Altshuller, G., and Rodman, S.. The innovation algorithm: TRIZ, systematic innovation and technical creativity. *Technical Innovation Centre* (1999).

Cao Guozhong, Guo Haixia, Yu Jiang, and Tan Runhua. "Computer Aided Product Innovation Software Based on Extended-Effect and Its Application." *World Congress on Software Engineering*, IEEE, VOL 2, PROCEEDINGS (2009), 63-67.

Choi, S. S., Cha, S. H. and Tappert, C. "A Survey of Binary Similarity and Distance Measures." *Journal of Systemics, Cybernetics and Informatics*, vol. 8, No.1 (2010), 43-48.

CREAX Function & Attributes Database (2011), available on line at: http://function.creax.com, http://attributes.creax.com/.

De Baets, Bernard, Saskia Janssens, and Hans De Meyer. "On the transitivity of a parametric family of cardinality-based similarity measures." *International Journal of Approximate Reasoning* 50.1 (2009), 104-116.

Donald, A. J., Keith, M. S. and Harold, H. H.. "Similarity coefficients: measures of co-occurrence and association or simple measures of occurrence." *The American Naturalist*, vol.133, No.3 (1989), 436-453.

Dunn, G., Everitt, B. S. *An Introduction to Mathematical Taxonomy*, Cambridge University Press (1982).

Goldfire (2017). available on line at: https://www.ihs.com/products/design-standards-software-goldfire.html.

Hong, J. (2017). *Prioritized TRIZ Solution Effect Idenfication Based on Similarity,* Ph.D. Dissertation, National Tsing Hua University, Hsinchu Taiwan. (In Chinese)

Jackson, D. A., Somers, K. M. and Harvey, H. H. "Similarity Coefficients: Measures of Co-occurrence and Association or Simple Measures of Occurrence." *The American Naturalist*, vol.133, No.3 (1989), 436-453.

Jimenez, Sergio, Fabio A. Gonzalez, and Alexander Gelbukh. "Mathematical properties of Soft Cardinality: Enhancing Jaccard, Dice and cosine similarity measures with element-wise distance." *Information Sciences* 367 (2016), 373-389.

Lee, Jangyong, and Soonhung Han. "Knowledge-based configuration design of a train bogie." *Journal of Mechanical Science and Technology*, 24 (12) (2010), 2503-2510.

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

Mann, Darrell. Hands-On Systematic Innovation for Technical System. IFR Press. 2nd edition (2007). ISBN 90-77071-02-4.

Meyer, A. S., Garcai, A. A. F., Souza, A. P. and Souza, C. L. “Comparison of Similarity Coefficients Used for Cluster Analysis with Dominant Markers on Maize (Zea mays L).” *Genetics and Molecular Biology*, vol. 27, issue.1 (2004), 83-91.

Oxford Creativity (2017), available on line at: http://wbam2244.dns-systems.net//EDB_Welcome.php.

Pro/Solutions KB (2009), available on line at: http://www.prosolutionskb.com/Help-New.htm.

Shen, Victor R.L., Tang, Cheng-Ying, and Jia-Hong Lee. “Analysis of the problem description in the Algorithm for Inventive Problem Solving using Petri nets.” *Knowledge-Based Systems*, 35 (2012), 290-303.

Sheu, D. Daniel, Chiu, S., & T. H. Lu. “TRIZ identification of solution models by function-attribute characteristics using mathematical measures.” The 5th international conference on systematic innovation. San Jose, California, U.S.A. July, (2014), 16–18. (Best paper award).

Sheu, D. Daniel, and Hei-Kuang Lee. “A proposed process for systematic innovation.” *International Journal of Production Research*. Vol. 49, No. 3, 1 February (2011), 847-868.

Sheu, D. Daniel, and Sheng Chia Chiu. “Prioritized relevant trend identification for problem solving based on quantitative measures.” *Computers & Industrial Engineering*. 107 (2017), 327-344.

System Association Methods for Identification of Patent Enhancements

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Abstract

This research developed a systematic patent enhancement opportunities identification and problems solving process based on TRIZ tools. The process includes three stages: 1. Patent identification; 2. Patent analysis; 3. Opportunities identification and ranking 4. Solution generation. In this process, the 7 elements of function (function, object, action principle, value, tool, attributes and carrying item) are considered as the targets of patent enhancement. This research used system association and CPC tri-level expansion methods to identify opportunities for patent enhancements. The contributions of this research include: (1) Providing a systematic method to identify opportunities for patent enhancements; (2) Establishing standard forms and descriptions to facilitate practical usage.

Keywords: TRIZ, Systematic Innovation, Patent Enhancement, CPC tri-level expansion, Knowledge／Effect Database, Su-Field analysis, System Association

1. Introduction

More and more countries and enterprises are thinking about how to expand their market and business thus intellectual properties become a very important method. Therefore, we need to strengthen our method regarding intellectual properties especially patent enhancement or circumvention. A study of patent enhancement method is carried out to integrate TRIZ methodologies and innovated product recognition tools complimented by systematic thought provoking questions and forms to generate more innovated ideas.

2. Literature review

Here we will be reviewing the methodologies and studies used in the paper.

2.1 Patent enhancement

D. Daniel Sheu and Jealousy Hong (2017) proposed that patent enhancement is to consider all the possible ways to enhance a patent by adding some functions/value or component to perfect a patent. There are two reasons for patent enhancement. First, to enhance our patent to prevent circumvention or surrounded by others. Second, to enhance other's patent to surround it for cross authorization. Xiu Ru Wang (2014) presented Patent Strengthening and Deployment Methodology based on TRIZ and Wang Yao-Ting (2017) TRIZ Based Systematic Patent Circumvention, Regeneration, and Enhancement Methods both proposed method in patent enhancement with TRIZ methodologies and verified through case studies.

2.2 TRIZ

TRIZ (Theory of Inventive Problem Solving) is proposed by Genrich Altshuller in 1946 by categorization and compilation of tens of thousands of patents in the world and created this systematic problem-solving technique. Daniel Sheu, Wang Yao-Ting (2017) proposed to use minimal components to solve the problem and achieve the desire function. Moreover, "Value" is the purpose of a system and patent enhancement is about how to add new components or change a property of the component to achieve the new function which can generate or supplement the value that is lacked from the system.

2.3 Su-Field Analysis, SFA

Su-Field Analysis uses the relationship between objects and fields to solve a problem. There are 76 standard solutions for problem solving, but they are complicated to use. Mann (2002) categorized the standard solutions into four types, "incomplete object or field", "measurements", "harmful interactions" and "under or excess interactions" to simplify the solutions. Belski (2007) proposed five rules and nine fields for generating solutions.

2.4 Knowledge／Effect Database

Knowledge/Effect Database provides three tools to solve a problem which are, function database, parameter database and patent database. Mann (2002) proposed that Knowledge／Effect Database provides users three options. First, more efficient function. Second, improve parameter performance of a system. Third, find out who and when the problem was solved.

2.5 Innovated product recognition tools

D. Daniel Sheu, Jealousy Hong, and Chia Lin Ho (2017) proposed that innovated inspirations mostly came from three innovated patterns, Space-Time-Interface, Conflict and Trends. This research emphasizes on trend, which is used to analyzed current technologies, society, environment and etcetera to predict its future development. This is done by focusing on recognizing the conflict in trend. Daniel Sheu and Zi-Huei Wang (2013) proposed that the tools related to this includes Function-Market Expansion(FME), 9 windows analyses and etcetera. 9 windows analyses uses space, time and interface along with past, present and future to determine the core of the problem.

2.6 KJ method

KJ method invented by Jiro Kawakitais one of the most popular problem-solving technique. Susumu Kunifuji (2013) demonstrated it by jotting down the thing that you observed and combine the similar items from a seemly complicated group.

3.1 Research methods

This section illustrates the research method used in this paper.

3.2 TRIZ and patent enhancement

The patent enhancement opportunities identification and problem-solving process mainly focuses on main function and feature function of a patent. Main function is the main purpose of the system. For example: the main function of a cell phone is to call and text. Feature function is what the patent claims. For example: a cell phone can make a call and text, moreover, it can surf the net, shopping and looking up directions. By identifying the core of the "problem" to find the enhancement opportunities and the "solutions" utilizing Knowledge/Effect Database and Su-Field Analysis. However, this paper will be prioritizing on "problem"; the "solutions" will be discussed later in a separate paper. Figure 1. illustrates TRIZ and patent enhancement concept.

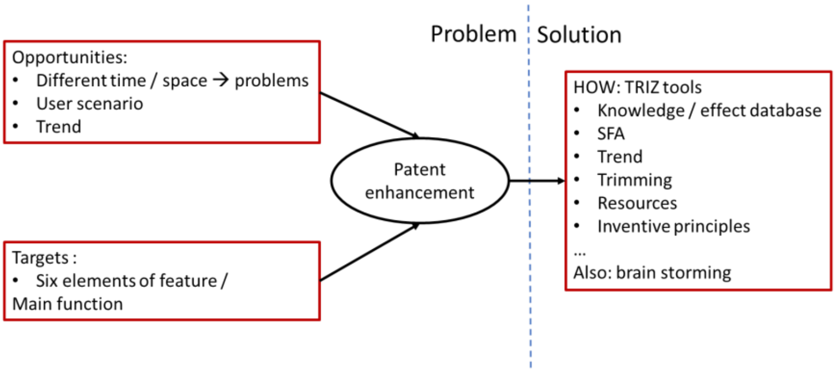


Figure 1 TRIZ patent enhancement concept

For the patent enhancement in this research, we will be focusing on the seven elements of a patent, function, object, principle, value, tool and attribute as illustrated in Figure 2.

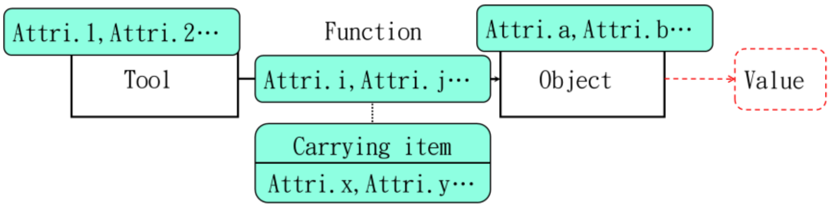


Figure 2 Seven elements of function

- Function: the function provided by the system/component.
- Value: the value provided by the main / feature function.
- Tool: the system or object that provides the function or it can be the patent itself.
- Object: the object that receives the function.
- Principle: the principle behind the function.
- Attribute: the attribute of the tool, function and object.
- Carrying item: the items carried by the function.

3.3 Analyzing process

This research developed a systemic approach to patent enhancement along with thought provoking tables that enables the users to identify enhancement opportunities more systematically. First, we need to understand the basic structure of a patent and its seven elements, combine system association and CPC tri-level expansion to become a systematic approach. This research is divided into four sections, patent identification, patent analysis, patent enhancement opportunities identification and patent enhancement solution process; as mentioned before, we will not be discussing much about patent enhancement solution process in this paper. Figure 3 illustrates the four sections of this paper.

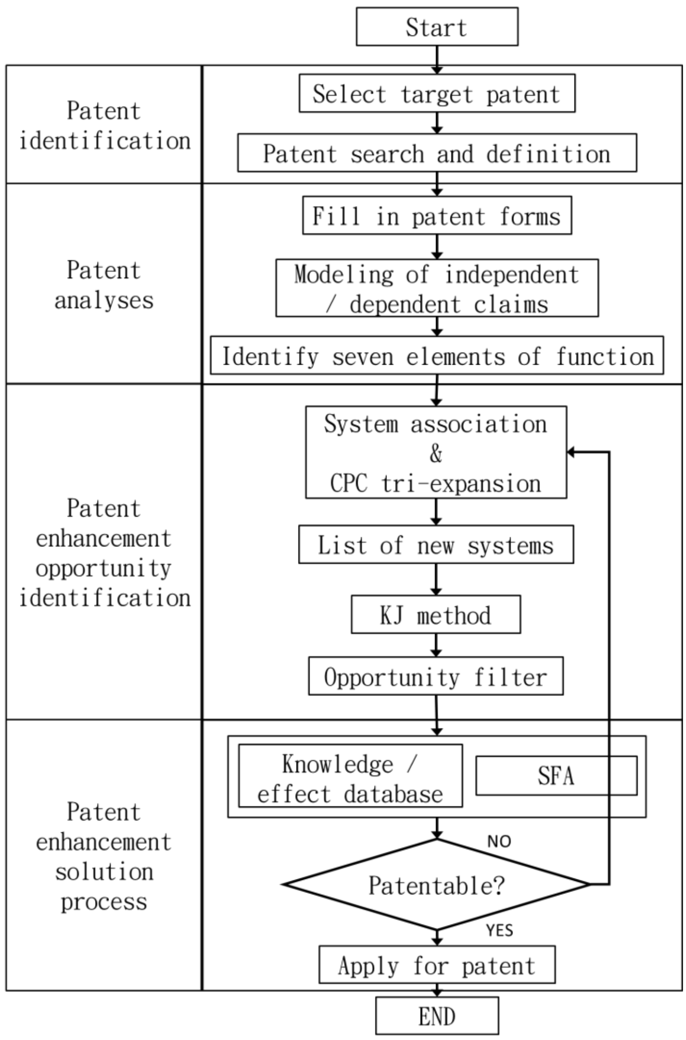


Figure 3 Patent enhancement opportunity identification and solution process

3.4 Patent search

Patent search is the first step of the process, a more thoroughly defined subject can ensure a more complete search. Please note that it is best to have the domain knowledge when doing the patent search. The keywords for patent search is defined by function, attribute and constrain then combine with the searching principles proposed by Mann (2002) which arrange the components mentioned above with AND operand into different combinations. An example is given in Table 1.

Table 1 Patent search example

1. Feature function / attribute	1. Main function / attribute
{Fill in the feature function of the system, fill in the feature attribute that the system is trying to keep or change}	{Fill in the main function of the system, fill in the main attribute that the system is trying to keep or change}
2. Constraints (component / attribute)	
{Fill in the constrains of the system or the component, fill in the constrain for the system to provide its function} {Example: for a bottle, the constrains might be, to operate in normal or high temperature and cheap and etcetera.}	
3. Search Commands	
{Use AND, OR operand to combine the functions, components, attributes, constrains into search command}	

{Example: heat (function + pot(component)+increase temperature(attribute)}

There might be multiple outcomes during the search and we proposed to select the patent base on the number of legal events and cites. The selected patent will then be filled into the patent summary as shown below in Table 2 Patent summary and modeling of independent / dependent claim.

Patent summary is to give the user an overall view of the patent and modeling of independent / dependent claim is to analyze the component (substance or field), function and attributes of the claims. D. Daniel Sheu, Johnson Chen, and Raymond Lin propose to use bold red letters with big sprocket to mark the component, bold blue letters with medium sprocket to mark the function and bold green letters with small sprocket to mark the attributes. These can help the user to complete functional analysis with ease and a crucial part in Su-field analysis.

Table 2 Patent summary

Patent abstract form			
Title	{Fill in the patent title}	Patent number	{Fill in the patent number}
CPC category	{fill the cpc category}		
Function / Result	{Fill in the function and the result}		
Know How	{Fill in the key technology}		
Independent Claim	{Fill in the independent / dependent claims and their models}		

3.5 System association

System association was improved from super system transfer ideology in TRIZ by Sheng Ling Wu (2014), Daniel Sheu (2017) expanded to incorporate all aspect of the system. The systems help the user to brainstorm from different space, time, interface, functions (feature function, main function), values, resources and environments as well as the inverse of the systems, it includes 9 windows, Scenario system, complimentary system, analogy system, same value system, heterogeneous system, competing system, quasi competing system, quasi complimentary system and inverse system. Table 3 illustrates the association of the systems and Table 4 illustrates the inverse systems and Table 5 illustrates the definitions of each system.

Table 3 Association systems

<table>
<tr><td colspan="2" rowspan="2">Association of systems</td><td colspan="2">Same environment</td><td>Different environment</td></tr>
<tr><td>Same object</td><td>Different object</td><td></td></tr>
<tr><td rowspan="4">Specific function or feature function</td><td>Same function</td><td>Competing system</td><td colspan="2">Quasi competing system</td></tr>
<tr><td>Different function</td><td colspan="2">Scenario system</td><td></td></tr>
<tr><td>Complimentary function</td><td>Complimentary system</td><td colspan="2">Quasi complimentary system</td></tr>
<tr><td>Disadvantages or insufficient</td><td colspan="3">9 windows</td></tr>
</table>

Generic function	Same general function	**Analogy system**
value	Same value	**Same value system**
resources	Share resources	**Heterogeneous system**

Table 4 Inverse systems

Inverse system	Inverse	Block/sabotage	Correction/enhancement
Main function	Inverse system 1 **Inverse system**	Inverse system 2 **Block system**	Inverse system 3 **Correction system**
System/component		Inverse system 4 **Sabotage system**	Inverse system 5 **Enhancement system**

Table 5 Definition of system association

System	**Definition**	**Usage / Example**
9 windows	Discover problems from time (past, present, future) and system level (super system, system, sub system)	How to incorporate the solutions from 9 windows to enhance the target system?
Scenario system	The systems exist in the nearby environment that operate on the same object but different function as the target system.	How to incorporate the solutions from scenario system to enhance the target system? (Example: drilling machine with XY platform becomes milling machine)
Complimentary system	The systems exist in the nearby environment that operate on the same object and have complimentary function to the target system.	How to incorporate the solutions from complimentary system to enhance the target system? (Example: combine fork and spoon and becomes fork spoon combo)
Quasi complimentary system	The systems that can generate synergy with the target system which is in the same process or environment but have different function and object. We might be able to modify the system to operate on the same object.	How to incorporate the solutions from quasi complimentary system to enhance the target system? (Example: pot and lid can modify the lid to become pot when flip it upside down)
Analogy system	The systems that are different in main function but same in the generic function or same type of product.	How to incorporate the solutions from analogy system to enhance the target system? (Example: swiss army knife combines scissors and knife)

Same value system	The systems that have different function as the target system but have the same value.	How to incorporate the solutions from same value system to enhance the target system?
		(Example: combine keyboard and mouse into keyboard touch pad combo)
Heterogeneous system	The systems that have different function / uncommon properties but have the share resources.	How to incorporate the solutions from heterogeneous system to enhance the target system? (Example: rice fish farming)
Competing system	The systems that have same main function and operate on the same object as the target system.	How to incorporate the solutions from competing system to enhance the target system? (Example: electrical scooter and bicycle becomes E-bike)
Quasi competing system	The systems that have same function but operate on different object as the target system. We might be able to modify the system to operate on the same object.	How to incorporate the solutions from quasi competing system to enhance the target system? (Example: tooth brush and electrical grinder can become electrical tooth brush)
Inverse system - inverse	The systems that have completely different main function as the target system.	How to incorporate the solutions from inverse system (inverse) to enhance the target system? (Example: pensile and eraser)
Inverse system - block	The systems that have the function to block the target system to perform its function.	How to incorporate the solutions from inverse system (block) to enhance the target system? (Example: ferrite bead)
Inverse system - correction	The systems that can correct / enhance the disadvantage of the target system.	How to incorporate the solutions from inverse system (correction) to enhance the target system? (Example: bacteria embedded wall for self-repairing)
Inverse system - sabotage	The systems that can sabotage the target system.	How to incorporate the solutions from inverse system (sabotage) to enhance the target system? (Example: fuse for extension cable)

The following section will explain the usage of each system and its thought provoking forms. The shaded areas in the forms are instructions and white areas are blanks to fill in. First, the 9 windows; 9 windows analyses is one of the innovative tools from TRIZ Trend theory. It can help the user to think from different space, time and interface to search for the disadvantages of the target system. Table 6 and Table 7 illustrate the disadvantages identification process and enhancement opportunity identification.

Table 6 9 windows disadvantages identification form

Scenario	{the scenario when the system is operated}		
Space/Time Domain	**Past**	**Current**	**Future**
Super-system	H. Super-system components: {fill in the super-system component} Disadvantage: {fill in the disadvantage of the target	B. Super-system components: {fill in the super-system component}	F. Super-system components: {fill in the super-system component}
	system in this scenario}	Disadvantage: {fill in the disadvantage of the target system in this scenario}	Disadvantage: {fill in the disadvantage of the target system in this scenario}
System	E. Scenario: {fill in the scenario} Target system: {fill in target system} Disadvantage: {fill in the disadvantage of the target system in this scenario}	A. Scenario: {fill in the scenario} Target system: {fill in target system} Disadvantage: {fill in the disadvantage of the target system in this scenario}	D. Scenario: {fill in the scenario} Target system: {fill in target system} Disadvantage: {fill in the disadvantage of the target system in this scenario}
Sub-system	I. Sub-system components: {fill in the sub-system component} Disadvantage: {fill in the disadvantage of the target system in this scenario}	C. Sub-system components: {fill in the sub-system component} Disadvantage: {fill in the disadvantage of the target system in this scenario}	G. Sub-system components: {fill in the sub-system component} Disadvantage: {fill in the disadvantage of the target system in this scenario}
※Please fill in the table from A to I and label each problem then fill in the according answer in the next opportunity form. Super-system: a bigger system that includes current system System: the system for analysis Sub-system: the components inside the system			

The guide to fill out the identification form is illustrated below：

1. From the current system(a), think about the problems in this scenario. Then going upwards and downwards to think about the problems in the super system(b) and sub system(c) in this scenario.
2. From the current system(a), going right and left to think about the problems in the future and the past in this scenario.
3. From the past system(e), going upwards and downwards to think about the problems in the super system(h) and sub system(i) in this scenario.
4. From the future system(d), going upwards and downwards to think about the problems in the super system(f) and sub system(g) in this scenario.
5. The solutions of the problems identified above will then be answered in the solution table.

Table 7 9 windows opportunities identification form

Space/Time Domain	**Past**	**Current**	**Future**
Super-system	{correspond to identification form section H problems 1, 2, 3 fill in answer 1, 2, 3}	{correspond to identification form section B problems 1, 2, 3 fill in answer 1, 2, 3}	{correspond to identification form section F problems 1, 2, 3 fill in answer 1, 2, 3}
System	{correspond to	{correspond to identification	{correspond to identification
	identification form section E problems 1, 2, 3 fill in answer 1, 2, 3}	form section A problems 1, 2, 3 fill in answer 1, 2, 3}	form section D problems 1, 2, 3 fill in answer 1, 2, 3}
Sub-system	{correspond to identification form section I problems 1, 2, 3 fill in answer 1, 2, 3}	{correspond to identification form section C problems 1, 2, 3 fill in answer 1, 2, 3}	{correspond to identification form section G problems 1, 2, 3 fill in answer 1, 2, 3}
※Please number each answer.			

Scenario system:

Scenario system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 8 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature / main function: what is the feature / main function of the target system?
- Object: what is the object of the feature function?
- Thought provoking questions(TPQ): What can we innovate from the Scenario systems?

Table 8 Scenario system – same object (feature / main function)

Scenario system			
Feature / main function		{fill in the feature / main function}	
Object of target system	Scenario	Function needed under this scenario	Enhancement ideas
{Fill in the object of target system}	{Fill in the scenario}	{Fill in the function needed under this scenario}	{Fill in the enhancement ideas}

Complimentary system:

Complimentary system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 9 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Process / scenario / environment: what is the current process / scenario / environment?
- Thought provoking questions(TPQ): What can we innovate from the complimentary systems?

Table 9 Complimentary system – same process / scenario / environment (feature /main function)

Complimentary system			
Feature / main function		{fill in the feature / main function}	
Object of target system	Complimentary system	Function of the complimentary system	Enhancement ideas
{Fill in the object of target system}	{Fill in the complimentary system}	{Fill in the function of the complimentary system}	{Fill in the enhancement ideas}

Quasi complimentary system:

Quasi complimentary system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 10 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Process / scenario / environment: what is the current process / scenario / environment?
- Thought provoking questions(TPQ): What can we innovate from the quasi complimentary systems?

Table 10 Quasi complimentary system – same process / scenario / environment (feature /main function)

Quasi complimentary system – same process / scenario / environment (feature /main function)			
Feature / main function		{fill in the feature / main function}	
Object of target system	Quasi complimentary system	Function of the quasi complimentary system	Enhancement ideas
{Fill in the object of target system}	{Fill in the quasi complimentary system}	{Fill in the function of the quasi complimentary system}	{Fill in the enhancement ideas}

Analogy system:

Analogy system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 11 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Generic function: what is the generic function of the target system?
- Product category: what is the product category of the target system?
- Thought provoking questions(TPQ): What can we innovate from analogy systems?

Table 11 Analogy system – same generic function / product category (feature /main function)

Analogy system		
Feature / main function	{fill in the feature / main function}	
Generic function of the target system	List the functions that belong to the same generic function	Enhancement ideas
{Fill in the generic function of the target system}	{Fill in the functions that belong to the same generic function and ideas to enhance the target system}	{Fill in the enhancement ideas}
Product category of the target system	List the products that belong to the same category	Enhancement ideas
{Fill in the product category of the target system}	{Fill in the products that belong to the same category and ideas to enhance the target system}	{Fill in the enhancement ideas}

Same value system:

Same value system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 12 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Object: what is the object of the feature /main function?
- Thought provoking questions(TPQ): What can we innovate from the same value systems? *Table 12 Same value system (feature /main function)*

Same value system	
Feature / main function	{fill in the feature / main function}

Value of the system	List the same value systems that have the same value as the target system	Enhancement ideas
{Fill in the value of the system}	{Fill in the same value systems}	{Fill in the enhancement ideas}

Competing system:

Competing system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 13 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Thought provoking questions(TPQ): What can we innovate from the competing systems?

Table 13 Competing system (feature /main function)

Competing system			
Feature /main function		{fill in the feature / main function}	
Competing systems	Advantages compare to target system	Disadvantages compare to target system	Enhancement ideas
{Fill in the competing systems}	{Fill in the advantages compare to target system}	{Fill in the disadvantages compare to target system}	{Fill in the enhancement ideas}

Quasi competing system:

Quasi competing system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 14 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Thought provoking questions(TPQ): What can we innovate from the competing systems? *Table 14 Quasi competing system (feature /main function)*

Quasi competing system			
Feature /main function		{fill in the feature / main function}	
Quasi competing system	Advantages compare to target system	Disadvantages compare to target system	Enhancement ideas

{Fill in the quasi competing system}	{Fill in the advantages compare to target system}	{Fill in the disadvantages compare to target system}	{Fill in the enhancement ideas}

Inverse systems:

Inverse system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 15 illustrates the guiding forms for feature function and main function.

- System: what is the target system?
- Feature /main function: what is the feature /main function of the target system?
- Thought provoking questions(TPQ): What can we innovate from the competing systems?

Table 15 Inverse system (feature /main function)

Inverse system		
Feature /main function	{fill in the feature / main function}	
Mode	Inverse system	Enhancement ideas
Inverse	{fill in the inverse system}	{Fill in the enhancement ideas}
Block	{fill in the block system}	{Fill in the enhancement ideas}
Correction	{fill in the correction system}	{Fill in the enhancement ideas}
Sabotage	{fill in the sabotage system}	{Fill in the enhancement ideas}
Enhancement	{fill in the enhancement system}	{Fill in the enhancement ideas}

Heterogeneous system:

Heterogeneous system lets the user to brainstorm through thought provoking problem and forms to identify the systems that can improve the target system. Table 16 illustrates the guiding forms for feature function and main function. ◦

- System: what is the target system?
- Resources: what are the resources in the target system?
- Thought provoking questions(TPQ): What can we innovate from the heterogeneous systems?

Table 16 Heterogeneous system – shared resources

Enhancement ideas		
{Fill in the enhancement ideas}	List the heterogeneous systems that can use the resources	Enhancement ideas

Enhancement ideas	{Fill in the heterogeneous systems}	{Fill in the enhancement ideas}

The enhancement opportunities generated by the system association will be listed in the enhancement opportunity list as illustrated in Table 17 and please remove similar ideas in this step to prevent over listing the list.

Table 17 Enhancement opportunity list

Enhancement opportunity list (do not list repeated ideas)	
sources	New systems
9 windows	{list the ideas from 9 windows}
Scenario system	{list the ideas from scenario system}
Complimentary system	{list the ideas from complimentary system}
Analogy system	{list the ideas from analogy system}
Same value system	{list the ideas from same value system}
Competing system	{list the ideas from competing system}
Inverse system	{list the ideas from inverse system}
Heterogeneous system	{list the ideas from heterogeneous system}
Quasi competing system	{list the ideas from quasi competing system}
Quasi complimentary system	{list the ideas from quasi complimentary system}

3.6 CPC tri-level expansion

CPC tri-level expansion (upper class, original class, equal class and lower class) uses the product from CPC category to expand the target patent. Its definitions are as follows:

Original class: original class is the class given by the patent committee, there can be one or more original class depends on the patent. For example, A01B 1/00 (hand tool).

Upper class: upper class is the class above the original class in CPC category. For example, A01B (soil working in agriculture), 、A01 (agriculture) 、A (human necessity).

Equal class: equal class is the class that is on the same level as the original class. For example, A01B 1/00 and A01B 47/00。

Lower class: lower class is at the bottom of the CPC category and it is the class under the original class. For example, A01B 1/08 (with blade)。

Our research finds that according to the CPC category there can exist three scenarios as illustrate in Table 19 and Table 20:

- The class given to the target patent is already at the bottom of the CPC category.
- There are one more class under the class given to the target patent.
- The class given to the target patent is not at the bottom of the CPC category but there is no classification under that class.

Table 18 The class given to the target patent is already at the bottom of the CPC category

Scenario 1: The class given to the target patent is already at the bottom of the CPC category illustrated by patent US3226149A

	Classification of target patent	Expandable classification 1	Expandable classification 2
Upper class	A	NA	NA
	A01	NA	NA
	A01B	NA	NA
	A01B 1/00	NA	NA
Original class	A01B 1/02	NA	NA
Enhancement opportunity		{fill in the enhancement opportunity}	

Table 19 There are one more class under the class given to the target patent

Scenario 2: There are one more class under the class given to the target patent illustrated by patent US3373308A			
	Classification of target patent	Expandable classification 1	Expandable classification 2
Upper class	H	NA	NA
	H05	NA	NA
	H05B	NA	NA
Original class	H05B 31/00	NA	NA
Lower class	H05B 31/0003	NA	NA
Enhancement opportunity		{fill in the enhancement opportunity}	

Table 20 The class given to the target patent is not at the bottom of the CPC category but there is no classification under that class

Scenario 3: The class given to the target patent is not at the bottom of the CPC category but there is no classification under that class illustrated by patent US3373308A US5003143A			
	Classification of target patent	Expandable classification 1	Expandable classification 2
Upper class	H	NA	NA
	H05	NA	NA
	H05B	NA	NA
Original class	H05B 11/00	NA	NA
Lower class	No other classification	NA	NA
Enhancement opportunity		{fill in the enhancement opportunity}	

This research realized that at the lower of the category lies a greater chance of finding the enhancement opportunities. Other classes can also find enhancement opportunities, but it is more difficult at the higher class. We have determined a few ways to find enhancement opportunities as followers:

Mode 1: Integrate lower class

This mode is the most intuitive mode which the user integrates useful items in the lower class to form a new idea as illustrate in Figure 4 which the idea is to combine shovel, blade and teeth to become shovel axe.

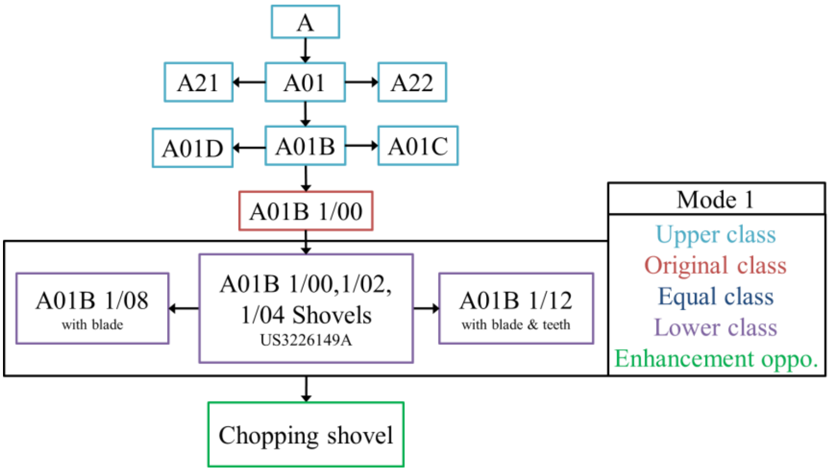


Figure 4 Integrate lower class

Mode 2: Integrate equal class

This mode integrates equal class to form a new idea as illustrate in Figure 5 which the idea is to combine shovel with A01B 47/00 (with electric potential) and A01B 51/00 (mount on tools) and its lower class A01B51/02 (propel by motor) finally becomes handheld subsoiler.

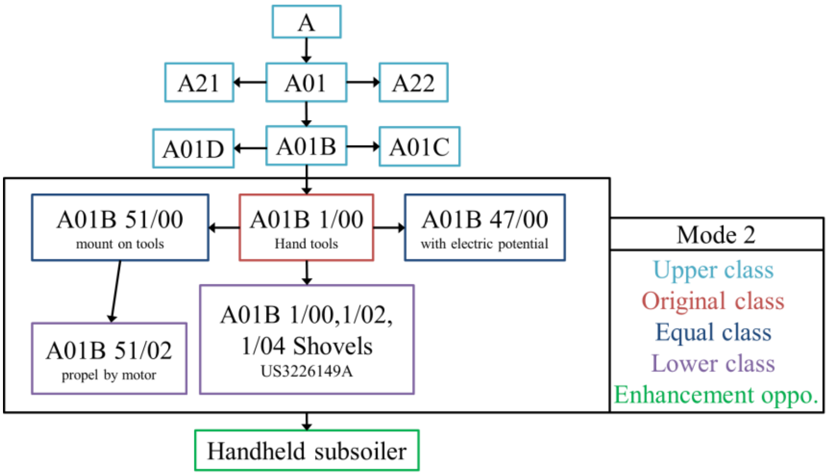


Figure 5 Integrate equal class

Mode 3: Integrate upper class

This mode integrates upper class to form a new idea as illustrate in Figure 6 which the idea is to combine F(heating) and its corresponding classes to generate fire making shovel concept which the user uses 2 shovels with flint like coatings to hit each other to make fire.

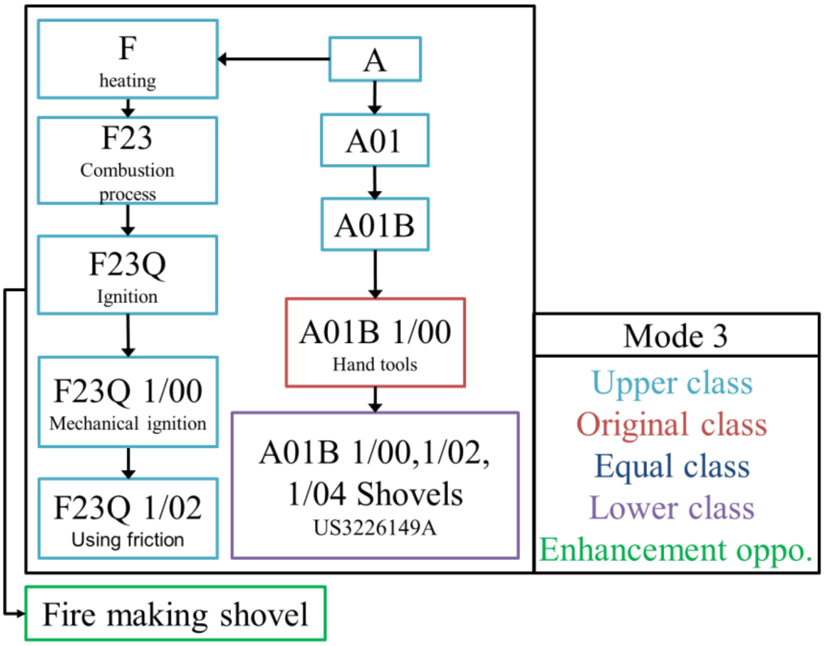


Figure 6 Integrate upper class

According to CPC category sometimes there will not be any lower class, thus the user can only use mode 2 and 3.

3.7 Patent enhancement opportunities evaluation

Since there will be many new ideas from the system association, KJ method is applied to combine the similar ideas for further evaluation. Pugh matrix is used in this research to perform the evaluation of the new ideas. A set of criteria chose for the evaluation and all the enhancement opportunities will be compared to the original patent and using numbers to get the sum of the criteria and this will decide the ideas going into the solution process.

4. Case study – Infrared smart glasses

In this section we are going to give a brief example to demonstrate our process. we decided on the topic of infrared smart glasses for our patent search as demonstrated in Table 21 and our search result is shown in Table 22.

Table 21 Patent search of infrared glasses

1A. Feature functions / attributes	1B. Main functions / attributes
measure detect	acquire information wearable
2. Constraints	
Glasses, frame, infrared sensor, monitor, infrared signal	
3. Search commands	

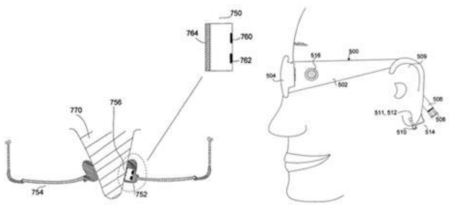
measure + acquire information + eyeglasses	measure + infrared sensor + infrared signal detect +
acquire information + eyeglasses	wearable + eyeglasses + monitor
measure + wearable + frame	…
detect + wearable + infrared sensor	

Table 22 Patent search result

Patent category	Patent number	Search command	Title	Cites	Legal events	Source	Search date
G02C	US7677723 B2	measure, acquire information, eyeglasses	Eyeglasses with a heart rate monitor	91	5	USPTO	2017/7/3
G02C	US7500746 B1	detect, acquire information, eyeglasses	Eyewear with radiation detection system	63	4	USPTO	2017/7/3
A61B	US20140343371 A1	Detect, wearable, infrared sensor	Wearable sensor device for health monitoring and methods of use	6	0	USPTO	2017/7/3

From out search result, we have decided to use, Eyeglasses with a heart rate monitor as out target patent (system) since it was cited 196 times by others and 5 legal events; we believe this is a patent with great potential. The patent is then filled into the patent summary and created the model of independent / dependent claim with functional analysis diagram as shown in Table 23, Figure 8, Figure 9 and Figure 10.

Table 23 Patent summary of US 7677723 B2

Patent abstract form			
	eglasses with a heart rate monitor	nt number	US 7677723 B2
C category	A61B5/02433; A61B5/6803; A61B5/6816; G02C11/10; A61B5/742		
Function / Result	A pair of glasses with a heart-rate monitor according to one embodiment. The heart-rate monitor is configured to measure the heart rate of the user of the glasses. The heart-rate monitor can include a sensor with a radiation transmitter and a radiation receiver. The radiation could be infrared radiation. In one approach, the receiver measures signals transmitted by the transmitter through a body part of the user to measure the user's heart rate. The sensor could be incorporated in a clip to clip onto the body part of the user, such as the ear lobe of the user. In another approach, the receiver measures signals transmitted by the transmitter and reflected by a body part of the user to measure the user's heart rate.		
Know How	Figure 7 illustrates a pair of glasses 500 having heart rate monitoring capabilities according to one embodiment. The pair of glasses 500 includes left and right temples 502 and left and right lens holders 504. In addition, the glasses can be coupled to a clip 510 having an infrared (IR) transmitter 511 and an IR receiver 512 on opposite sides of one end of the clip 510. In one embodiment, an IR sensor includes the IR transmitter 511 and the IR receiver 512.		
	Figure 7 Technical diagram of US 77723 B2 		
Independent Claim	**A {pair of glasses} for a user [comprising]:** **a {frame} for the glasses;** **a {heart-rate monitor} with *(at least a portion)* of the {electronics} of the heart-rate monitor being [embedded] in the frame, wherein the heart-rate monitor is [configured] to [acquire] {heart rate data} *(pertaining to the heart rate of the user)*;** **an {electronic device} *(at least partially)* [embedded] in the frame and [configured] to [acquire] {user exercise data}; and** **an {audio output system} configured to [output] {audio signals} containing {heart rate information} and/or {exercise information}, the heart rate information being *(dependent on the acquired heart rate data)*, and the exercise information being *(dependent on the acquired user exercise data)*.** **An {electronic apparatus} that is configured to be [worn] by a {user} *(In the vicinity of the user's head)* [comprising]:** **a {heart-rate monitor} with (*at least a portion*) of the heart-rate monitor being [embedded in] the apparatus, the heart-rate monitor being configured to [measure] {heart rate data} (*pertaining to the heart rate of the user*);** **an {electronic device} with (*at least a portion*) of the electronic device**		

	being [embedded] In the apparatus and configured to [acquire] {user exercise data}; and {wireless circuitry} [embedded] in the apparatus and configured to [allow] {wireless transmission of signals} (*pertaining to the measured heart rate data*) and the user exercise data to (*at least one*) other electronic device, and wherein the heart-rate monitor [includes] a {radiation transmitter} and a {radiation receiver} to [measure] the heart beat data pertaining to the heart rate of the user. An {electronic apparatus} that is configured to be [worn] by a {user} in the vicinity of the users head [comprising]: *(at least one)* {speaker} configured to [provide] {audible sound} to the user; a {nose pad}; being [embedded] in the apparatus and configured to [acquire] user {exercise data}; and a {monitor} that is configured to [measure] a {physical condition} *(of the user)*, with *(at least a portion)* of the monitor being [embedded] in the {nose pad}, wherein the {monitor} is configured to [measure] the physical condition of the user of the apparatus, wherein to [measure] the physical condition of the user, *(at least a portion)* of the {nose pad} is configured to [contact] with the {nose} of the user, and wherein an {audio alert} is [provided] to the user of the apparatus via the *(at least one)* {speaker} if the physical condition measured or the user exercise data is *(beyond a corresponding threshold)*. **FA diagram of the claims are shown in Figure 8, Figure 9 and Figure 10**

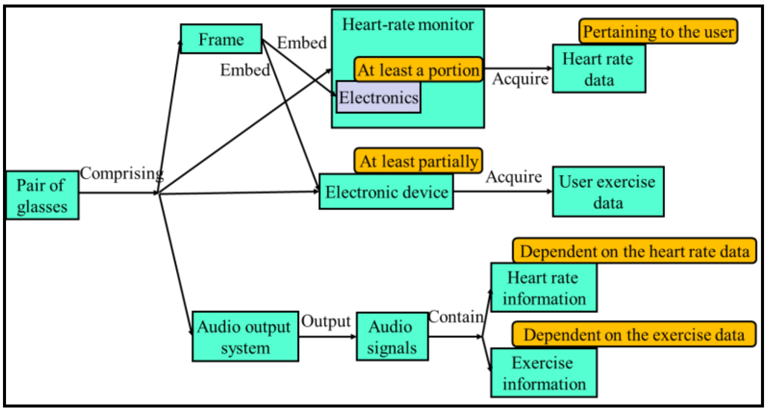


Figure 8 FA diagram independent claim 1

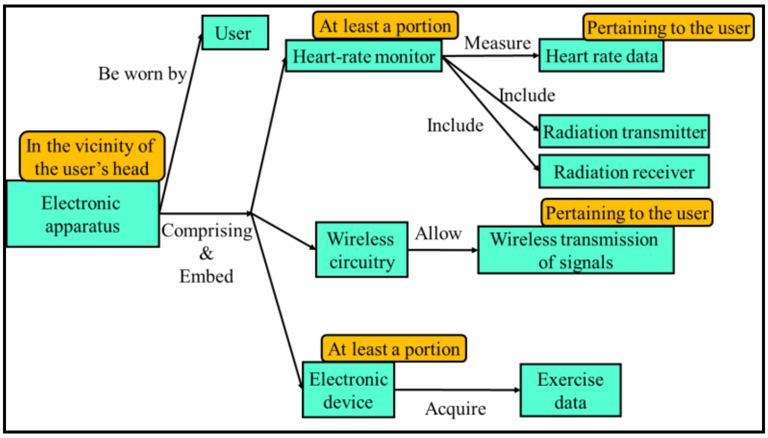


Figure 9 FA diagram independent claim 2

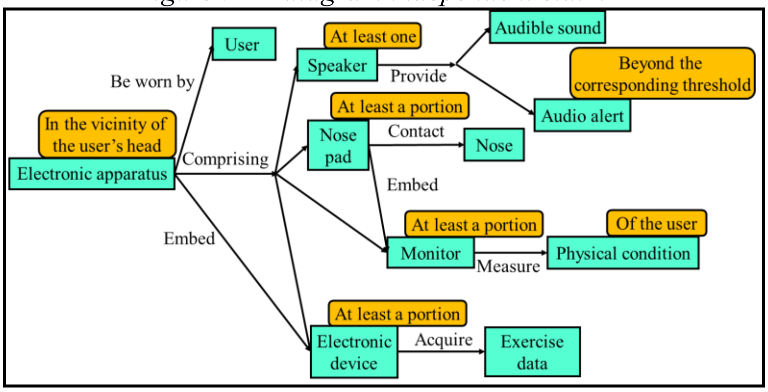


Figure 10 FA diagram independent claim 3

4.1 Identify seven elements of function

Seven elements of function are analyzed as shown in Table 24. *Table 24 Six elements of US 7677723 B2*

Title: Eyeglasses with a heart rate monitor		
	Feature function	Main function
Function	Measure heart rate	Adjust eyesight
Object	Body, heart	eyes
Principle	infrared	optics
Value	Warning, notification	Protect eyes
Tools	Infrared sensor	Lenses
Attribute	The sensor should place behind the nose rest and the frame	
Carrying item		

4.2 Patent enhancement opportunity identification

In this section, system association will be carried out to identify enhancement opportunities. First, in 9 windows analyses we need to choose the scenario when the system is operated to look for disadvantages in the target system. For the simplicity of the paper only the feature function will be carried out in the system association as show in Table 25.

Table 25 9 windows disadvantages identification of US 7677723 B2

Scenario	Driving, riding bicycle or motorcycle		
Space/ Time Domain	**Past**	**Current**	**Future**
Super-system	Production line: needs to maintain quality	Sun: effects eyesight Rain: damages the glasses People: need to monitor blood pressure / need oxygen	Eye: eye pressure too high People: body temperature too high
System	Lack of coverage around the	Cannot detect road condition	Cannot use without power
	head No radio functions	Cannot make phone calls Cannot show location	
Sub-system	Lenses/frame: Lack of coverage around the head No radio function	Frame: slip off Lenses: stain / scratches Speaker: cannot notify road condition	Frame/lenses: scratches signal receiver: damaged

※Please fill in the table from A to I and label each problem then fill in the according answer in the next opportunity form. Super-system: a bigger system that includes current system System: the system for analysis Sub-system: the components inside the system

In the opportunity form, directly answer the problems from the previous form, do not need to answer repeated problems as shown in Table 26.

Table 26 9 windows opportunities identification of US 7677723 B2

Space/ Time Domain	**Past**	**Current**	**Future**
Super-system	Automatic assembly	Sunglasses Waterproof infrared glasses Blood pressure detectable glasses Oxygen level notifiable glasses	Glasses that can reduce eye pressure Solar powered infrared glasses Focal adjustable glasses Glasses with body temperature monitoring function
System	Full coverage infrared glasses Infrared glasses with radio function	Road condition detectable glasses Glasses with phone call function Glasses with GPS	Glasses with battery status Wireless charging glasses Bio-degradable glasses
Sub-system	Enlarge the frame and lenses	Angle adjustable frame Water repellent lenses Speaker to notify road condition	Increase frame/lenses structural integrity Increase signal reliability
※Please number each answer.			

Scenario system:

Table 27 Scenario system of US 7677723 B2

Scenario system – same object (feature function)		
Target system and its feature function	Object of the feature function	List the Scenario systems. How can the Scenario systems enhance the target system?
Infrared glasses / detect heart beat	Body/heart	Speaker/Music playback glasses

Complimentary system:

Table 28 Complimentary system of US 7677723 B2

Complimentary system – same process / scenario / environment (feature function)		
List the target system and its process / scenario / environment	List the disadvantages in the process / scenario / environment	List the complimentary systems? How can the complimentary systems enhance the target system?
Infrared glasses/ (turn on → LED notification → turn off → charging)	LED (broken, cannot show notification)	Vibrator/vibration notification glasses

Quasi complimentary system:

Table 29 Quasi complimentary system of US 7677723 B2

Quasi complimentary system – same process / scenario / environment (feature function)		
Target system and its process / scenario / environment?	List the disadvantages in the process / scenario / environment	List the quasi complimentary systems? How can the quasi complimentary systems enhance the target system?
Infrared glasses/glasses box	Dirty glasses	Supersonic vibrator/clean the glasses

Analogy system:

Table 30 Analogy system of US 7677723 B2

Analogy system – same generic function / product category (feature function)	
Generic function of the target system	List the functions that belong to the same generic function and ideas to enhance the target system
Detect solid	Conduction/detect face temperature to determine body status
Product category of the target system	List the products that belong to the same category and ideas to enhance the target system
Glasses/electronic lenses	Camera/video recording glasses

Same value system:

Table 31 Same value system of US 7677723 B2

Same value system (feature function)

Value of the system	List the same value systems that have the same value as the target system	How to incorporate the same value system to the target system?
Notify body status	Body fat sensor	Glasses that can detect percentage of body fat

Competing system:

Table 32 Competing system of US 7677723 B2

Competing system (feature function)			
Competing systems	Advantages of the competing systems. How to incorporate them?	Disadvantages of the competing systems. How to improve them?	Disadvantages of the target systems. How to avoid them?
Heart rate monitoring watch	Can tell time/time telling glasses	Short battery life/solar powered glasses	Heavy/carbon frame glasses

Quasi competing system:

Table 33 Quasi competing system of US 7677723 B2

Quasi competing system (feature function)		
List the quasi competing systems?	Advantages of the quasi competing systems. How to incorporate them?	Disadvantages of the quasi competing systems. How to improve them?
NA	NA	NA

Inverse systems:

Table 34 Inverse system of US 7677723 B2

Inverse system (feature function)	
Inverse systems that can invert / modify / correct / sabotage the target system.	How to incorporate them to the target system?
Signal disruptor	Signal filter/booster glasses with antenna

\Heterogeneous system:

Table 35 Heterogeneous system of US 7677723 B2

Heterogeneous system – shared resources

Resources in the target system	List the heterogeneous systems that can use the resources. How can we incorporate them to the target system?
LED	Led light/high lumen LED light for craftsman

The enhancement opportunities generated by system association will be listed in the enhancement opportunity list as illustrated in Table 36 and please remove similar ideas in this step to prevent over listing the list.

Table 36 Enhancement opportunity list

Enhancement opportunity list (do not list repeated ideas)	
Sources	New systems
9 windows	Automatic assembly Full coverage infrared glasses Infrared glasses with radio function Enlarge the frame and lenses Sunglasses Waterproof infrared glasses Blood pressure detectable glasses Oxygen level notifiable glasses Road condition detectable glasses Glasses with phone call function Glasses with GPS Angle adjustable frame Water repellent lenses Speaker to notify road condition Glasses that can reduce eye pressure Solar powered infrared glasses Focal adjustable glasses Glasses with body temperature monitoring function Glasses with battery status Wireless charging glasses Bio-degradable glasses Increase frame/lenses structural integrity Increase signal reliability
Scenario system	Speaker/Music playback glasses
Complimentary system	Vibrator/vibration notification glasses
Quasi complimentary system	Supersonic vibrator/clean the glasses

Analogy system	Conduction/detect face temperature to determine body status Camera/video recording glasses
Same value system	Glasses that can detect percentage of body fat
Competing system	Can tell time/time telling glasses Short battery life/solar powered glasses Heavy/carbon frame glasses
Quasi competing system	NA
Inverse system	Signal filter/booster glasses with antenna
Heterogeneous system	Led light/high lumen LED light for craftsman

4.3 CPC tri-level expansion

As we can see from patent abstract for the CPC category for US 7677723 B2 includes: A61B 5/02433; A61B 5/6803; A61B 5/6816; G02C 11/10; A61B 5/742. We will go through each one in this section.

4.3.1 A61B 5/02433

A61B 5/02433 is already at the bottom of CPC class, so we will proceed with mode 2 and 3 in Table 37 and Table 38.

Table 37 Mode2: integrate equal class of A61B 5/02433

Mode2: integrate equal class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/02433 for infra-red radiation	A61B 5/0006 ECG or EEG signals
Enhancement opportunity		Use ECG signal to control the smart glass

Table 38 Mode3: integrate upper class of A61B 5/02433

Mode3: integrate upper class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/02433 for infra-red radiation	NA
Enhancement opportunity		NA

4.3.2 A61B 5/6803

A61B 5/6803 is already at the bottom of CPC class, so we will proceed with mode 2 and 3 in Table 39Table 40.

Table 39 integrate equal class of A61B 5/6803

Mode2: integrate equal class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/6803 Head-worn items, e.g. helmets, masks, headphones or goggles	A61B 5/0051 by applying vibrations
Enhancement opportunity		Have vibration notification function

Table 40 integrate upper class of A61B 5/6803

Mode3: integrate upper class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	A61B 2505/00 Evaluating, monitoring or diagnosing in the context of a particular type of medical care
Original class	A61B 5/ 6803 Head-worn items, e.g. helmets, masks, headphones or goggles	NA
Enhancement opportunity		Have heart rate detection function for elderly home care

4.3.3 A61B 5/6816

A61B 5/6816 is already at the bottom of CPC class, so we will proceed with mode 2 and 3 in Table 41Table 42.

Table 41 integrate equal class of A61B 5/6816

Mode2: integrate equal class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA

Original class	A61B 5/6816 Ear lobe	NA
Enhancement opportunity		NA

Table 42 integrate upper class of A61B 5/6816

Mode3: integrate upper class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/6816 Ear lobe	NA
Enhancement opportunity		NA

4.3.4 G02C 11/10

G02C 11/10 is already at the bottom of CPC class, so we will proceed with mode 2 and 3 in Table 43Table 44.

Table 43 integrate equal class of G02C 11/10

Mode2: integrate equal class		
	Classification of target patent	Expandable classification 1
Upper class	G	NA
	G02	NA
	G02C	NA
	G02C 11/00	NA
Original class	G02C 11/10 Electronic devices other than hearing aids	G02C 11/10 Illuminating means
Enhancement opportunity		Have LED light for use in darkness

Table 44 integrate upper class of G02C 11/10

Mode3: integrate upper class		
	Classification of target patent	Expandable classification 1
Upper class	G	NA
	G02	NA
	G02C	NA
	G02C 11/00	G02C 11/00 Attaching auxiliary optical parts
Original class	G02C 11/10 Electronic devices other than hearing aids	NA
Enhancement opportunity		Can attach other lenses such as sun glasses lens

4.3.5 A61B 5/742

A61B 5/742 is already at the bottom of CPC class, so we will proceed with mode 2 and 3 in . *Table 45 integrate equal class of A61B 5/742*

Mode2: integrate equal class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/742 using visual displays	A61B 5/0008 Temperature signals
Enhancement opportunity		Can display temperature on the lens

Table 46 integrate upper class of A61B 5/742

Mode3: integrate upper class		
	Classification of target patent	Expandable classification 1
Upper class	A	NA
	A61	NA
	A61B	NA
	A61B 5/00	NA
Original class	A61B 5/742 using visual displays	NA
Enhancement opportunity		NA

4.4 KJ method

The list from above will be sorted using KJ method as illustrate in Table 47

Table 47 Sorting of ideas

Category	Ideas
Monitoring/notification	Blood pressure detectable glasses Oxygen level notifiable glasses Road condition detectable glasses Glasses with GPS Speaker to notify road condition Glasses with body temperature monitoring function Glasses with battery status Vibrator/vibration notification glasses Conduction/detect face temperature to determine body status Glasses that can detect percentage of body fat Have vibration notification function Have heart rate detection function for elderly home care

Structure	Full coverage infrared glasses Enlarge the frame and lenses Waterproof infrared glasses Angle adjustable frame Focal adjustable glasses Bio-degradable glasses
	Increase frame/lenses structural integrity Heavy/carbon frame glasses Can attach other lenses such as sun glasses lens
Entertainment	Radio function Glasses with GPS Speaker/Music playback glasses Glasses with phone call function
Utility	Water repellent lenses Glasses that can reduce eye pressure Solar powered infrared glasses Increase signal reliability Camera/video recording glasses Camera/video recording glasses Can tell time/time telling glasses Led light/high lumen LED light for craftsman Supersonic vibrator/clean the glasses Have LED light for use in darkness Can display temperature on the lens
Control	Use ECG signal to control the smart glass

Once the ideas are sorted they will be evaluate by the Pugh Matrix, Table 48 illustrates the finalized ideas for the solution process.

Table 48 Finalized ideas

Target system: Eyeglasses with a heart rate monitor		Enhancement opportunities							
		A		B		C		E	
		Full coverage hot patch glasses for reducing eye pressure		Blood pressure and oxygen level detectable glasses		Video recording glasses		Body fat detectable glasses	
Criteria	Weight	Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score

Innovation	30%	4	1.2	5	1.5	4	1.2	3	0.9
Functionality	30%	5	1.5	4	1.2	4	1.2	4	1.2
Technical feasibility	15%	4	0.6	4	0.6	3	0.45	4	0.6
Usefulness	15%	4	0.6	3	0.45	3	0.45	3	0.45
Market size	10%	4	0.4	4	0.4	3	0.3	3	0.3
Profit	5%	3	0.15	3	0.15	3	0.15	2	0.1
Total score	100%	4.45		4.3		3.75		3.55	
rank		1		2		3		4	
Continue?		Yes		Yes		No		No	

4.5 Solution process

In this section, we will be giving a brief explanation on making the enhancement opportunities feasible by using TRIZ tools (knowledge effect database and SFA). First, the full coverage hot patch glasses for reducing eye pressure will be solved by using knowledge/effect database and blood pressure and oxygen level detectable glasses will be solved by SFA accordingly.

4.5.1 Full coverage hot patch glasses for reducing eye pressure

The functions of the full coverage hot patch glasses for reducing eye pressure includes, cover the eyes, lower eye pressure and hot patching. If we turn these functions into generic functions, they will become, protect solid, absorb field and produce field. Moreover, these functions are related to pressure and infrared energy; we can transform these into generic attributes, decrease pressure and stabilize energy. Table 49 illustrates the solution from knowledge/effect database.

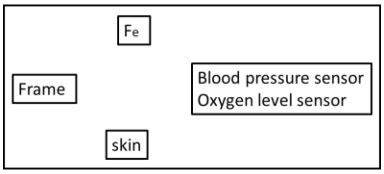
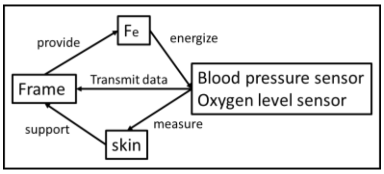
Table 49 Knowledge/effect database solution

Enhancement opportunities	Full coverage hot patch glasses for reducing eye pressure		
New functions	Cover eyes Reduce eye pressure Hot patch eyes	Generic function	Protect solid Absorb field Produce field
New attributes	Pressure Energy	Generic attributes	Decrease pressure Stabilize energy
Usable effect list	Infrared Radiation Electro-optic effect	Usable resource list	Arch
Solution	Embed an infrared generator into the frame to generate infrared energy towards the surrounding of our eyes to increase blood circulation to lower eye pressure. With the same infrared generator from above, we design the frame to cover/contact the surrounding of our eye and let the infrared energy heat up the frame to hot patch our eyes.		

4.5.2 Blood pressure and oxygen level detectable glasses

Table 50 illustrates the solution process using SFA

Table 50 SFA solution

Enhancement opportunities	Blood pressure and oxygen level detectable glasses	New function	Detect blood pressure Detect oxygen level
Target system components	Frame, heart rate monitor, electronics (PCB and etcetera), nose rest	Target system FA	Neglected in this paper
Difference	Components to detect blood pressure and oxygen level		
SFA model at problem point	 *Figure 11 SFA model at problem point*		
SFA model for the solution	Rule 0  *Figure 12 SFA model for the solution*		
Solution	As we can see from Figure 11and Figure 12 by using the power that was supporting the heart rate monitor to power the blood pressure and oxygen level sensor to detect or body and send the data back to the frame for processing.		

Summary

This research proposed system association methods for identification of patent enhancements. This process combines innovative product identification tools and TRIZ methodologies, its main contributions are as follows:

- Integrate system association and CPC tri-level expansion to create a systematic method to enhance a patent
- The opportunities are then solved by TRIZ tools which completes the whole process.

Reference

- Belski, I. (2007), "Improve Your Thinking: Substance-Field Analysis", Melbourne. A, TRIZ4U.
- D. Daniel Sheu, Jealousy Hong, and Chia Lin Ho (2017), *New Product Identification and Design through Super-system Trimming*, Computers & Industrial Engineering 111 (2017) 251–262, DOI: 10.1016/j.cie.2017.07.008 (SCI/2.632)
- D. Daniel Sheu and Jealousy Hong (2017). Resource Identification Method Based on Demand-Supply Thought Provoking Questions for Problem Solving, *International Journal of Systematic Innovation*, 4(4), 67-82.

- D. Daniel Sheu, Zi-Huei Wang (2013). TRIZ-based Systematic Circumvention Method for Patent Clusters, *International Journal of Systematic Innovation*, 2(3), 38-55.
- D. Daniel Sheu (2017). Systematic patent circumvention, enhancement and regeneration. Taiwan: AgiTech, (Book Chapter 3) (In Chinese)
- D. Daniel Sheu, Johnson Chen, and Raymond Lin (2018), Systematic Opportunities Identification of Patent Enhancement and Problem-Solving Process, the 10th Systematic Innovation Conference and Annual Meeting of Society of Systematic Innovation, Taichung, Taiwan, 2018/01/20. (In Chinese)
- Mann, D.L. (2002), *Hands-on Systematic Innovation for Technology and Engineering*, CREAX press, ISBN: 9077071024
- Susumu Kunifuji (2013), “A Japanese problem solving approach: the KJ-Ho method”, Andrzej M.J. Skulimowski (ed.): Proceedings of KICSS'2013, pp. 333-338
- Sheng Ling Wu (2014). Computer-aided Systematic Innovative Product and Service Identification System, National Tsing Hua University, Taiwan (In Chinese)
- Wang Yao-Ting (2017). TRIZ Based Systematic Patent Circumvention, Regeneration, and Enhancement Methods, National Tsing Hua University, Taiwan.
- Xiu Ru Wang (2014). Patent Strengthening and Deployment Methodology based on TRIZ and Extenics, National Tsing Hua university, Taiwan. (In Chinese)

Parameter Deployment and Parameter manipulation (Parameter Domination and Parameter Separation) for Solving Self - Contradictions in Business and Management

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Abstract

Physical contradiction is based on two contradictory demands placing on a same parameter and system. Because of scenario, Physical Contradiction called as “Self-Contradiction” in Business TRIZ, is at a heart of contradictory problem. If we can solve the self-contradiction entirely, it indicates that a complex problem will be solved more effective. This research introduces “Parameter Deployment and Manipulation for solving physical contradiction in Technical TRIZ” into Business TRIZ. This method provides us with some problem-solving directions which have multiple and integrated perspectives, that is able to propose more solutions to solve self-contradictions. Although parameter manipulation has three model to solve self-contradiction, we just introduce two model – “parameter domination” and “parameter separation” to the Business TRIZ. Finally, we believe that the new method will enhance disadvantage that exist methods which lack of systematization and synergy. This research proves this new method that is able to propose some good solutions by performing business and management case in practice, and increases 300% performance of problem solving.

Keywords: TRIZ, Systematic Innovation, Physical Contradiction, Parameter Manipulation, Parameter separation

1. Introduction

1.1 Motivation

Due to rapid development of business environment and organization, Business and Management issue that number of members involved in it is increase. It seems very common and usual situation when the globalization and information technology prevail among of world. In this scenario, it leads to the scale of enterprises and organizations becomes bigger and bigger, and more complexity. Finally, contradictions in the enterprises or organizations are more and more. How to allocate the benefit, coordinate the work and solve the problem that caused by the situation that we said is a very important issue nowadays, and then create win-win situations in the end. Although we have many tools, method and process that make us solve contradiction, these exist way we solve problem and contradiction has some disadvantages (lacks of integration). We want to develop a new integrated and systematic procedure and tools that based on TRIZ theory to assist users or managers to solve the root contradictions for enterprises and organizations. Finally, we can improve and enhance performance of business operation.

1.2 Goal

We introduce Parameter Deployment and Parameter Manipulation that used in technical and engineering field into the Business and Management issue. Furthermore, we adjust and revise Parameter Deployment and Parameter Manipulation that make it more suitable for situation of business and management. Finally, we improve the problems that caused by exist method and tools, making solutions we propose become better and more complete, solve the contradictions and problems successfully in the end. Parameter manipulation has three models of operation – Parameter Domination, Parameter Separation and Parameter Transfer. We focus on Parameter Domination and Parameter Separation, hoping that can solve the problems and contradictions more effective. As a result, we can apply a systematic procedure and methods to assist enterprises and organizations to enhance performance of the organizations that operated.

2. Literature review

Here we will be reviewing the methodologies and studies used in the paper.

2.1 TRIZ for business and management

TRIZ is a theory of systematic innovation that developed and proposed by Genrich Altshuller. Because TRIZ also called as "Theory of Inventive Problem Solving" in western countries, and then somebody call TRIZ as "TIPS". Daniel Sheu (2014) considers TRIZ is a method that learn and extract some intelligence that proposed by predecessors, we are able to take these ideas and thoughts to analyze or solve the problem that we face.

At first, TRIZ applied in technical and engineering field. For many years, some scholar effort to develop and propose some new method in the business and management, even apply in software development and social issue, etc. The fundamental concept for Business and Management TRIZ is similar to Technical TRIZ, but methods and tools are very different because of different appliance and property. Therefore, we cannot use the methods and tools from Technical TRIZ to Business and Management TRIZ directly. There is a huge and critical issue that we meet – How to transit some tools and method of Technical TRIZ to the field of Business and Management?

2.2 Physical contradiction and self-contradiction

In Technical TRIZ, the definition of Physical Contradiction is two contradiction demands placing on a same parameter and system. The contradictory demands indicate that the demand we cannot satisfy in the same time, and come from the same parameter. Because the term “Physical” is not appropriate for Business and Management scenario, we called “Self-Contradiction” as Physical Contradiction in issue of Business and Management issue.

From Contradiction Relationship Diagram proposed by Darrell Mann (2007), we show Fig1. It indicates that self-contradiction is always a critical issue in most of problems. If we are able to solve the self-contradictions, we solve problems more fundamental, the other follow-up problems solved in the meantime. As a result, how to solve self-contradictions is a key problem for enterprises and organizations.

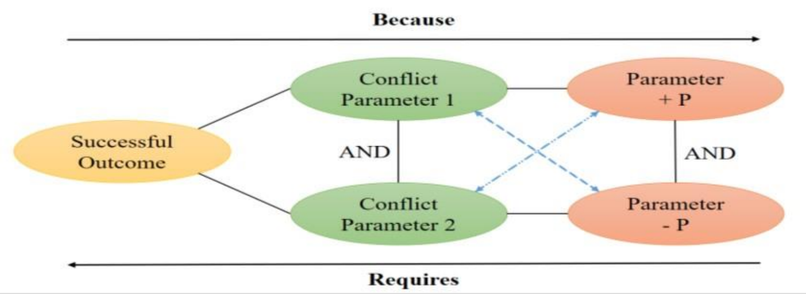


Fig 1 Contradiction Relationship Diagram

2.3 Separation principle

Separation Principle was developed by Darrell Mann, a method to solve self-contradiction for Business and Management. It combines with four strategies of separation – “time”, “space”, “conditions”, and “transfer to alternative system” to satisfy two contradictory demands (Darrell Mann, 2004). However, there are two disadvantages for separation principle, are the key point that we need to overcome.

1. **There is no Synergy and integration** – Because we use four strategies of separation to analyze and solve problems independently, it is very difficult for us to combine our thought and solutions.
2. **There is no concrete process of solving problems –** All of strategies of separation provide directions of solving problem (40 Inventive Principles), there is no a specific process for us to propose some solutions.

2.4 Parameter separation

Royzen (2008) proposed the concept of "Parameter Separation". The definition is when a contradictory parameter has two different demands, and one of two demands is satisfied with one factor, or both of different demands are satisfied with two different factors. Therefore, we set a contradictory parameter as object to separate, using different factor to satisfy respective demand for contradictory parameter. However, there is not any methods and tools to perform parameter separation. Finally, there is a critical concept is that there is not any relationship with separation principle.

2.5 System transfer

Daniel Sheu (2014) indicated a concept from his research. When a problem occur in exist system, we are able to solve a problem by transferring our problem to another system or object, which lead to a problem that is solved in other system or make this problem become unimportant. However, system transfer is similar to parameter separation; there is not any tools and method to perform it systematically. System transfer is an excellent concept for us because has more opportunity to come up with some innovative solutions.

2.6 Parameter Manipulation

Proposed 17+10(N-1) strategies of problem solving (Like Fig 2). We want to extend these strategies of problem solving (yellow part) to apply in business and management issue. Fortunately, we do it successfully and assist enterprises and organizations to propose some solutions that come from different perceptions to solve self-contradiction that the companies or organization meet.

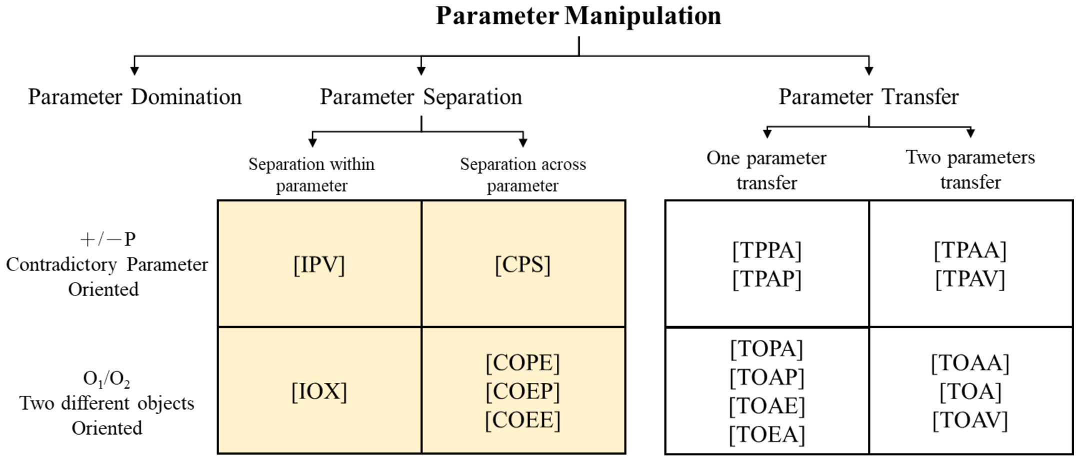


Fig 2 Parameter manipulation Diagram

3. Research Method

This section illustrates the research method used in this paper. Fig 3 is our procedure.

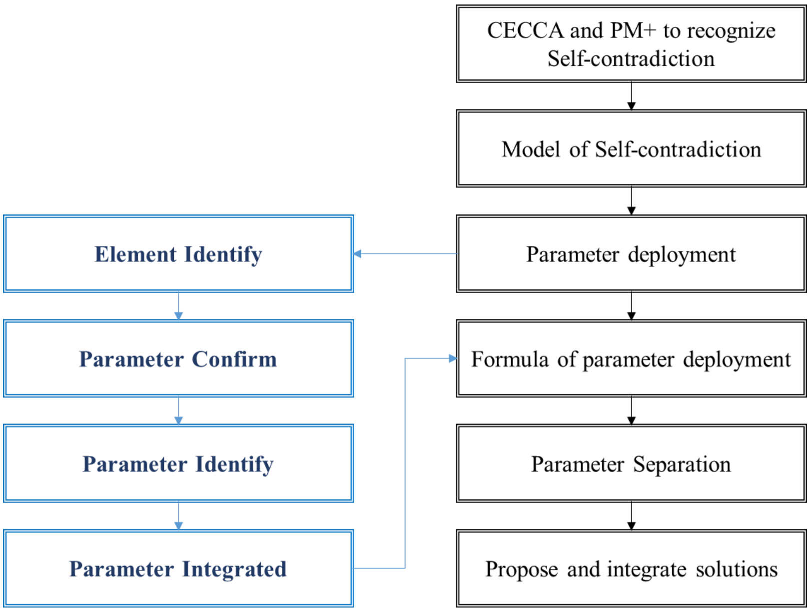


Fig 3 Parameter deployment and parameter manipulation process

3.1 Recognize contradiction

Parameter deployment and parameter manipulation is a procedure and method to solve self-contradiction. If we want to solve a self-contradiction, “how to recognize self-contradiction?” in our procedure is an initial step. We use CECCA, PM+ or RCA+ to identify contradictions. Afterward, users should perform parameter deployment by element identification, parameter confirmation, parameter identification and parameter integration. As a result, we realize what parameter that we could use to solve problem, and then continue to process follow-up. Finally, we match parameters that deployed by us with parameter separation, and then, to propose some solutions to solve self-contradiction by parameter separation.

3.2 Model of self-contradiction

"Model of self-contradiction" is a standard form to explain the situation of self-contradiction for enterprises and organizations. That is a good method for user to identify demand of contradiction and their respective objectives (O_1/O_2) rapidly. There is a model of self-contradiction below it. To [O_1]_________________, [P]_________________ should be [+P]_________, But To [O_2]_________________, [P]_________________ should be [-P]_________.

3.3 Parameter deployment

In this study, the disadvantages of any element must be related to the function or attribute of the element itself, or related to the function or attribute of its surrounding elements. Therefore, when an attribute of a system element self-contradiction, it can be found by itself or other elements that interact with it, find a function for that attribute, and solve the contradictory problem by adjusting the relevant attributes of the functional element.

3.3.1 Central element and subject system

We should explain some terms before we introduce parameter deployment and manipulation. These terms include central element, interactive element, and subject system. The definition of these terms show in Table 1.

Table1 Definitions of terms

Term	Definition
Central element	That is central point of self-Contradiction, include contradictory parameter, and two different objective (O_1/O_2). Sometimes, a contradictory problem is composed of two or three central elements.
Interactive element	That is some elements have interactive relationships with central elements.
Subject system	Subject System is combine with all of central elements and interactive elements. Subject system is our range when we perform parameter deployment and manipulation (separation and domination) to solve self-contradiction.

3.3.1 Parameter definition

When the parameter impact two objectives (O_1/O_2) or contradictory parameter (P) remarkably, we call parameter as “Constituent Parameter”. Furthermore, according to relationship between constituent parameter, we can classify parameter for “Common Parameter” and “Exclusive Parameter”. Common Parameter is going to divide into two kinds of parameters – Compatible Parameter and Contradictory Parameter. The definition of parameter show in table 2 and figure 4.

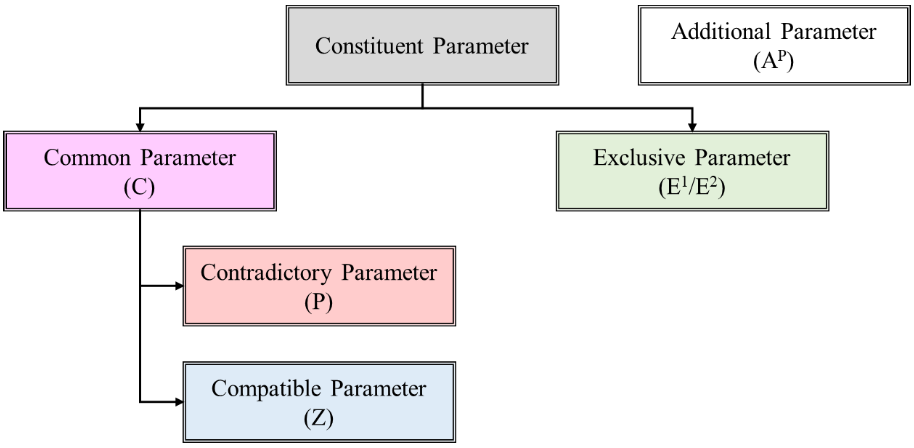


Fig 4 Parameter Relationship Diagram

Table 2 Definition of parameter

Symbol	Term	Definition
X	Constituent Parameter	The parameter impact two objectives (O_1/O_2) or contradictory parameter (P) remarkably.
C	Common Parameter	The parameter is one kind of Constituent Parameter that impact on two objectives simultaneously.

Z	Compatible Parameter	The parameter is one kind of Common Parameter that could satisfy with demand in the meantime, also in the same condition.
P	Contradictory Parameter	The parameter is one kind of Common Parameter that could not satisfy with demand in the meantime.
E	Exclusive Parameter	The parameter just satisfy one of two demands in the one time. It divide into objective 1 and objective 2 exclusive parameter that is indicate the exclusive parameter is going to satisfy with which objective 1 (E^1) or objective 2 (E^2).

3.3.2 Generic formula of Parameter deployment

The parameter deployment proposed in this study is to assist user to identify the relationship between each relevant parameter and two different objectives (O_1/O_2) systematically, and to expand the generic formula by constructing the parameters of the problem. The problem of self-contradiction is expressed clearly and remarkably to facilitate the subsequent resolution of the contradictory problem by means of parametric manipulations. The generic formula for the parameters of the dichotomous objectives and contradictory parameters is as follows:

P_1^1 E_1^1 Z_1^1 ➢ $O_1=fn(\uparrow, \ldots ; \uparrow, \ldots ; \uparrow, \ldots)$

P_1^2 E_1^2 Z_1^2 ➢ $O_2=fn(\downarrow, \ldots ; \uparrow, \ldots ; \uparrow, \ldots)$

➢ $\pm P=fn(X_1, X_2, X_3, \ldots)$

3.4 The spirit of solving problem of the parameter manipulation

The spirit of solving problem of the parameter manipulation is to deploy the Generic formula of Parameter deployment of the two different objectives (O_1/O_2) and the contradictory parameters (P) respectively, and to make the two contradictory demands (O_1/O_2 or +P/-P) to satisfy respectively at the same time by parameter domination, parameter separation or parameter transfer. The two determinants (contradictory parameters, exclusive parameters, and compatible parameters) are satisfied at the same time, or by different value domains of the same decisive factor, or met by the same decisive factor at the same time to resolve the self-contradiction. In my study, I just focus on parameter domination and parameter separation:

- Two contradictory demands are satisfied with compatible parameter in the mean time.
- Two different domains of a certain constituent parameter within the subject system meet two contradictory demands.
- The two different parameters obtained after splitting the contradictory parameters to satisfy two contradictory demands respectively.
- Two contradictory demands are met by two different constituent parameters within the subject system.

Based on the spirit of problem solving of the parameter manipulation, we propose 6 strategies of problem solving.

3.5 Parameter Domination

The Parameter Domination proposed in this study is based on the first spirit of problem solving of the parameter manipulation. Through the deployment of the parameters of the two different objectives, the compatible parameters of the two different objectives are identified from all of parameters, and this parameter is enhanced to reach two different objectives (O_1/O_2) significantly and simultaneously.

3.6 Parameter Separation

The parameter separation proposed by second to forth spirit of problem solving of the parameter manipulation. Parameter separation integrates existing separation principles (space, time, condition, transition to an alternative system, and Royzen's parameter separation), and satisfy the two contradictory demands (O_1/ O_2 or +P/-P) according to the constituent parameter (Contradictory parameter or Exclusive parameter). However, parameter separation is divided into "Separation within Parameter" and "Separation across Parameters".

3.6.1 Separation within parameter

Separation within Parameter is to satisfy two contradictory demands (O_1/O_2 or +P/-P) by different value domains of the same specific parameter (such as space, time, etc.), that is, certain parameters reach one of the contradictory demands in one of the range. Another contradictory demand reach in another range; exist separation principles proposed by Darrell Mann (space separation, time separation, situation separation, system level separation, etc.) all belong to this category.

3.6.2 Separation across parameter

Separation across Parameters involves the need for two contradictory demands to be satisfied simultaneously by different constituent parameters, ie, one constituent parameter satisfies one of two demands and the other constituent parameter satisfies another. Separation across Parameters can be subdivided into two ways, depending on the types of contradictory demands to be separated:

- **Separation:** The two contradictory demands (O_1/O_2) that can be satisfied with the different constituent parameters of the self-contradiction in the same time.

- **Splitting:** Contradictory parameter can be divided into two different parameters (P^+/P^-), and then to satisfy with two contradictory demands (+P/-P).

3.6.3 Problem-solving strategy

3.6.3.1 Separation within parameter

This study proposes a solution strategy “IPV” for parameter separation in “contradictory parameter oriented”. The explanation is as follows:

[IPV]：I－Separation within Parameter；P－Contradictory parameter oriented；V－Satisfied (+P/-P) with different domains respectively.

The contradictory parameters can meet the contradictory demands of two different objectives under different values of specific parameters, that is, the specific parameter meets the first demand of objective for contradictory parameter (+P) in one value domain, and in another value domain is to satisfy the second demand of objective for contradictory parameters (-P). Specific parameters include "space," "time," "condition," "transition to an alternative system," or other parameters.

Taking the factory relocation in Chengdu as an example, in order to reduce the labor cost, the company decided to relocate the factory in Chengdu; in order to reduce the transportation costs, the company decided not to relocate the factory in Chengdu. If an enterprise uses the time separation, it can refer to the relevant inventive principles of time separation to come up with some solution to solve self-contradiction. Therefore, the company adopts the “26th inventive principle: Copy”, and proposes that before the preferential policies are over, refer to the solutions of other manufacturers facing relocation problems. With strategic planning, its experience was copied into this relocation strategy to overcome the problem of the increase in the cost of relocation to inland transportation.
Finally, in order to resolve self-contradiction.

3.6.3.2 Separation across parameter

[CPS]：C－Separation across Parameter；P－Contradictory parameter oriented；S－Splitting contradictory parameter.

For the two different objectives or their central element splitting contradictory parameters, the contradictory demands (+P/-P) of the contradictory parameters of the two dissimilar targets can be assumed by the splitting contradictory parameters (P+/P-).

In order to reduce the labor costs, the company decided to relocate the factory in Chengdu; for the sake of reducing transportation costs, the company decided not to relocate the factory in Chengdu. Through the CPS problem-solving strategy, the company has divided the relocation decision into labor-intensive departments relocating decision and knowledge intensive departments relocating decision. Relocating labor-intensive and supporting operations (Customer service or human resource...) to the Chengdu, and then to reducing the cost of labor; In the meantime, the knowledge-intensive operation (R&D test) will be retained in Dongchen. After all, professional, R&D personnel are relatively easy to recruit in the first-tier cities such as Guangzhou and Shenzhen.

The cost of transportation is going to be assigned to Chengdu inland freight to reduce. **[COPE]：C－Separation across Parameter；O－Different objectives oriented；PE－P satisfy with O_1、E^2 satisfy with O_2**

Assume the contradictory parameter (P) reach the demand of the first objective (O_1). At this time, the impact of the contradictory parameter on the second objective (O_2) is compensated with the exclusive parameter (E^2) of the second objective.

Taking the example of whether the company prepares goods in advance, in order to allow the goods to reach the customer (O_1) on time, they want to stock some goods in advance (+P); in order to avoid the increase in inventory cost (O_2), it is hoped that the company will not perform early stocking (-P). Through the COPE problem-solving strategy, companies can decide to stock some goods in advance and deliver products to customers on time, and then introduce capacity plans to match the demand of customers with the suppliers' supply effectively. This will reduce excess inventory to decrease in inventory cost.

[COEP]：C－Separation across Parameter；O－Different objectives oriented；EP－E^1 satisfy with O_1、P satisfy with O_2

Assume the contradictory parameter (P) reach the demand of the second objective (O_2). At the meantime, the impact of the contradictory parameter on the first objective (O_1) is compensated by the exclusive parameter (E^1) of the first objective.

Taking the enterprise consolidation as an example, in order to achieve a reduction in management costs (O_1), companies determine the team consolidation (+P); in order to achieve experienced employees do not lose (O_2), the company rejects team consolidation (-P). Through COEP problem-solving strategy, the company decides not to implement the team consolidation in order to achieve that the experienced employees do not lose; when the human resources department executes the employee recruitment, in addition to the capability assessment, other indicators, such as matching degree, are additionally evaluated. , personality and background, to allow employees who meet the corporate culture to join, reduce management costs.

[COEE]：C－Separation across Parameter；O－Different objectives oriented；Ignore P，E^1 satisfy with O_1、E^2 satisfy with O_2

Ignoring the contradictory parameter (P), the demand of the first objective (O_1) is met by its exclusive parameter (E^1), and the demand of the second objective (O_2) is met by its exclusive parameter (E^2).

Taking the enterprise consolidation as an example, in order to achieve a reduction in management costs (O_1), companies determine the team consolidation (+P); in order to achieve experienced employees do not lose (O_2), the company rejects team consolidation (-P). Through the COEE problem-solving strategy, companies ignore the contradictory parameters. In order to reduce the cost of management, let the human resources department revise the complex organizational structure and turn it into a flattened organization; at the same time, in order to prevent experienced employees from keeping away, employees are allowed to subscribe for the company's stock to improve coherence of employee.

3.7 IOX

The IOX (Extension) is developed by our study will execute all the strategies that related with contradictory parameter (P) again to try to find out more and the multi-level problem-solving method to solve self-contradictions.

If the contradictory problem has more than one contradictory parameters (P), then practice [IOX] by other contradictory parameters (P2, P3,...). If the contradictory parameter "P" is involved in each strategy, the current contradictory parameter P^1 is converted to P^2 to find other possible problem solving solution. With the method of parameter manipulation, the IOX problem solving strategy allows the user to expand into 5+4 (N-1) problem solving strategies in addition to the five problem solving strategies for parameter separation of existing parameter operations, where N is the number of contradictory parameter in the issue. The number of contradictory parameters is determined by parameter deployment. For example, if a case gets 3 contradictory parameters through the process of parameter deployment, the case has a total of 13 (5+8) problem solving strategies to help users solve the self-contradiction.

4 Practical Case

4.1 Introduction

A software company did not achieve sales goal last year so they want to realize and analyze why the sales goal did not achieve. According RCA and CECCA, we can know what contradiction leads to this situation. Therefore, when the price is high, customer don't want to purchase the software, but we can get more revenue: when the price is low, that is elevate customer purchase intention, but it can reduce our revenue. That is a typical self-contradiction problem.

4.2 Model of self-contradiction

To [O_1] elevate customers purchase intention, [P] Software's price should be [+P] low price, But To

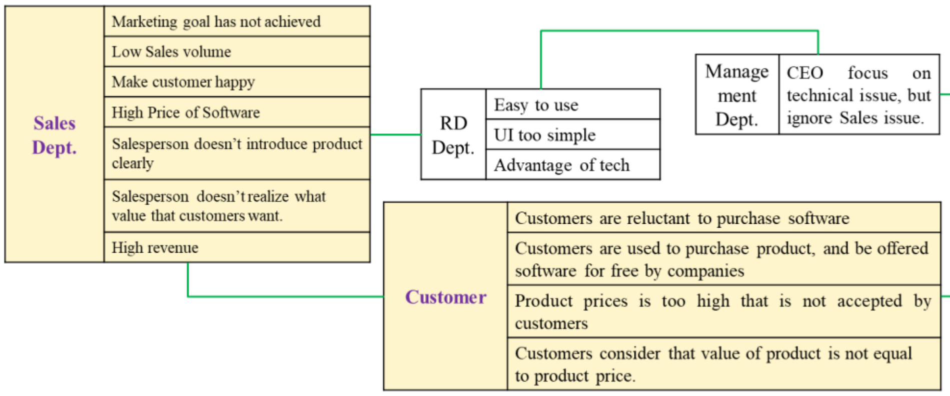
[O_2] increase revenue from selling product, [P] Software's price should be [-P] high price.

4.3 Step of parameter deployment

In order to obtain the relevant parameters for resolving problem of the self-contradiction, all relevant elements of the case should be identified by using an element identification table. The results of the relevant parameters are deployment by the relevant elements as shown in Table 3 below.

Table 3. Table of Element identification

To elevate customers purchase intention, Software's prize should be low price, But To increase revenue from selling product, Software's prize should be high price.				
O_1	Parameter：Purchase intention	Central element：Customer	P	Central element：Sales Department
O_2	Parameter：Sale volume	Central element：Sales Department		
Interactive Element Figure (By case)				



In order to resolve the self-contradiction actually, it is necessary to understand how the relevant elements affect the two different objectives or contradictory parameters by their parameters. Based on the impact of this result, this study can identify the contradictory parameter, exclusive parameters and compatible parameters of "the company's sales did not achievement cases". This study uses a parameter identification table to complete it. The results are shown in Table 4.

Table 4 Table of Parameter identify

System：Software company for measure device							
O_1	Customer willing to purchase software			O_2	Increase revenue of software		
Sales Department		R&D Department		Management Department		**Customer**	
1	Sales Volume	1	Easy to use	1	CEO focus on sales or research	1	Customer Expectation
2	**Product Prize**	2	Product Complexity			2	Purchase Intention
3	Product information delivery effectiveness	3	Technical Skill			3	Product cognition differences
4	Perceived value					4	Customer Satisfaction
5	Sales Amounts						

Central Element / Interactive Element											
Sales Department			R&D Department			Management Department			**Customer**		
ID	**O_1**	**O_2**	**ID**	**O_1**	**O_2**	**ID**	**O_1**	**O_2**	**ID**	**O_1**	**O_2**
1	X	↑	1	↑	X	**1**	**E**	**E**	1	↑	X
2	↓	↑	2	↓	X				2	↑	X
3	↑	X	3	↑	X				3	↓	X
4	↑	X							4	↑	X
5	X	↑									

Then, by associating and deducing the parameters of the two different objectives and the contradictory parameters, other relevant factors that affect the two parameters of different objectives and the contradictory parameters are identified, and these relevant factors are found through the parameter integration table. The relationship between two different objectives expands the results of the parameter deployment further. The results of its parameter integration table are shown in Table 5 below.

Table 5 Table of Parameter integration

System：Software company								
O_1	Customer willing to purchase software			O_2	Increase revenue of software			
O_1 Parameter	Purchase Intention		O_2 Parameter	Sales Volume		Contrad-par	Product Prize	
Related Factors	• Customer Demand		Related Factors	• Product Cost		Related Factors	• Product function	
	• Selective flexibility						• Product quality	
	• Amount of ad						• Service Diversity	
							• Product properties	
Related Factors	**O_1**	**O_2**	**Related Factors**	**O_1**	**O_2**	**Related Factors**	**O_1**	**O_2**
Customer Demand	→	X	Product Cost	X	↓	Product function	↑	X
Selective flexibility	↑	X				Product quality	↑	X
Amount of ad	↑	X				Service Diversity	↑	X
						Product properties	↑	X

After the steps that above are completed, the study completes the steps for the parameter deployment of this case, and displays the results as a parameter deployment table, as shown in Table 6. Red indicates a contradictory parameter (P); purple indicates an exclusive parameter (E); yellow indicates a compatible parameter (Z).

Table 6 Parameter deployment Table

[O_1] Achieve customers willing to purchase software =

fn (**Product Price↓**； Product information delivery effectiveness↑ ， Perceived value↑ ， Easy to use↑ ， Product Complexity ↓ ， Technical Skill↑ ， Customer Expectation↑ ， Purchase Intention↑ ， Product cognition differences↓ ， Customer Satisfaction↑ ， Customer Demand→ ， Selective flexibility↑ ， Amount of ad↑ ， Product function↑ ， Product quality ↑ ， Service Diversity↑ ， Product properties↑ ； **CEO focus on sales or research E**)

[O_2] Achieve revenue of software increase =

fn (**Product Price↑**； Sales Amounts↑ ， Sales Volume↑ ， Product Cost↓ ； **CEO focus on sales or research E**)

[+/-P]：**Product Price** = fn (Sales Amounts、Market Factors、Enterprise Strategy)

4.4 Perform problem solving by parameter separation

4.4.1 PD

Parameter domination use compatible parameter to solve self-contradiction. The results of the problem solving are shown in Table 7.

Table 7 Parameter manipulation table - PD

System：Software companies			
Parameter domination (PD)			
O_1	**Customers willing to purchase software**	**O_2**	**Revenue of software increase**
$[O_1]$ Achieve customers willing to purchase software = fn (**Product Price**↓； Product information delivery effectiveness↑， Perceived value↑， Easy to use↑， Product Complexity↓， Technical Skill↑， Customer Expectation↑， Purchase Intention↑， Product cognition differences↓， Customer Satisfaction↑， Customer Demand→， Selective flexibility↑， Amount of ad↑， Product function↑， Product quality↑， Service Diversity↑， Product properties↑； **CEO focus on sales or research E**) **$[O_2]$ Achieve revenue of software increase** = fn (**Product Price**↑； Sales Amounts↑， Sales Volume↑， Product Cost↓； **CEO focus on sales or research E**) **[+/-P]**：**Product Price** = fn (Sales Amounts、Market Factors、Enterprise Strategy)			
Compatible Parameter	**CEO focus on sales or research E**	**Compatible Parameter**	**CEO focus on sales or research E**
Strategy	**Solution for solving self-contradiction**		
CEO focus on sales or research E	Persuaded the CEO to change the “technology-oriented” operation strategy in the past to the “technical-oriented” and “market-expanding-oriented” business strategy.		

4.4.2 IPV

The separation within parameter satisfies two contradictory demands (+P/-P) by different value domains of the same specific parameter (such as space, time, etc.). Some tools and method for Separation within parameters belongs to the traditional separation principle, and solves the problem with Darrell Mann's 40 inventive principle. This study is to add the separation of other self-variable parameters to assist in problem solving. The results of the problem solving are shown in Table 8.

Table 8 Parameter manipulation table IPV

<table>
<tr><td colspan="6">System：Software companies</td></tr>
<tr><td colspan="6">Separation within parameter - IPV</td></tr>
<tr><td colspan="2">Product Price =
fn (Sales Amounts、Market Factors、Enterprise Strategy)</td><td>Determinant Factor</td><td colspan="3">Sales Amounts、Market Factors、Enterprise Strategy</td></tr>
<tr><td>Contradictory Para.</td><td>Product Price</td><td>+P</td><td>Low Product Price</td><td>－P</td><td>High Product Price</td></tr>
<tr><td>TPQ</td><td>ANS</td><td>IP</td><td colspan="3">Solution for solving self-contradiction</td></tr>
<tr><td>Where do I want +P?
Where do I want –P?</td><td>Normal Demand Customer
Mass Demand Customer</td><td>1.2.3.17.13.14.
7.30.4.24.26</td><td colspan="3">(IP01): According to software function, divide our software into different module. Customers select some function modules suiting for their demand.
The software's price based on how many function module that customers select finally.</td></tr>
<tr><td>When do I want +P
When do I want –P</td><td>Promotion Not Promotion</td><td>15.10.19.11.16.21.
26.18.37.34.9.20</td><td colspan="3">(IP19): Provide a software of trial version in the period time (3-5 days), make our potential customer more realize our product and increase purchase intention.</td></tr>
<tr><td>What condition do I want +P?
What condition do I want -P?</td><td>Normal User
Professional User</td><td>35.26.1.32.36.2.
31.38.39.28.29</td><td colspan="3">(IP36): Company changes our product and service to provide integrated service that customer analysis or solution proposed to increase add-value of product.</td></tr>
<tr><td>Transition to super-sys.
Transition to sub-sys.</td><td>Other Commentary company
Other product dept.</td><td>Super : 5.6.22.23
Sub :
1.25.40.33.12</td><td colspan="3">(IP05): Collaborate with complementary software or other related software vendors to make products more performant. At the same time, discounts can be given to customers through the All-in-one package.</td></tr>
<tr><td>Other parameter</td><td>Separation domain</td><td colspan="4">Solution for solving self-contradiction</td></tr>
<tr><td>Marketing factor</td><td>Ahead of competitors
Lags behind competitors</td><td colspan="4">When companies are ahead of their competitors in the market, they can obtain more markets by decreasing the price of their products, thereby increasing the competitive pressure of competitors. When the product lags behind competitors, it analyzes the strengths and weaknesses of competitors' products, transforms their weaknesses into strengths of our product, improves product performance, and increases customers' willingness to buy.</td></tr>
</table>

4.4.3 CPS

Separation across parameter separates two contradictory demands (+P/-P or O_1/O_2) into different constituent parameters to satisfy simultaneously. When considering the solution of resolving the problem with parameter across separation, the problems can be solved by using the CPS problem solving strategy. The results are shown in Table 9.

Table 9 Parameter manipulation table -CPS

<table>
<tr><td colspan="4">System: Software company</td></tr>
<tr><td colspan="4">[CPS]</td></tr>
<tr><td colspan="4">[O] Achieve customers willing to purchase software =
1
fn (Product Price↓ ； Product information delivery effectiveness↑ ， Perceived value↑ ， Easy to use↑ ， Product Complexity↓ ， Technical Skill↑ ， Customer Expectation↑ ， Purchase Intention↑ ， Product cognition differences↓ ， Customer Satisfaction↑ ， Customer Demand→ ， Selective flexibility↑ ， Amount of ad↑ ， Product function↑ ， Product quality↑ ， Service Diversity↑ ， Product properties↑ ； CEO focus on sales or research E) [O]
Achieve revenue of software increase =
2
fn (Product Price↑ ； Sales Amounts↑ ， Sales Volume↑ ， Product Cost↓ ； CEO focus on sales or research E)
[+/-P] ：Product Price = fn (Sales Amounts 、Market Factors 、Enterprise Strategy)</td></tr>
<tr><td>P</td><td>Product Price</td><td>Splitting Para.</td><td>Normal Product’s Price (P+) Advanced Product’s Price (P-)</td></tr>
<tr><td>Strategy</td><td colspan="3">Solution for solving self-contradiction</td></tr>
<tr><td>[CPS]
$P \rightarrow P^{+}$ ， P^{-}</td><td colspan="3">Provide product of normal version to customers for free. However, when customers need to use advanced function, they should pay some fee to unlock some advanced function (High Price)</td></tr>
</table>

4.4.4 COPE

With COPE's problem-solving strategy, the user can let (P) to reach (+P) to meet first objective (O_1), and then to introduce exclusive parameter (E^2) to meet objective 2 (O_2)". See Table 10 below.

Table 10 Parameter manipulation table - COPE

System：Software company			
[COPE]			
[O_1] Achieve customers willing to purchase software = fn (**Product Price**↓；Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑；**CEO focus on sales or research E**) **[O_2] Achieve revenue of software increase** = fn (**Product Price**↑；Sales Amounts↑，Sales Volume↑，Product Cost↓；**CEO focus on sales or research E**) **[+/-P]**：**Product Price** = fn (Sales Amounts、Market Factors、Enterprise Strategy)			
P	Product Price	**Determinant factor**	Sales Amounts、Market Factors、Enterprise Strategy
O_1 Exclusive Parameter (E^1)	Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑	**O_2 Exclusive Parameter (E^2)**	Sales Amounts↑，**Sales Volume**↑，**Product Cost**↓
Strategy	**Solution for solving self-contradiction**		
[COPE] $P \rightarrow O_1$ $E^2 \rightarrow O_2$	**[Sales Volume]:** Elevate sales volume by setting low product price. Afterward, it makes more customers get used to operate our software. Finally, we charge some fee by another way(update…). **[Product Cost]**：Crowdsourcing, let customers or users propose some ideas and suggestion, and then realize what product our customers want. Furthermore, come up with some creative ideas.		

4.4.4 COEP

With COEP's problem-solving strategy, the user can let (P) to reach (-P) to meet second objective (O_2), and then to introduce exclusive parameter (E^1) to reach objective 1 (O_1). See Table 11 below.

Table 11 Parameter manipulation table - COEP

<table>
<tr><td colspan="4">System：Software company</td></tr>
<tr><td colspan="4">[COEP]</td></tr>
<tr><td colspan="4">[O_1] Achieve customers willing to purchase software =
fn (Product Price↓；Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑；CEO focus on sales or research E) [O_2] Achieve revenue of software increase =
fn (Product Price↑；Sales Amounts↑，Sales Volume↑，Product Cost↓；CEO focus on sales or research E)
[+/-P]：Product Price = fn (Sales Amounts、Market Factors、Enterprise Strategy)</td></tr>
<tr><td>P</td><td>Product Price</td><td>Determinant factor</td><td>Sales Amounts、Market Factors、Enterprise Strategy</td></tr>
<tr><td>O_1 Exclusive Parameter (E^1)</td><td>Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑</td><td>O_2 Exclusive Parameter (E^2)</td><td>Sales Amounts↑，Sales Volume↑，Product Cost↓</td></tr>
<tr><td>Strategy</td><td colspan="3">Solution for solving self-contradiction</td></tr>
<tr><td>[COEP]
$E^1 \rightarrow O_1$
$P \rightarrow O_2$</td><td colspan="3">[Perceived value]: Due to increasing value and function for product, Manager restructure our project team at first to let sales department join research project, and then, the salesperson will realize our product main value and function. Finally, they will increase purchase intention.
[Diversity Service]: In addition to sale software, we provide some value-added service to increase revenue. For example, consult, output some proposal or analyze date more deeply.
[Technical Skill]: Add some new internet technology in software, customers are able to upload and back-up their data or information to internet. In the meantime, all departments access and delivery data and information rapidly in the company.
[Selective flexibility]：Customers can tell us what function and interface they need to use, we will customize a new software for specific customer.</td></tr>
</table>

4.4.5 COEE

With COEE's problem-solving strategy, the user can introduce Exclusive parameter (E^2) to reach (O_2) to reach demand of objective 2 (O_2), and introducing exclusive parameter (E^1) to reach demand of objective 1 (O_1). See Table 12 below.

Table 12 Parameter manipulation table - COEE

<table>
<tr><td colspan="4">System：Software company</td></tr>
<tr><td colspan="4">[COEE]</td></tr>
<tr><td colspan="4">[O] Achieve customers willing to purchase software =
1
fn (Product Price↓；Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑；CEO focus on sales or research E) [O]
Achieve revenue of software increase =
2
fn (Product Price↑；Sales Amounts↑，Sales Volume↑，Product Cost↓；CEO focus on sales or research E)
[+/-P]：Product Price = fn (Sales Amounts、Market Factors、Enterprise Strategy)</td></tr>
<tr><td>P</td><td>Product Price</td><td>Determinant factor</td><td>Sales Amounts、Market Factors、Enterprise Strategy</td></tr>
<tr><td>O_1 Exclusive Parameter (E^1)</td><td>Product information delivery effectiveness↑，Perceived value↑，Easy to use↑，Product Complexity↓，Technical Skill↑，Customer Expectation↑，Purchase Intention↑，Product cognition differences↓，Customer Satisfaction↑，Customer Demand→，Selective flexibility↑，Amount of ad↑，Product function↑，Product quality↑，Service Diversity↑，Product properties↑</td><td>O_2 Exclusive Parameter (E^2)</td><td>Sales Amounts↑，Sales Volume↑，Product Cost↓</td></tr>
<tr><td>Strategy</td><td colspan="3">Solution for solving self-contradiction</td></tr>
<tr><td>[COEE]
$E^1 \rightarrow O_1$
$E^2 \rightarrow O_2$</td><td colspan="3">[Product properties、Product cost]：Analyze exist software what advantage and disadvantage that our software has. Furthermore, we enhance our advantage and compensate disadvantage to strengthen software. In the meantime, we focus on what main point that we should research. Finally, decrease cost of product indirectly.</td></tr>
</table>

5. Summary

In contrast to the self-contradiction method of the separation principle in the past, the method of parameter deployment and parameter manipulation (Parameter domination and Parameter separation) can help user to perform different strategies for problem solving (PD/CPS/COPE/COEP/COEE), and propose more and more comprehensive solutions to improve the problem-solving performance of the company. Table 13 below shows the case where the sales goal is not achievement for the study. The comparison of the parameter deployment and manipulation or the traditional separation principle, our study shows that the parameter separation and parameter domination can enhance 300% performance of solving problem. The new procedure and method we proposed is much better than traditional separation principle. In addition to the increase in the number of problem solving solutions, the solutions that separation principle propose are also bring up fully in the parameter domination and parameter separation. Therefore, the user don't worry about using parameter domination and parameter separation will cause solutions to be omitted. We extent our solutions and the important things is to old solutions are combined in our solution list.

Table 13 Performance comparable table

Method and Procedure	**The number of solutions**	**Performance and result**
Separation principle (Darrell Mann，2004)	8	
Parameter deployment and manipulation - Parameter Domination Parameter Separation (Daniel Sheu, 2017)	**24**	**Increase 300 %**

Reference

English Reference：

Mann, D.L. (2004). Hands on systematic innovation for Business and Management, CREAX press.

Mann, D.L. (2007). Hands on systematic innovation, CREAX press.

Royzen, Z. (1997). “Solving Contradictions in Development of New Generation Products Using TRIZ”,The TRIZ Journal.

Chinese Reference：

許棟樑 (2014)，萃智創新工具精進：上篇，亞卓國際顧問股份有限公司。許棟樑 (2017)，萃智商業管理創新：上篇，亞卓國際顧問股份有限公司。

蔡美惠 (2012)，「績效導向的觀點關係分析以辨識和解決組織衝突」，國立清華大學工業工程與工程管理研究所碩士論文。

葉俐靖 (2015)，「參數展開與操作：物理衝突的新解法」，國立清華大學工業工程與工程管理研究所碩士論文。

孫韻翔 (2016)，「物質-功能-屬性模型和參數操作法解物理衝突」，國立清華大學工業工程與工程管理研究所碩士論文。

The positive effects of using observation-based technique in cocreation to gain empathy in the healthcare service in Taiwan: a case study

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Abstract

The aim of this paper is to provide the design-thinking strategy to gain deeper empathy in patient care by using observation-based technique in the co-creation.

We compared photos of two steps to figure out significant points that different between them. The first step, design students did not use the observation-based tools to collect data. It was messy and did not have a system throughout notes in the first step. The data were collected is a surface of the problem. The second step, they used the observation-based technique (e.g. POEMS) to collect and organize date and then collaborated with nurses for fixing data. The information was collected and put in the POEMS chart. Their observations were structured and completely.

Based on the feedback and data analysis, POEMS tool is to evaluate and organize the data in the observation stage. It defines a range of field to let users observe broader and deeper. Using this tool also help them elicit people's experiences and thoughts. Moreover, participants directly knew the significant differences when they used POEMS that increase their confidence in creating and believe their facilitators. Additional, with the joining of experts, the data becomes completely that understand the patient needs and problems. The outcomes form the experiment improve the care for that patient or in health-care service development.

Keywords: co-design, design thinking, POEMS framework, user-centered

1. Introduction

"The interpersonal relationship between clinicians and patients is an epitome of human connection". Empathy in healthcare can help clinicians reach closer "the fulfillment of the need for affiliation and support" (Hojat, 2007). Empathy is the ability to understand and share the feelings of another, especially, a physician's attitude. It not only affect patients and their families but also ensure public trust in the medical profession (Riess, 2010). According to (Blane and Mercer, 2011), physician empath is an important matter that patients concern. The lack of empathy in healthcare leads to increase the number of low health literacy patients who not providing inaccurate or incomplete histories, missing appointments, failing to follow medication instructions (Chu and Tseng, 2013).

Applying design thinking in co-creation to solve the problems is a key process that increases empathy to define a problem and generate many solutions through ideation and prototyping (Suh et al., 2014). According tim Tim Brown, "design thinking is a human-centered approach to innovation", we hosted the co-creation workshop including design students and nurses. In that, nurses contributed their understanding and empathy, combining with design students who applied design thinking to find out the problems and optimal solutions. Otherwise, the previous papers did not use any tools for the purpose of empathy in patient care.

The aim of this paper is to provide the design-thinking strategy to gain deeper empathy in patient care by using observation-based technique in the co-creation. To prove it, part of collecting data was separated into two steps. The first steps, design students did not use any observationbased tool. The second step, design students used the observation-based technique (e.g. POEMS) to collect the data of patient's emotional, psychological and physical and collaborated and then collaborated with nurses for fixing data. Finally, we compared the results of two steps to investigate the positive effects of using observation-based tools and co-creation in healthcare system.

2. Literature review

▪2.1 Observation-based tool

This experiment is based on the observation-based as a technique for data collection (Miniard et al., 1991). Observation-based constitutes the first phase of the process and provide the basic information. According to Mead and Bower (2000), having a number of factors can affect to the reliability of any observation-based measure: "bias in the same sample, the experience and training of observers, and the degree of subjective judgment required when applying the measure".

One of the major intervention in this study was the implementation of the design thinking process using the POEMS to filter the data into “people”, “objects”, “environments”, “message/media”, “Services” groups. The POEMS framework is used to organize and more understand the data are collected with the observed activity (Kumar, 2004). Analyzing data can gain insight about user needs, requirements and behaviors.

▪2.2 POEMS framework

According to Kumar (2004), POEMS is a framework that helps user organize information and elements that connect with the observed activity. Analysis qualitative data from an organize information process can lead to a conclusion and action (Miles et al., 1994). It has five elements:

(1). People – who are in this situation

(2). Objects – things that people interact with

(3). Environments – it about the environment, space, light….

(4). Message/media – information that is being transferred during the activity.

(5). Services - a person or system offering services to enable the activity.

▪2.3 Collaborate sketch (C-sketch)

The collaborate sketch is the development and evaluation of a technique for generating ideas in collaborative design setting (Shah et al., 2001). This is a collaborate activity that requires group members to quickly sketch design solutions with couple minutes. Then, passing it to a different member. The activity finishes when each member has already done sketching. The main purpose of it is to create as many solutions as possible. With the limited time, each sketch was drawn is original thinking. Then, turning it to another member without any explanation that may appear to misunderstand. It leads to the next sketch is totally different from the previous sketches. This point is a mystery point of this method. It is useful to find out purely ideas.

When finished sketching, explanations are required for the participants to present their sketches. After that team members need to make a decision for voting and together develop sketches they chose.

3. Method

The methodology in this paper is a case study. The data was analyzed in the healthcare and design for their purpose. A workshop was hosted in three days. On the first day, participants went to Chang Gung nursing village and experienced the comparison process between the first step, participants do not use any observation-based tool. The second step, they can use the observationbased technique. On the second day, they observed the target users and used POEMS to take note and organize information. Next, each group showed their direction and received feedback from experts. On the third day, a final product was showed and got the comments from experts (Fig.1)

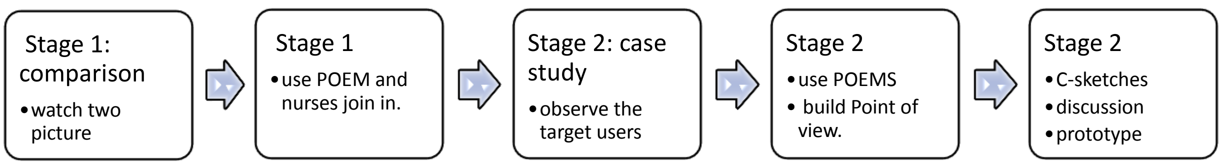

Figure 1. The experiment's process.

▪3.1 Stage 1: comparison

At the beginning of the process, the participants who are undergraduate and graduate students were separated into six groups. Each group was asked to observe two pictures and wrote down everything they saw on stick-note within ten minutes (Fig 2) (Fig 3).

Figure 2. Two Pictures that participants have to observe

Figure 3. Write down information and take note

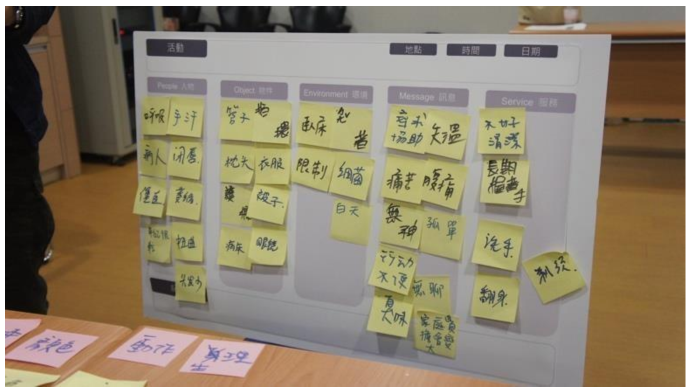

Figure 4. Separate information into POEMS

Facilitators introduced POEMS to participants on the second step (Fig 4). Then, they had a group discussion to pick up the notes they thought important and put on the POEMS chart. Finally, nurses who have experience in this field join this activity. They checked the POEMS and took out the things they thought are not important. With their experience, they added more notes that they thought are critical or the participants missed out (Fig 5). The workshop was taken photos in each step for collecting data.

Figure 5. Nurses joined in this step with pink notes.

▪3.2 Stage 2: case study.

Firstly, participants started with observation and experience step. They observed the elderly and wrote down everything they saw in POEMS. Next, they experienced bandage the fingers like the nurse makes the bandage for a spastic hand (Fig 1).

Secondly, they went back to the discussion. Then, information was separated into pain and gain. Key points were picked up to make the Point of View (Fig 6). In this step, they chose 10 key points to put on the POV's form. Each participant selected one to develop their own point of views. Then, they did collaborate sketch and turned around in a group to write down their ideas and functions.

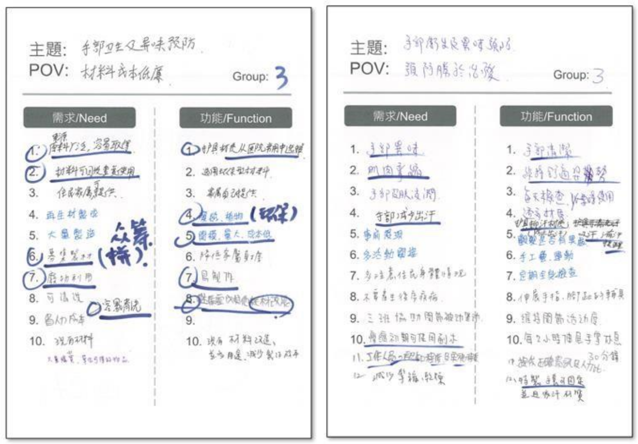

Figure 6. The point of view sketches.

Thirdly, it has a group discussion and voted some key points in each sheet. They had 5 needs and functions. Form that, they made sketches and had a short presentation to experts and received comments on the first generation idea. Based on this comments, they continued to work in group to make a prototype and the second generation idea.

After one week, they came back to the workshop and showed their work to discuss with experts for creating the final generation idea in this workshop. Finally, at the end of the day, they had a 20 minutes presentation for experts who are professional in nursing and design major to receive feedback and comment (Fig 7).

Figure 7. The 20 minutes presentation.

4. Result

▪4.1. Result of stage 1

We compared photos of each step to figure out significant points that differentiate between them. It was messy and did not have a system throughout notes in the first step. The data were collected is a surface of the problem. When moving to the second step, the information was collected and put in the POEMS chart. Their observations were structured. In the “people” area, the elements around human or patients that they observed in two pictures was filled in it such as “breath”, “younger”, “less hair” … were separated in object area. In the environment, the time is “day-time”, the “dust in the air” or “ limited space”. In additionally, for a message, the participants feel the patient in pictures “need help” because they can not do it by themselves. The fingers of a patient are closed fist that air can not ventilate and have high moisture to easy carry virus and having “bad smell”. Otherwise, the hand’s bandage needs to change everyday to keep hygiene that wasting money. Next, service is the final race, “not easy to clean”, “closed fist”, “wash hand”, “ turn over”… was filled in this area (Fig 8).

Figure 8. Separate information into POEMS

After the nurse checked and added more information, the data becomes completely with the expert recommends. They removed information not important in this situation and add more information such as “wind-stroke” was added into people area and “patient”, “anchylosis”, “Sweaty hands”. “trismus”, “spasticity”, “ben wrist” was kept in it. “Bandage” and “Scented sachet” was filled by a nurse in the object section. Next, environment section, “be a tie”, “dust in the air”, “limited space”, “lay down on a bed” was kept in this section. “degenerative arthritis”, “product”, “comfortable”, “blisters” was added by a nurse in Message part. Especially, a lot of information was added by nurses in service section such as “separate”, “dry”, “change”… (Fig 9).

Figure 9. Separate information into POEMS and nurses joined in it.

▪4.2. Result of stage 2: case study

Following the stage 2 of the process, the target customer is the patient with anchylosis who is difficult to open their hands. That leads to having a bad smell and infectious diseases. Additionally, it requires nurse or carers to spend a lot of time and force to clean patient hands and fingers. Those kinds of product do not available on the market, so nurses or carers have to create by themselves. Most of it can not be reused that waste materials and resources.

After observation patients, they found out needs such as “can be reused”, “easy to clean”, “Powerable” and “Universal Design”. Functions commensurate with needs are “removable and clean”, “deep clean”, “length adjustable” (Fig 10).

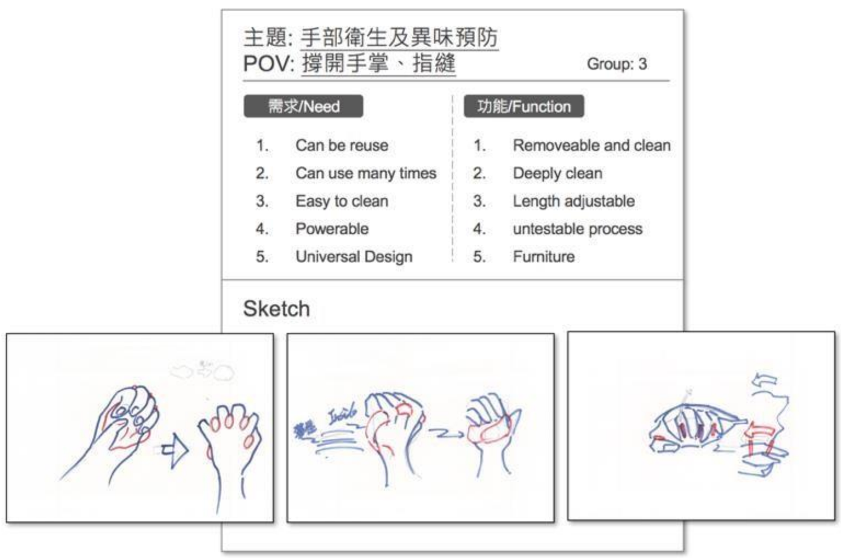

Figure 10. The needs and functions of target users.

For that, they designed objects to solve the bad smell problem, keep hygiene and prevent the consequences of spastic-hand. This is flexible and can use in anywhere. The purpose of Bubble Hand is to help open and ventilate patient’s hands. Eco-friendly plastic is used in the design which can reuse and non-toxic. With three materials can be selected to put inside are water, air, and cotton. When putting material inside, the product can be blown up and make the patient’s hands open. Combining ergonomic and elasticity materials, it brings comfortable for patients and time-saving for nurses or carers (fig 11).

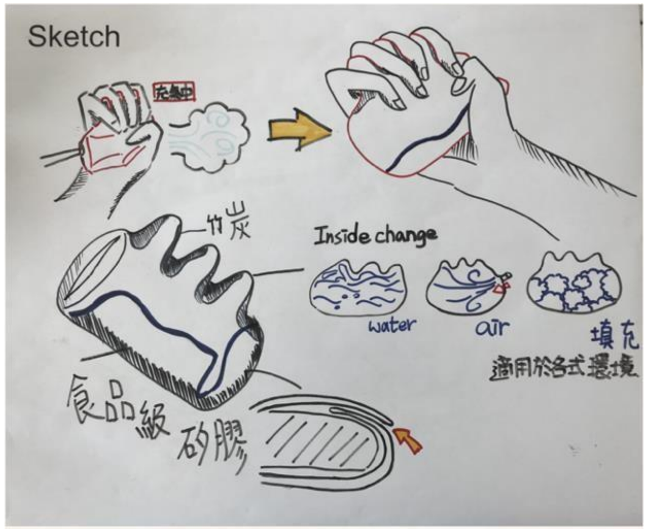

Figure 11. The sketching of product.

The using process of this product is simple. Firstly, putting it in patient's hand with a stable position. Secondly, blowing the product up by air. Finally, keeping it to let patient's hand ventilate that prevent the bad smell, carry virus and contagion (Fig 12).

Figure 12. The process of using Bubble Hand.

5. Discussion

The product – Bubble hand is the outcome they got through the process that observation, taking note, using POEMs to organize the information, building the point of view, sketching the first generations, discussion, developing the final products. Since, experts of nursing and design field were invited to give feedback. They appreciated Bubble Hand is the creative and useful product that focus on human-centered. Especially, it makes with eco-friendly materials and can reuse. Moreover, it also is an independent product with convenient, easy to use. Solving the spastichand problems with the material solution that let the gap of fingers ventilate, avoid the bad smell and keep hygiene.

On the hand, experts gave feedback and comment to participants that they need to spend more time to observe and research the spasticity patient to point out the best holding posture and the effective way to put material (air, water or cotton) inside product. The other problem is to protect users from carrying virus and contagion because of use by many users. Those of it is the limitation of this research for lack of time.

6. Conclusion

Based on the feedback and data analysis, POEMS tool is to evaluate and organize the data in the observation stage. It defines a range of field to let users observe broader and deeper. Using this tool also help them elicit people's experiences and thoughts. Moreover, participants directly knew the significant differences when they used POEMS that increase their confidence in creating and believe their facilitators. Additional, with the joining of experts, the data becomes completely to understand the patients needs and problems.

It is the early stage of developing a product which needs more time to research and development to become the final product. But the outcom of this stage (brainstorm stage) is significant and efficient to create the simple, creative and effective design – Bubble Hand. Solving the complex problems in a simple way by using the elasticity of material to let the spastic patients can open their hands and ventilate.

Apply this design-thinking strategy by using the observation-based technique in the cocreation, the outcomes form the experiment not only help the nurses or carers who take care the spastic-hand patients more efficient and time-saving but also improve the quality of care for that patient or in health-care service development.

▪Reference

Blane, D., and Mercer, S., Compassionate healthcare: is empathy the key? *Journal of Holistic Healthcare*, 2011, **8**(3).

Hojat, M., Empathy in patient care: antecedents, development, measurement, and outcomes, *Springer Science and Business Media*, 2007.

Kumar, V., *User insights tool. A Sharable Database for Global Research,* 2004. Retrieved from https://www.id.iit.edu/wp-content/uploads/2015/03/user-insights-tool-kumar_iwips2004.pdf

Mead, N., and Bower, P., Measuring patient-centredness: a comparison of three observation-based instruments, *Patient education and counseling*, 2000, **39**(1), 71-80.

Miles, M. B., Huberman, A. M., Huberman, M. A., and Huberman, M., Qualitative data analysis: An expanded sourcebook, 1994 (Sage).

Miniard, P. W., Bhatla, S., Lord, K. R., Dickson, P. R., and Unnava, H. R., Picture-based persuasion processes and the moderating role of involvement, *Journal of consumer research*, 1991, **18**(1), 92-107.

Riess, H., Empathy in medicine—a neurobiological perspective, *Jama*, 2010, **304**(14), 1604-1605.

Shah, J. J., Vargas-Hernandez, N., Summers, J. D., and Kulkarni, S., Collaborative Sketching (CSketch)—An idea generation technique for engineering design, *The Journal of Creative Behavior*, 2001, **35**(3), 168-198.

Suh, J., Peixoto, N., Seshaiyer, P., Lee, K. H., Jung, Y., and Suh, D., Using Design Thinking Tools to Promote Innovation in Engineering Students, *the International Conference on Engineering Education (ICEE 2014),* 2014.

Searching for Innovative Respiratory Rate Monitoring Devices: A case study and review of TRIZ Standard Solutions Class 4 and MAR Operator

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Abstract

Respiratory rate is a vital sign used to monitor the healthiness of human being. There have been many attempts to develop portable respiration rate monitoring devices in the past few decades, but there is no clear explanation of the development processes which can be called systematic innovation.

This paper aims at searching for innovative respiration rate monitoring devices using TRIZ (Theory of Inventive Problem Solving)'s systematic innovation tools of Standard Solutions Class 4 : Detection and Measurement. Many existing devices solutions including new ideas are reviewed and analyzed along with each of the Standard Solutions. More than 20 ideas and solutions come up and cover all the 17 standard solutions in class 4. Review and discussion are given at the end for future development of the tools and an innovative development process for medical device is proposed.

Keywords: Medical device, Product development, Systematic innovation, TRIZ standard solutions, MAR Operator.

1. Introduction

Respiratory rate is a vital sign used to monitor the healthiness of human being. An abnormal respiratory rate can lead to serious physical and mental illness. People are increasingly more concerned with their health than before and are looking for portable medical devices that can monitor their vital signs. Unfortunately, most of the portable medical devices in the market can monitor only heart rate, blood pressure and body temperature. There have been many attempts to develop portable respiration rate monitoring devices in the past few decades, but there is no clear explanation of the development processes which can be called systematic innovation.

This paper aims at searching for innovative respiration rate monitoring devices using TRIZ (Theory of Inventive Problem Solving)'s systematic innovation tools of Standard Solutions Class 4:

Detection and Measurement and MAR Operator to explore their strength for idea generation and to propose an innovative development process for medical device. The next 2 sections will give an overview of respiratory system and TRIZ's System of Standard Solutions together with MAR Operator.

The 4th section will deploy TRIZ Standard Solutions Class 4 and MAR Operator to search for innovative respiration rate monitoring devices. Result and discussion will be given on section 5 with the innovative development process for medical device proposed.

2. Respiratory System

In order to sustain life, human body need to produce sufficient energy. Energy is produced by the process of oxidation where food molecules are combined with oxygen to form carbon dioxide and water. Thus the human body must have an organ system designed to exchange carbon dioxide and oxygen which is called the respiratory system. The respiratory system inhales oxygen to enter the lungs and exhales carbon dioxide out of the body.

External air enters the respiratory system through the nose and mouth and passes down the pharynx and through the larynx. The entrance to the larynx is covered by epiglottis that automatically closes during swallowing to prevent food or drink from entering the airways. The trachea branches into two bronchi which lead to the lungs. The bronchi branch into bronchioles. Thousands of small air sacs called alveoli are at the end of each bronchiole. At the surface of each alveolus, a gas exchange between oxygen and CO2 takes place. The oxygen enters in the blood stream while the CO2 is exhaled into the atmosphere. With each inhalation, the autonomic nervous system in the brain sends nerve signal to the muscles of the diaphragm and the rib cage which causes them to contract. As a result, it creates more space in the thoracic cavity for the lungs to expand. This makes air pressure inside the lungs decreases below the air pressure of the air outside the body and causes the atmospheric air with oxygen to be inhaled into the lungs which expands the circumference of the chest and abdomen accordingly. And with each exhalation the diaphragm and rib cage muscles relax. This causes the lungs to return to their original volume. Air pressure is now reversed and so the air with carbon dioxide is exhaled. This decreases the circumference of the chest and abdomen as in Figure 1.

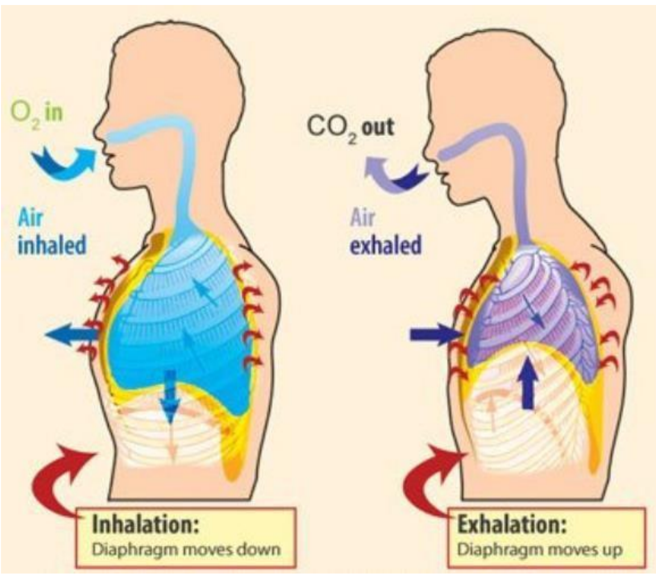

Figure 1. Inhalation and Exhalation of Respiratory System.

During each respiration cycle, there are changes in the parameters of substances and fields in the system and its' environment which can be detected and measured indirectly in order to determine the respiration rate as shown in Table 1.

Table 1. Parameters changes of substances and/or fields in the respiration system and its' environment.

Respiration system and its' environment	Parameters Changes of substances and fields
1. Movement of the lungs	1.1 Changes in the diameter and circumference of the chest and abdomen 1.2 Changes in the mechanical energy (pressure) and acoustic energy (sound) of the chest and abdomen
2. Air flow in and out through the airway	2.1 Changes in the humidity of air flow 2.2 Changes in the thermal energy (temperature), the mechanical energy (pressure) and acoustic energy (sound) of the air flow 2.3 Changes in CO2 level in the air flow
3. Exchanges of gas	3.1 Changes in CO2 level in the blood 3.2 Changes in O2 level in the blood
4. Co-ordination with other systems in the body	4.1 Changes in nerve signal from the brain 4.2 Changes in pumping signal of the heart

Parameters changes of substances and fields in the respiration system and its' environment in Table 1 can be utilized to generate ideas for development of innovative respiratory rate monitoring devices. But this will depend on the expertise of the development teams which is likely to be a trial and error process based on their knowledge and experience which is called psychological inertia.
Instead of using ones' limited knowledge and experience on trial and error, TRIZ provides a systematic ways to guide the problem solving process for a breakthrough innovation. The next sections will explain the mostly used TRIZ tool called System of Standard Solutions and use it to explore and ideate the possibilities using respiratory rate monitoring devices as case study.

3. TRIZ's System of Standard Solutions and MAR Operator

The System of Standard Solutions is developed by G. Altshuller between 1975 to 1985 to solve common inventive problems called standard problems (G. Altshuller, 1985). The System of Standard Solutions is used in conjunction with Substance-Field Modeling and Analysis to identify the initial problem situation and suggest suitable standard solutions (G. Altshuller et al, 1998). It consists of 76 Standards which are classified into 5 classes and 18 subclasses of with class 1 deals with improving interactions and eliminating harmful effects; class 2 deals with enhancing the efficiency of the system; class 3 deals with the evolution of the system; class 4 deals with detection and measurement; and class 5 deals with strategies in the application of the Standards (J. Terninko et al, 2000). Substance-Field

Modeling and Analysis reveals the problem types of which the corresponding class or subclass of standard solutions are deployed accordingly. The problem types are mainly divided into incomplete substance-field model; insufficient or inefficient useful function; harmful effects or interaction of the systems and finally detection and measurement problem (G. Cameron, 2010). The minimal number of components for a complete substance-field model of a technical system comprises two substances and one field, which forms a triangle through their interaction. Once a substance-field model has been formulated, a suitable solution can be searched for from the 76 Standards depending on the types of problems as in the simplified flow-chart based on the flow chart of N. Khomenko in Figure 2.

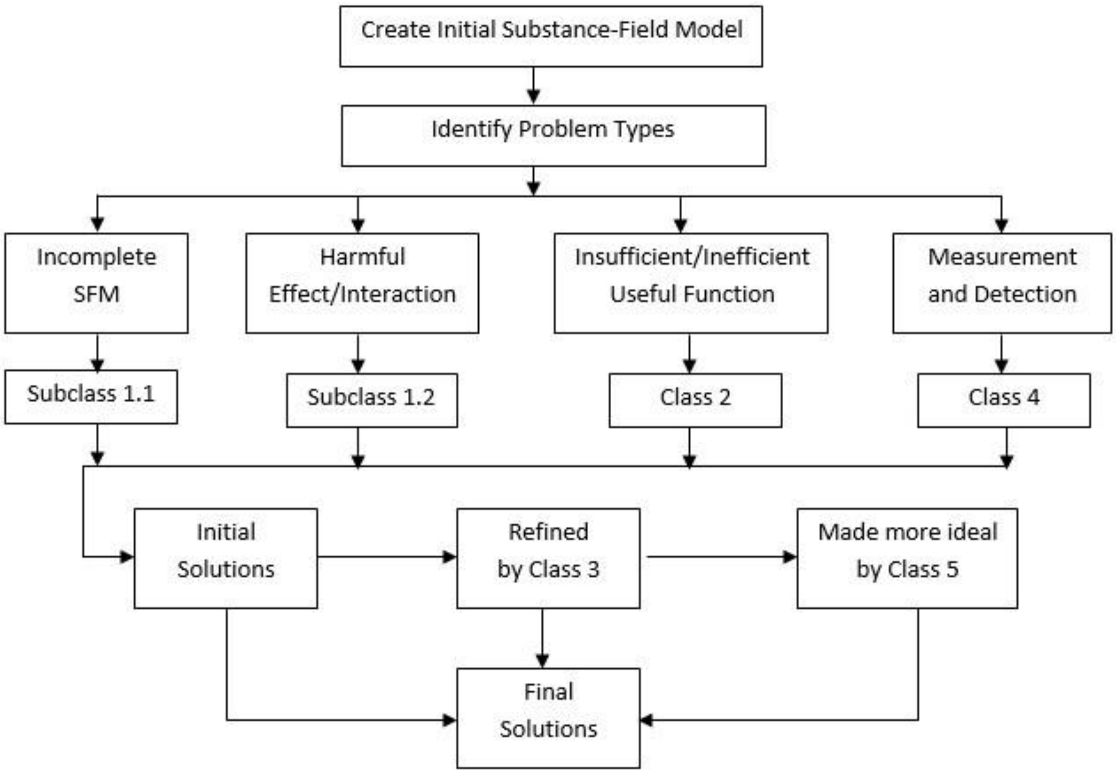

Figure 2. Flow-chart of applying 76 Standard Solutions (based on N. Khomenko**)**

In his previous study (T. Benjaboonyazit, 2016), the author has analyzed System of Standard Solutions and simplified it into MAR Operator for TRIZ beginners as in Table 2.

Table 2. The MAR Operator

Number	Operator Name	Description
1	M: Modify	Modify the existing substance and/or field in the initial Substance-Field Model and/or its environment.
2	A: Add	Add new substance and/or field into the initial Substance-Field Model.
3	R: Replace	Replace the existing substance and/or field in the initial Substance-Field Model with new substance and/or field.

In the next section, TRIZ's System of Standard Solutions will be deployed to generate ideas in searching for innovative respiration rate monitoring devices and MAR Operator will be used to refine the initial solutions.

4. Case Study and Review of Standard Solutions Class 4 and MAR Operator

Standard Solutions Class 4 consists of 5 subclasses which are divided into totally 17 standard solutions. Each standard solution will be explained along with examples of product solutions and research ideas for respiratory rate monitoring device after which MAR Operator will be used to refine the initial solutions.

4.1. Indirect Methods

4.1.1. Changing a problem

Modify the system in a way that eliminates the need for measuring or detecting it.

Example: Respiratory rate is measured to feedback to control an automatic ventilator. The system can be modified by utilizing nerve signal from the brain to the diaphragm to control the automatic ventilator directly without the need to measure respiratory rate. (F. T. Tehrani et al, 2008).

4.1.2. Operations with a copy of an object or a system

If it is impossible to apply Standard Solution 4.1.1. to a problem with detection or measurement, it is appropriate to manipulate a copy or photo of an object instead of the object itself.

Example: Instead of measuring respiratory rate by detecting directly thermal change of the exhaled air around the nose of the patient. An non-contact infrared imaging technique is used to select salient thermal features on the human face and analyze the change caused by respiration (Zhen Zhu et al, 2015). Nakajima et al. (2001) also used a static camera to detect thoracic movements to determine respiration rate.

4.1.3. Changing measurement problem to successive detection

Use 2 detections instead of continuous measurement, if 4.1.1 or 4.1.2 cannot be used.

Example: In respiration process, air is breathed in and out through the airway which creates acoustic sound to the nearby tissues. Doctors use stethoscope to listen to this sound and measure the respiratory rate by counting for 30 second. Instead of this long time measurement, we can just measure the time interval between the first 2 consecutive peak and estimate the respiratory rate as in Figure 3. The normal respiratory period should fall between 3.0-4.3 seconds.

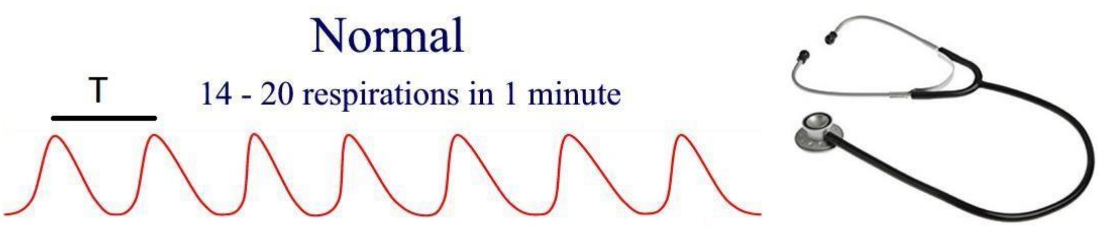

Figure 3. Estimate the respiratory rate using 2 consecutive measurement.

4.2. Building Measurement Su-Field Models

4.2.1. Synthesis of a Measurement Substance-Filed System

If an incomplete Su-Field Model is difficult to measure or detect, the problem can be solved by completing a regular or double Su-Field Model with a field at an output

Example: The exhaled gas contains heat which cannot be measured directly. A temperature transducer (thermistor) is placed near the nostril to be warmed by exhaled gas. The resistance of thermistor will change in response to the temperature change which can be measured by the change in electric current passing through it. The data can be processed to determine respiratory rate (Maneesh Gupta et al, 2013),

4.2.2. Introduction of easily detectable additives to a system

If a system or its part is difficult to detect or measure, the problem can be solved by transitioning to the internal or external complex Su-Field Model with the introduction of easily-detected additives

Example: The exhaled gas contains moisture which cannot be measured directly. A humidity sensor is placed near the nostril to absorb moisture in exhaled gas. The conductivity of the humidity sensor will change as the function of the moisture or humidity which can be measured with the change in electric current passing through it. The data can be processed to determine respiratory rate (Hailong Yan et al, 2016).

4.2.3. Introduction of easily detectable additives to the environment

If a system is difficult to detect or measure at certain moments in time, and it is impossible to introduce additives, additives capable of generating an easily-detected field should be introduced into the environment; changes in the state of the environment will provide information about changes in the system

Example: Pressure sensor arrays are attached on the surface of the bed which can be considered as the environment outside the respiratory system. Pressure sensor is made of Force Sensing Resistors (FSRs) which will change it value in response to the force or pressure of the respiration cycle delivered to it. The data is measured and processed to determine the respiration rate (Yoshifumi Nishida et al, 1998).

4.2.4. Obtaining easily detectable additives from the environment

If additives cannot be introduced into the environment of the system as in 4.2.3, then create them by decomposing or changing the state of something that is already in the environment, and measure the effect of the system on these created additives

Example: Air around the body of patients can be considered as dielectric material between 2 electrodes of a capacitor, one uses the body as electrode, the other one is made of mesh screen conductor placed at a fixed distance from the patient's torso. The value of capacitance varies due to body surface area changes during respiratory activity and can be measured and processed to determine the respiration rate (Robert E. Barrow et al, 1969).

4.3. Enforcing Measurement Su-Field Models

4.3.1. Use of physical effects

The effectiveness of measurement and/or detection in a Su-Field Model can be enhanced by utilizing physical phenomena

Example: Physical phenomena such as strain gauge which works by changing resistance when stretched can be used to strap around a patient's chest or abdomen, it will convert the expansion and contraction of the rib cage or abdominal area to a rise and fall of the signal which respiratory rate can be calculated (Neema M., 2011).

4.3.2. Exciting resonance oscillations

If it is impossible to directly detect or measure changes in a system, and passing a field through the system is impossible as well, the problem can be solved by generating resonance oscillations of either the system as a whole or a part of it; variations in oscillation frequency provide information about changes in the system

Example: Impedance pneumography is a bioimpedance recording for indirect measurement of respiration. Using superficial thoracic electrodes, the impedance pneumography measures respiratory volume and rate through the relationship between respiratory depth and thoracic impedance change. Four electrodes are used, two for injecting high frequency current into the thorax and two for measuring voltage drop along the current path which impedance changes, accordingly respiratory volume and rate can be calculated. Variations in current frequency are tested to determine the optimal ranges of measurement for different tissue structure models (Shweta V. Potdar et al, 2016).

4.3.3. Detecting change in the natural frequency

If applying Standard Solution 4.3.2 is impossible, information about the state of the system can be obtained via free oscillations of an external object or of the environment linked to the system.

Example: A pair of ultrasonic transmitter and receiver can be placed in the environment between the patient during sleep to measure respiratory rate non-contactly. The device measures the frequency shift produced by the velocity difference between the exhaled air flow and the ambient environment, i.e., the Doppler effect as in Figure 4 (Philippe Arlotto et al, 2014). The same result can also be achieved by measuring the received signal strength (RSS) of the RF transmitter and receiver pair placed between the test subject (Ossi K et al, 2014).

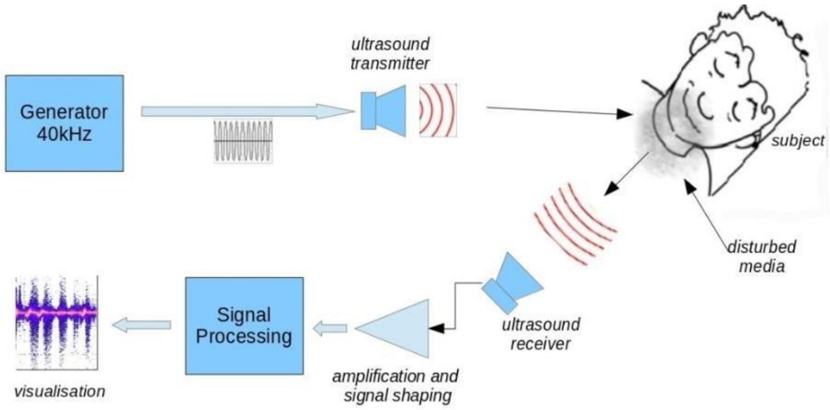

Figure 4. An Ultrasonic Contactless Sensor for Breathing Monitoring (Philippe Arlotto et al, 2014).

4.4. Transition to Ferro-Field Models

4.4.1. Use of a ferromagnetic substance and a magnetic field

Add or to make use of a ferromagnetic substance and a magnetic field in a system (by means of permanent magnets or loops of electric current) to facilitate measurement.

Example: Magnetic particles or magnetic dust inhaled into the lung are harmful, but it can perform useful functions for studying the lungs performance or measuring respiratory rate derived from the changes of magnetic field due to the respiratory activity.

4.4.2. Replacing substances with ferromagnetic particles

Add magnetic particles to a system or change a substance to ferromagnetic particles to facilitate measurement by detection of the resulting magnetic field

Example: Instead of using the harmful magnetic particle, eddy current can be induced into human body like the thorax using external excitation coil. Eddy current can be regarded as magnetic particle in terms of the magnetic field it creates. The change in conductivity of the thorax can be monitored by impedance measurements based on eddy current induction without any need for contact between instrumentation and body as in the Figure 5 (D. Teichmann et al, 2010).

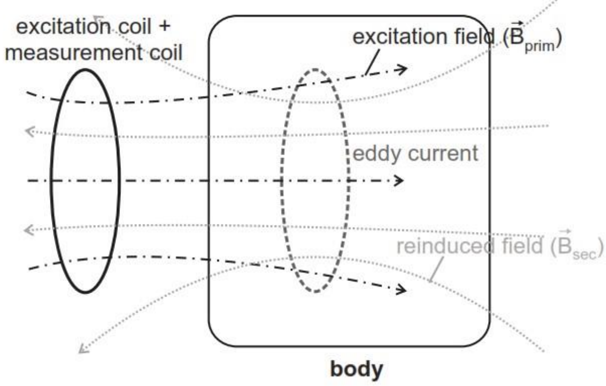

Figure 5. Respiration monitoring based on magnetic induction using a single coil (D. Teichmann et al, 2010)

4.4.3. Introducing ferromagnetic additives in the substance

If the effectiveness of measurement and/or detection can be enhanced via transitioning to a Ferro-Field Model, but substance substitution with ferromagnetic particles is prohibited, this transition can be performed by creating a complex Ferro Field Model through the introduction of additives into the substance.

Example: In measuring respiration air volume, changes in the diameters of the thorax and abdomen is monitored by putting transmitter coils to the back of the patient below the rib cage and abdomen, and receiver coils to the front surface of the rib cage and abdomen. Analog circuitry drives the transmitter coils to create change of magnetic field which induces voltage on the receiver coils which are proportional to the diameters of the abdomen and rib cage, respectively. Respiration air volume can be estimated along with respiratory rate as in Figure 6 (Michael D, 1981)

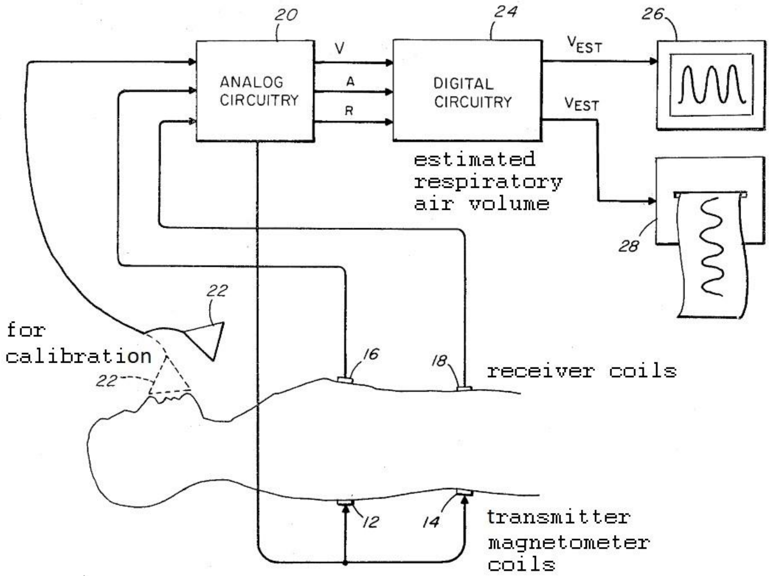

Figure 6. Respiration air volume measurement by induction coils (Michael D, 1981)**.**

4.4.4. Introducing ferromagnetic additives in the environment

If the effectiveness of measurement and/or detection can be enhanced via transitioning to a Ferro-Field Model, but the introduction of ferromagnetic particles is prohibited, the particles should be introduced into the environment

Example: Magnetic particles can be mixed into fabric yarns woven into T-shirt fitted to the body. Changes of magnetic field profile due to movement of the chest can be monitored and processed to determine the respiratory rate.

4.4.5. Use of physical effects occurring on Ferromagnetic systems

The effectiveness of a measurement and/or detection Su-Field Model can be enhanced by applying physical phenomena such as, for example, the Curie effect, Hopkinson effect, Barkhausen effect, magneto-elasticity, etc.

Example: Utilizing hall effect by attaching a pair of permanent magnet and hall effect sensor onto the chest or abdomen to measure the changes of magnetic field due to the movement of the chest or abdomen caused by respiratory activity.

4.5. Direction of Evolution of Measurement Systems

4.5.1. Formation of bi and poly systems

The effectiveness of a measurement and/or detection Su-Field or Pre-Ferro-Field Model at any stage of evolution can be enhanced by building a bi- or poly-system.

Example: CO2 in exhaled gas can be detected by using technique of Non-Despersive Infrared Sensor (NDIR) which consists of IR lamp, sample chamber, optical filter and IR detector. During each inspiration and expiration cycle, the system measures the IR intensity that reach IR detector after being absorbed by CO2 at certain wavelength. Changes in CO2 concentration or partial pressure can be measured and respiration rate can be calculated accordingly. To increase the accuracy of the measurement, another set optical filter and IR detector for different wavelength of gas (usually N2) is used for reference channel as in the Figure 7. (Dhrupesh S Shah et al, 2016).

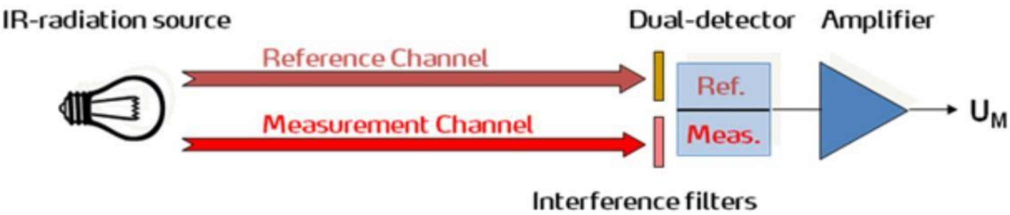

Figure 7. NDIR Gas Sensor (Source: http://www.eoc-inc.com)

Another example can be raised by Respiratory Inductance Plethysmography (RIP) which uses 2 inductive belts to strap around the chest and abdominal wall to improve the accuracy of respiration air volume and respiration rate measurement (GG Mazeika et al, 2007).

4.5.2. Measuring the derivatives of a function

Instead of a direct measurement of a phenomenon, measure the first and second derivatives in time or in space.

Example: The expansion and contraction of the chest or abdomen during respiratory activity can be used to drive a small dynamo to generate electromotive force which equals to the rate of change of the magnetic flux which is proportional to the rate of change of the circumference of the chest or abdomen. Instead of measuring the circumference of the chest or abdomen, the first derivative of the circumference can be measured to calculate air volume and respiratory rate. (Bryson P. et al, 2013).

All the ideas and initial solutions attained above can be further refined and idealized to be more effective and harm-free systems using standard solution class 3 and class 5 for those who are keen on TRIZ or using the simplified MAR Operator for TRIZ beginners as will be demonstrated with the initial solution in 4.4.3 as below.

The problems can be identified as the inefficient useful function of inducing electromotive force between Transmitter Coil and Receiver Coil. The initial substance-field model can be created as in

Figure. 8, with Magnetic Field interacts with Transmitter Coil as Tool (S2) and Receiver Coil as object (S1) to induce inefficiently electromotive force on Receiver Coil.

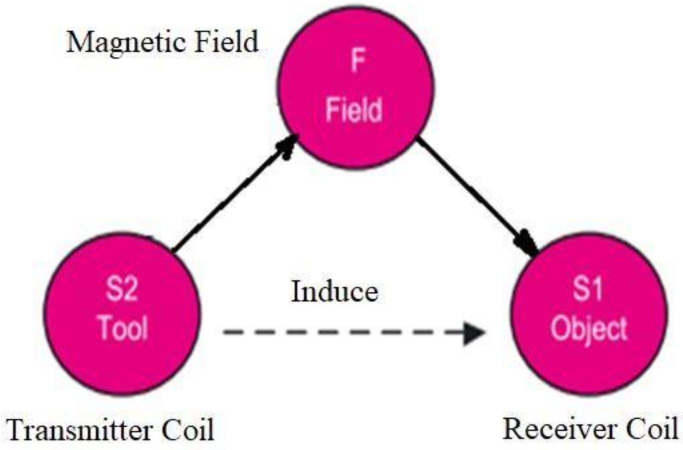

Figure 8. Initial substance-field model of insufficient useful function

The MAR Operator in Table 2 is deployed for the initial substance-field model in Figure 8 and the ideas are generated as in Table 3.

Table 3. The MAR Operator and Ideas generated for improving magnetic induction

MAR Operator	Component	Ideas generated
Modify	Field	1. Use resonance frequency.
	Substance	2. Divide transmitter coil into multiple sets of coil.
Add	Field	-
	Substance	3. Add capacitor in the receiver coil to match the frequency of the transmitter coil.
Replace	Substance and Field	4. Replace the system with capacitor electrodes attached between the back and front of the chest and abdominal wall, and measure the change in electric field.

5. Result and Discussion

Standard solutions class 4: measurement and detection is used it to explore and generate ideas using respiratory rate monitoring devices as a case study. The result is quite satisfactory with 20 ideas and solutions coming up and covering all the 17 standard solutions in class 4. Although some of the ideas and solutions are already in the market and some are under research and development without relying on TRIZ. It is the author's belief that with TRIZ's systematic innovation tools, the problems can be analyzed and the solutions can be reached systematically covered all the possibilities with more efficiency and shorter lead time.

With this case study of respiratory rate monitoring devices, the standard solutions in class 4 is reviewed and the results prove that all the standard solutions in class 4 are innovative guidelines for ideas generation and problem solving. Although some of standard solutions might sound duplicated such as standard solution 4.3.1 and 4.4.5 which should be grouped together as “applying physical phenomena, or scientific effects”, it is understandable that using magnetic materials and magnetic field for engineering problem solving is very popular in the past so much as the subclass 4.4 Transition to Ferro-Field Models is dedicated to it and applying magnetic phenomena, or scientific effects is separated from 4.3.1 to emphasize in standard solution 4.4.5. However, the standard solutions in subclass 4.4 are still useful and applicable to both engineering systems and physiological systems as shown in the examples above.

The subclass 4.5 Direction of Evolution of Measurement Systems has 2 standard solutions, i.e. 4.5.1 Transition to Bi- and Poly-Systems and 4.5.2 Direction of Evolution which seems too specific and narrow. It should be broadened to cover more directions of evolution to help generate more ideas, such as evolution toward Micro-Levels and increased use of fields which stated that Technological systems tend to transition from macro-systems to micro-systems, and during this transition, different types of energy fields are used to achieve better performance or control (as in the case of respiratory rate monitoring devices, it might give hints to idea of LASER as the transition from mechanical, thermal, chemical, electrical and magnetic energy) or the law of coordinating rhythms of system’s parts might give hints to derive the respiratory rate from Electrocardiogram (ECG) which is based on the fact that respiration has a modulating effect on the ECG.

The initial solutions ideated from of the Standard Solutions Class 4 might not be the best solutions and should be refined by Class 3 and idealized by Class 5 as suggested by N. Khomenko in Figure 2. For those who are not keen on TRIZ, the simplified MAR Operator for TRIZ beginners can be used as effectively as demonstrated with the initial solution of 4.4.3 in the previous section.

The idea generation and problem solving process used in this study can be generalized to be utilized in the development of other medical devices, besides the respiratory rate monitoring device. The generalized development process can be summarized into three major parts, i.e., the analysis of the physiological system to identify parameter changes of substances and/or fields in the system or its’ environment due to the activity of measurement target, the deployment of the Standard Solutions Class 4 to explore all possibility and generate ideas using each standard solution as guidelines and the refinement of initial solutions using MAR Operator to improve the useful function and/or eliminate harmful function as shown in Figure 9.

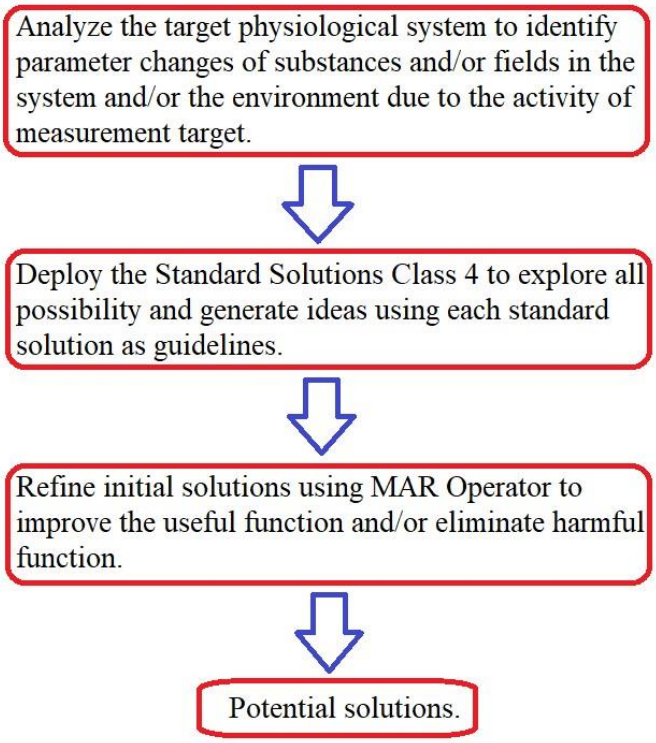

Figure 9. The generalized development process for medical devices

6. Conclusion

TRIZ is originated in engineering system patents studies to formulate database and principles governing directions of evolution and creative problem solving. It can also be applied to biological system, especially physiological system concerning the detection and measurement of human body signal.

This paper aims at searching for innovative respiration rate monitoring devices using TRIZ's systematic innovation tools of Standard Solutions Class 4 and MAR Operator. The result is quite satisfactory with 20 ideas and solutions come up and cover all the 17 standard solutions in class 4. All the 17 standard solutions in class 4 are reviewed and discussed. An example of refining the initial solution by MAR Operator is demonstrated to attain potential solutions. Finally, the generalized development process is proposed for medical devices. Future studies will be required for other medical devices.

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Reference

Bryson P. et al, (2013). Electromagnetic Biosensing of Respiratory Rate, IEEE Sensors-8215.

D. Teichmann, J. Foussier, and S. Leonhardt, “Respiration monitoring based on magnetic induction using a single coil,” in IEEE Biomedical Circuits and Systems Conference (BioCAS), Paphos, Cyprus, 3-5 Nov 2010, pp. 37–40.

Dhrupesh S Shah et al, Development & Characterization of NDIR based CO2 Sensor for Manned Space missions, Proc. of SPIE 2016, Vol. 9880 98801H-1 .

F. T. Tehrani, “Automatic control of mechanical ventilation. Part 2: the existing techniques and future trends,” Journal of Clinical Monitoring and Computing, vol. 22, no. 6, pp. 417–424, 2008.

G. Altshuller, B. Zlotin, A. Zusman, and V. Philatov “Substance-Field Analysis,” in Tools of Classical TRIZ. Ideation International Inc., 1998, ch. 6, pp 100-108.

G. Altshuller. (1985). 76 Standard Solutions, translated and edited by Shinsuke Kuroswa. (2013) [Online]. Available: http://www.trizstudy.com/altshuller1988.html

GG Mazeika, R Swanson, Respiratory inductance plethysmography an introduction, - Pro-Tech Services Inc., Mukiteo, WA, USA, Tech. Rep, 2007.

Gordon Cameron. “Inventive Standards and Su-Field Modeling,” in Trizics: Teach yourself TRIZ, how to invent, innovate and solve "impossible" technical problems systematically. TRIZICS.COM, LLC, 2010, ch. 8, pp 133-159.

Hailong Yan, Li Zhang, Ping Yu, and Lanqun Mao, Sensitive and Fast Humidity Sensor based on a Redox Conducting Supramolecular Ionic Material for Respiration Monitoring,Anal. Chem., 08 Dec 2016.

J. Terninko, E. Domb, and J. Miller, The seventy-six standard solutions, Classes from 1 to 5, TRIZ Journal, 2000.

K Nakajima et al, Development of real-time image sequence analysis for evaluating posture change and respiratory rate of a subject in bed, Physiol. Meas. 22 (2001) N21–N28.

Maneesh Gupta, Hana Qudsi, Low-Cost, Thermistor Based Respiration Monitor' 39th Annual Northeast Bioengineering Conference, 2013.

Michael D. Goldman, MEASURING RESPIRATORY AIRVOLUME, United States Patent, Patent Number 4,258,718, Mar. 31, 1981.

N. Khomenko, How to use Standard Solution, [Online]. Available: http://triz.co.kr/TRIZ/frame.html

Neema M, Peripheral Paced Respiration Influencing User Physiology during Information Work, UIST’11, October 16–19, 2011.

Ossi K, Neal P, Non-invasive Respiration Rate Monitoring Using a Single COTS TX-RX Pair, IEEE 978-1-4799-3146-0/14, 2014.

Philippe Arlotto, Michel Grimaldi, Roomila Naeck, Jean-Marc Ginoux, An Ultrasonic Contactless Sensor for Breathing Monitoring, Sensors 2014, 14, 15371-15386.

Robert E. Barrow, Arthur J. Vorwald, Capacitance Respirometry, Archives of Environmental Health: An International Journal, 19:4, 579-585, 1969.

Shweta V. Potdar et al, Monitoring Breathing Rate using Bio-impedance Technique, International Conference on Computing Communication Control and automation (ICCUBEA), 12-13 Aug. 2016.

T. Benjaboonyazit, Simplification of System of Standard Solutions for TRIZ beginners using MAR Operator, Proceedings of TRIZfest 2015, September 10-12.

Yoshifumi Nishida etal, Unrestrained and Non-invasive Monitoring of Human's Respiration and Posture in Sleep Using Pressure Sensors, Journal of The Robotics Society of Japan, Vol. 16 No. 5, pp. 705～711, 1998.

Zhen Zhu, Jin Fei, Ioannis Pavlidis, Tracking Human Breath in Infrared Imaging, Proceedings of the 5th IEEE Symposium on Bioinformatics and Bioengineering , 2015, 0-7695-2476-1/05.

Exploring the Formulation of Book Pricing Strategies with a TRIZ Approach to Business Management

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Abstract

This study first explores the factors that influence the pricing of e-books and physical books, and then book pricing strategies formulated with a TRIZ approach to business management. In this study, the conflict points of book pricing are spotted first, namely exchange rate fluctuation, market share, update speed, penetration price, preferential activity, and differential price. The corresponding positive and negative effects for the six conflict points are identified respectively. Next, the corresponding parameters for the positive and negative effects are used to identify each parameter's corresponding TRIZ-based principle of invention respectively. The principles of invention are then used to formulate book pricing strategies. Finally, the book pricing strategies are recommended to the publishing industry as a reference for new book pricing.

Keywords: Book pricing strategy, TRIZ approach to Business Management, TRIZ-based principles of invention, Publishing Industry

1. Introduction

The development of the globalized publishing industry faces multiple challenges that change quickly. The factors that influence book pricing not only involve markets and competitors, but also those such as interdependence, supply and demand between the publishing industry and readers.

Take the book market in Taiwan in 2015 for example. The publishing industry market for physical books (upstream) is estimated to be NTD 19.93 billion, and that for bookstores (downstream) is estimated NTD 23.85 billion. The e-book publishing industry (upstream) is estimated to be NTD 0.32 billion while the digital dealer market (downstream) is estimated to be NTD 0.61 billion. With a market worth nearly NTD 45 billion, how to use pricing strategies to create a competitive pricing niche for books is the key issue for this study. E-book pricing models are divided into five categories: long tail theory, brand value, reader positioning, product life cycle, and free pricing. Paper book pricing models are also divided into five types, namely demand elasticity, resale price maintenance system, production cost, psychological pricing and competitor pricing.

This study aims to formulate strategies for book pricing with TRIZ-based principles of invention, which will have been spotted with the positive and negative effects of the conflict points. The conflict points will be found out with the TRIZ approach to business management, which is detailed in the book Hands on Systematic Innovation by Darrell Mann (2004).

2. Literature Review

Book prices were determined by previous experiences of the supplier and the demander of the book market. Nowadays, the factors that influence book pricing are determined by expert judgments, customer surveys, historical data analysis, etc. Consequently, the pricing will differ along with the changes of customer habits, competitive positions, distribution channels, and national conditions. Books are divided into physical books and e-books when they are priced with different pricing strategies. In this way, the publishing industry and readers are both able to maximize their profits and needs. Therefore, the study will discuss the pricing strategies for e-books and physical books, respectively.

▪2.1 E-book pricing strategy

E-books are referred to the published physical books whose words, pictures and images are digitalized and presented with multimedia. Consequently, the e-books are interactive, and they have hyperlinks and can be retrieved. E-book pricing strategies consist of long tail theory, brand value, reader positioning, product life cycle and free pricing.

2.1.1 Long Tail Theory

The Long Tail Theory is founded on the 80/20 Rule. The theory enables businessman to continue making profits until in the late phase of sales so that a considerable profit can be obtained by multiplying the long-tailed niche commodity with a very low unit price. Based on the Long Tail Theory, two strategies can be formulated for e-books, namely bundling pricing and custom pricing.

Bundling pricing refers to the strategy that a sales system will automatically recommend relevant e-books when customers buy one, and the customers enjoy discounts if they buy the recommended books. The more e-books they buy, the lower the unit price for the e-books will be. In this way, the consumers are led to buy more e-books at a time. As for custom pricing, it means that various customized supplies and demands can prolong the long tail of the e-book sales without limits. Online bookstores can analyze the interest, profession and educational needs of the consumers with their purchase records. With that, the bookstore will customize book information for them, which will be sent to them by e-mail or by phone message. In this way, promotional information of the similar and relevant books is sent to the previous consumers so as to promote sales.

2.1.2 Brand Value

Brand value is an intangible asset for enterprises, which represents the enterprises' reputation, brand image, consumers' recognition for the brand, and consumers' loyalty to the brand. A successful brand will help the enterprise spot its position in the market and its own strengths and weaknesses when compared to other brands. If consumers like the brand and they are willing to buy, they will buy its new arrivals. For instance, consumers will wait in a queue to buy NIKE sneakers that are newly issued products. Similarly, the brand value of e-books is closely related to their pricing strategy.

2.1.3 Reader positioning

The publication of e-books needs to take into account the needs of readers. When they are published, they need to be properly positioned. The introduction of the books should be concise yet powerful. If they can satisfy the needs of the readers, they can sell a good price.

2.1.4 Book life cycle

The life cycle refers to the process in which a book enters into the market and then exits the market. The process includes four stages, namely market entry, growth, maturity and recession. Jin-Zhao Liu (2009) put forward suggestions and strategies for pricing strategies with the theories like marketing, product life cycle, and the demand of book users.

2.1.5 Free pricing

The price mechanism of free pricing is that the buyer and the seller determine the price together by way of bargaining. They decide on the final price for the book based on their objective judgment for its value. The key for the seller to make a profit lies in how to properly price e-books. Generally speaking, the prices for e-books are often low at first and later their prices are raised, for the seller means to make consumers get used to pay for the e-books first. Later he raises the price slowly. In this way, the publishers make a profit.

2.2 Physical book pricing strategy

Physical books are the ones with writing and printing as their media, enabling readers to leaf it through at any time and leaf it back and forth. The pricing strategies for physical books include demand elasticity, resale price maintenance system, production cost, psychological pricing and competitor pricing.

2.2.1 Demand Elasticity

Demand elasticity means the demand for a product changes along with the prices. The more substitutes a good has, the bigger its elasticity will be. The paper book is a commodity that lacks price elasticity. Usually, manufacturers increase sales revenue by raising prices. However, the price elasticity for diverse types of paper books is different. For instance, the price elasticity of textbooks is lower than that for educational reference books. The elasticity for the popular books about recipes, health and others is higher than that for professional books. That is why popular books are sold at a relatively low price.

2.2.2 Resale Price Maintenance System

Resale price maintenance refers to the price at which a fixed counterparty resells a commodity to a third party. The pricing of paper books is influenced by the diversification of the layout and the enthusiasm of the authors. As long as the books possess specialty, and of cultural and public nature, and the market mechanism is used flexibly, they will be able to exert effects on the pricing.

2.2.3 Production Cost

As for the pricing based on production costs, the price of a paper book is set according to actual production costs and appropriate profits. It has two pricing methods: one is cost-based pricing and the other is target profit pricing. The former is a pricing method based on the cost of a single book plus a certain percentage of profits. That is to say, the price of a single book = the cost of a single book * (1+ profit margin). The pricing of a paper book = (the price of the book + the royalty) * 3 or 2.5. The latter is the target profit pricing method. According to this method, a paper book is determined based on its total cost, target profit, and expected sales volume, namely the price of a paper book = (total cost + target profit) / expected sales volume. The advantage of the approach is that the target profit can be realized as long as the sale of the book reaches the expected sales volume.

2.2.4 Psychological pricing

The so-called psychological pricing is a pricing approach with the use of readers' psychology and their concept of prices. There are three specific practices for the psychological pricing. (1) Mantissa pricing: an integer is not chosen as a price, but 9 is taken as the mantissa of the price. In this way, the consumers will produce an illusion that the price is not high. (2) Integer pricing: the mantissa of the price is 0. This practice is often applied to high-end, high-value, and high-quality paper books. (3) High-price strategy: for those books which are treasured or preserved copies, or short-lived publications, they are often high priced. Usually, there are often limited copies for the books. In this way, a considerable profit can be achieved in a short-term.

2.2.5 Competitor pricing

Competitor pricing is based on the publication prices of market competitors. The price of paper books is set above the competitive price within the industry. In addition, the publishing industry will reserve profits for downstream bookstores when pricing to prevent the paper book from being unsalable.

This study uses the TRIZ approach to business management to draw up a book pricing strategy. This section first discusses the TRIZ theory and the TRIZ principles of invention. Later, it explains how to combine the pricing strategy with the principles.

3. Methodology

3.1 TRIZ Theory and Principles of Invention

TRIZ is the abbreviation of Teoriya Reahniya Izobretatelskikh Zadatch, the name of the theory in Russian. It means an inventive problem-solving theory. It was translated into English as Theory of Inventive Problem Solving, which means innovative problem solving theory. The TRIZ theory was developed into an analytical problem solving tool, which contains 39 engineering parameters, contradictory matrix, 40 principles of invention and the Algorithm of Invention Problem Solving (ARIZ).

Althshuller put forward 40 TRIZ-based invention principles by reviewing about 200,000 patents. The Root Conflict Analysis (RCA) proposed by Darrell Mann (2002) maps the business systems and the contradictions that arise within their environments. With the RCA, new ideas and solutions can be generated to increase the market share and profits. TRIZ has been gradually applied to non-technical fields such as society, business, culture and art. In 2004, Darrell Mann published the book titled *Hands on Systematic Innovation*. In that book, he started using the TRIZ approach to business management. Also, he proposed many innovative business solutions. He combined the contradictory matrix with business, which became a contradiction matrix for business management, and later evolved into 40 TRIZ-based principles of invention for business management, as shown in Table 1.

Table 1. The 40 TRIZ principles of invention used in business

No.	Inventive Principle	No.	Inventive Principle
1	Segmentation	21	High Speed
2	Extraction	22	Blessing in Disguise
3	Local Quality	23	Feedback
4	Asymmetry	24	Intermediary
5	Merging	25	Self-Service
6	Universality	26	Use of Copies and Models
7	Nesting	27	Cheap and Short Life

8	Counterweight	28	Principle Replacement
9	Prior Counteraction	29	Flows and Flexibility
10	Prior Action	30	Border Conditions Change
11	Caution in Advance	31	Holes and Networks
12	Tension Removal	32	Visibility Change
13	Other Way Round	33	Homogeneity
14	Non-Linearity	34	Discard and Recover
15	Dynamization	35	Parameter Change
16	Slight Less Or More	36	Paradigm Shift
17	Another Dimension	37	Relative Change
18	Resonance (Coordination)	38	Enriched Environment
19	Periodic Action	39	Inert environment
20	Action Continuity	40	Composite Structures

3.2 Combination of book pricing strategies with the prnciples of invention

The books can be categorized into e-books and paper books. In the literature review, this study describes the pricing strategies for e-books and paper books separately. There are five strategies for each category and 10 strategies in total. The 10 pricing strategies are combined with the 40 invention principles to find out the corresponding relationship between the strategies and the principles, as shown in Table 2. This table can be used when pricing conflicts are discussed later. When the contradiction produced by the 31 business management TRIZ parameters (as shown in Table 3) will be fed back to the invention principles, one can immediately spot the corresponding book pricing strategy.

Table 2 Pricing Strategy and Invention Principle

Category	Pricing strategy	Inventive Principle
E-book	1.Long tail theory	14 Non-Linearity \ 15 Dynamization \ 20 Action Continuity \ 28 Principle Replacement \ 37 Relative Change
	2.Brand value	10 Prior Action \ 38 Enriched Environment
	3.Reader positioning	3 Local Quality \ 7 Nesting \ 14 Non-Linearity
	4. Book life cycle	19 Periodic Action \ 36 Paradigm Shift
	5. Free pricing	15 Dynamization

Paper book	1.Demand elasticity	14 Non-Linearity \ 29 Flows and Flexibility
	2.Resale price maintenance system	33 Homogeneity
	3. Production cost	35 Parameter Change
	4.Psychological pricing	9 Prior Counteraction \ 16 Slight Less Or More \ 22 Blessing in Disguise
	5.Competitor pricing	11 Caution in Advance \ 12 Tension Removal \ 18 Resonance (Coordination)

Table 3. 31 TRIZ parameters for business management

No.	Parameter	No.	Parameter
1	Activity Effectiveness	2	Activity Variability
3	Activity Expense	4	Activity Time
5	Activity Complexity	6	Activity Convenience
7	Activity Safety	8	Activity Reliability
9	System Effectiveness	10	System Variability
11	System Expense	12	System Time
13	System Complexity	14	System Convenience
15	System Safety	16	System Reliability
17	Internal Risk	18	External Risk
19	Information Sharing	20	Information Loss
21	Information Flow	22	Feedback
23	Material Flow	24	Harmful Effects to System
25	Harmful Effects from System	26	Adaptability /Versatility
27	Organizational Tension	28	Organizational Stability
29	Customer tension	30	Customer Stability
31	Environment Stability		

4. Book Pricing strategy

To find out book pricing strategies, the factors that are taken into account during the pricing should be spotted first based on the conflicting points of pricing. This section first discusses the conflicting points of book pricing. Secondly, the TRIZ parameters of business management are used to find out the corresponding invention principles. At last, the factors that determine the pricing of books are spotted with the principles of invention, and later the pricing strategies are formulated. They are now described as follows.

4.1 Conflicting points of book pricing

The book *Power pricing, How Managing Price Transforms the Bottom Line* published by Dolan and Simon in 2004 states that book prices are subject to exchange rate fluctuations, market shares, and the speed of version updates, penetration prices, and preferential activities.

4.1.1. Exchange rate fluctuation

Book pricing is influenced by exchange rate fluctuations. The depreciation of domestic currency is conducive to the export of books while the appreciation of domestic currency is helpful to the import of books.

4.1.2 Price increase

Along with book prices increasing, the unit profit of books rises. Accordingly, the relative market share will be reduced.

4.1.3 Speed of version updates

To respond to changes in the market, the book editions should be constantly updated. If the editions are not updated for a long time, consumers will reduce their willingness to buy, which results in slow sales and increasing inventory costs. In this way, loyal customers may decrease. Also, the monopoly and leadership will be lost.

4.1.4 Penetration price

In order to stimulate sales, books are often issued with a low initial entry price to attract readers and gain market share. On the other hand, it will result in ineffective management for booksellers. For instance, defected books that enter into the market will lead to bad reputation due to their high market share.

4.1.5 Preferential activity

The bookseller launches different preferential activities for varied types of books from time to time. Before the activities, different media are used to inform consumers of the news as quickly as possible. If the promotional period has passed, the discount will no longer be available to the consumers. The preferential activity is resorted to improve the sales performance.

4.1.6 Differential pricing

Booksellers will set different prices for books based on the price level in different countries in order to increase elastic profits. On the other hand, the method may make consumers feel unfair.

This study, based on the aforesaid six conflict points, finds out the positive and negative effects for each conflict point, as shown in Table 4.

Table 4. Conflict points for pricing

Contradiction	Positive effect	Negative effect
1. Exchange rate fluctuation	Domestic currency depreciation conducive to exporters	Domestic currency appreciation conducive to importers
2. Price increase	Unit profits increase	Market share decreases
3. Speed of version updates	Innovative/diversified versions update quickly	Leadership lost with a low update
4. Penetration price	Market share increases	Defected books
5. Preferential activity	Sellers respond quickly	Buyers respond slowly
6. Deferential pricing	Profits increase	Customers feel unfair

4.2 Find out corresponding principles of invention with TRIZ parameters

According to Table 4, the corresponding parameters for the positive and negative effects of the six conflict points are spotted respectively from the 31 TRIZ parameters. Later, corresponding invention principles for the parameters are found out, as shown in Table 5.

Table 5. The corresponding parameters of the positive and negative effects of conflict points

Contradiction	Positive effect	Negative effect
1.Exchange rate fluctuation	Parameter 9 (System Effectiveness)	Parameter 11 (System Expense)
2.Price increase	Parameter 9 (System Effectiveness)	Parameter 31 (Environment Stability)
3. Speed of version updates	Parameter 5(Activity Complexity)	Parameter 31 (Environment Stability)
4.Penetration price	Parameter 31(Environment Stability)	Parameter 24 (Harmful Effects to System)
5.Preferential activity	Parameter 21(Information Flow)	Parameter 26 (Adaptability /Versatility)
6.Deferential pricing	Parameter 9 (System Effectiveness)	Parameter 30 (Customer Stability)

4.3 The Principles of invention used to find out the factors that influence book pricing

In this section, according to the conflict points, their corresponding principles and the factors that influence book pricing will be found out.

4.3.1 Conflict Point One

The first conflict point is the exchange rate fluctuation. Parameter 9 and 11 and the corresponding TRIZ-based principles are Principe 11, 7, 29 and 36.

Strategy 5 for book pricing is found out with Principle 11 Caution in advance. The exchange rate fluctuation is taken into account when books are priced to prevent from the exchange rate loss. Strategy 3 is spotted with Principle 7 Nesting and Table 2. Reader positioning is taken into account when books are priced. Strategy 1 for paper book pricing is found out with Principle 29 Flows and Flexibility and Table 2. The price elasticity is taken into account when books are priced.

Based on Principle 11, 7, and 29, this study can find out the strategies that correspond to Conflict Point One (Exchange rate fluctuation). A. The exchange rate fluctuation is taken into account to avoid exchange rate loss. B. The book positioning should be considered according to the topics of the books. In this way, consumers will not change their purchase along with the change of the pricing caused by the fluctuation of the exchange rate. C. When the domestic currency depreciates, the cost of imported books rises. In this instance, the prices of the books should be adjusted. For those with a low price elasticity of demand, professional books, for example, their prices can be significantly adjusted in this instance. For those with a high price elasticity of demand, their prices can be adjusted slightly or there are no changes in the prices in that case.

4.3.2 Conflict Point Two: Price increase

Parameter 9 and 31 and their corresponding principles are Principle 10, 19, 37 and 33.

Based on Principle 10 Prior Action and Table 2, Strategy 2 is spotted, i.e. brand value. Based on Principle 19 Periodic Action and Table 2, Strategy 4 is spotted, i.e. life cycle. Based on Principle 33 Homogeneity and Tabl2 2, Strategy 2 is spotted, i.e. resale price maintenance system.

Based on Principle 10, 19 and 33, the strategies that correspond to Conflict Point Two can be spotted, respectively. A. If the publishing industry is raising book prices, it is advised to consolidate its brand value first. In this way, it can be avoided that the market share declines when product prices are raised. B. The bookseller can raise or decrease book prices to avoid the situation that the market share slips with an increased price. C. It is suggested to adopt a fixed resale price to avoid horizontal competition. In this way, a considerable profit space is reserved for downstream bookstores and a friendly and cooperative win-win relationship can be achieved.

4.3.3 Conflict Point 3: Speed of version updates

Parameter 5 and 31 and the corresponding principles are 5, 15, 34, and 24.

Based on Principle 5 Merging and Table 2, Strategy 4 is spotted, i.e. psychological pricing. Based on Principle 15 Dynamization and Table 2, Strategy 1 is spotted, i.e. Long tail theory.

With Principle 5 and 15, this study can find out the following strategies for the conflict of the speed of version updates. A. Different speeds of updates are adopted for different categories of books. B. Long Tail Theory can be used to avoid selling dilemmas caused by low version updates. Through bundling and a custom pricing strategy, the profit will continue to be made in the late phase of sales.

4.3.4 Conflict Point Four: Penetration price

Parameter 31 and 24 and their corresponding principles are Principle 35, 10, 37 and 24.

Based on Principle 10 Prior Action and Table 2, Strategy 2 is spotted, i.e. brand value. Based on Principle 37 Relative Change and Table 2, Strategy 10 is spotted, i.e. Long tail theory.

With Principle 10 and 37, the researchers find out the strategies that correspond to Penetration Price. A. The sold books are of brand value. As long as the quality of the books is ensured, readers will be willing to purchase serial books and the like. B. The clearance books can be sold with a penetration price.

4.3.5 Conflict Point Five: Preferential activity

Parameter 21 and 26, and the corresponding principles include 18, 38, 12 and 14.

Based on Principle 18 and Table 2, the fifth paper pricing strategy is spotted, i.e. competitor pricing. According to this principle, new books are priced at the same level as the competitor when they are newly issued products. In this way, a price war can be avoided. Instead, other non-price competitions will be adopted to attract consumers.

4.3.6 Conflict Point Six: Deferential pricing

Parameter 9 and 30 and their corresponding principles are Principle 12, 27, 34 and 24.

Based on Principle 12 Tension removal and Table 2, Strategy 5 is spotted, i.e. competitor pricing. According to this principle, the same pricing strategy is formulated with others in the industry when new books are issued. In this way, consumers will be less likely to feel unfair.

5 Conclusion and Future research directions

Through literature review, this study first finds out the five pricing models for e-books, namely long tail theory, brand value, reader positioning, production life cycle and free pricing, and the five pricing models for paper books, i.e. demand elasticity, resale price maintenance system, production cost, psychological pricing and competitor pricing. Secondly, the ten book pricing strategies are mapped to the 40 TRIZ-based invention principles for business management. In this way, each book pricing model consists of one to several inventive principles. For example, the long tail pricing theory for e-books consists of Principle 14 Non-linearity, Principle 15 Dynamization, Principle 20 Action Continuity, Principle 28 Replacement, and Principle 37 Relative change. Thirdly, the TRIZ approach to business management is used to draw up a book pricing strategy. Six pricing conflict points are spotted based on the book *Pricing Bible* by Dolan and Simon (2004), namely exchange rate fluctuations, market share, the speed of version updates, penetration prices, preferential activities, and differential pricing. With these six pricing conflict points, appropriate and innovative pricing strategies are found out. The strategies can be used as the basis of book pricing for the publishing industry to maximize the niche in the competitive market.

▪Reference

Ching-Ching Chang (2013). Pricing strategy of China's publishing units and price policy. A dissertation for Master's Degree at Hebei University in Baoding, Hebei Province, China.

Darrell Mann (2002), "Hands-On Systematic Innovation", CREAX Press, Belgium.

Darrell Mann (2004), "Hands on Systematic Innovation: For Business and Management,".

Robert J. Dolan and Herman (2014), "Power Pricing: How Managing Price Transforms the Bottom Line"

Bringing the Systematic Thinking to Evaluate the Implementation of Industry 4.0

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Abstract

With advances in information and telecommunication technologies and data-enabled decision making, smart manufacturing can be an essential component of sustainable development. In this era, the promising significant opportunities to reduce cost boost productivity and improve quality is based on the integration or combination of simulated replicas of actual equipment, Cyber-Physical Systems (CPS) and regionalized or decentralized decision making into a smart factory. However, this integration also presents the industry with novel unique challenges. The stream of the data from sensors, robots, and CPS can aid to make the manufacturing smart. Therefore, it would be an increased need for modeling, optimization, and simulation to the value delivery from manufacturing data. This paper aims to outline the approach that was used to develop a system dynamics model to evaluate a superior design of Industry 4.0 implementation for smart manufactory.

Keywords
Casual-Loop Diagram; Industry 4.0; Smart Manufacturing; System Dynamic.

1. Introduction

1.1 Industrial Revolutions

The manufacturing industry has undergone subsequent revolutions throughout the time since the first Industrial Revolution. Until now the world has witnessed three industrial revolutions. The first industrial revolution started with the development of the steam engine and the introduction of heavy mechanical manufacturing equipment [3]. The second one made mass production possible, fostered by the advent of electricity in the assembly line [23]. Automation of production processes through the massive use of information and communication technologies was at the center of the third industrial revolution. Lastly, the development of Cyber technologies integrated into digital ecosystems of all industry value chain contributed to the development of the fourth industrial revolution, named "Industry 4.0".

1.2 An Overview of Industry 4.0

During the last decades particularly, the use and evolution of Information and Communication Technologies (ICT) in the industry have become unavoidable, mainly by being vital for increasing the organizational efficiency and its level of competitivity [13]. Those revolutions have led to changes in the mean of production going from massive use of steam to sophisticated manufacturing processes. Intelligent manufacturing takes advantage of advanced information and manufacturing technologies to achieve flexible, smart, and reconfigurable manufacturing processes in order to address a dynamic and global market [24]. With these new trends and technologies, a new concept, Industry 4.0, was introduced by German during the Hannover Fair event in 2011, which symbolizes the beginning of the 4th industrial revolution.

Industry 4.0, coined for the first time in Germany represents a strategic initiative which aimed at creating smart factories where manufacturing technologies are upgraded and transformed by

CPS, the Internet of Things (IoT), and cloud computing [15]. It is the superposition of several technological developments that embraces both products and processes. Industry 4.0 is related to the so-called CPS [19] that describe the merger of digital with physical workflows [16]. In the Industry 4.0 era, manufacturing systems are able to monitor physical processes, create a so-called "digital twin" (or "Cyber twin") of the physical world, and make smart decisions through real-time communication and cooperation with humans, machines, sensors, and so forth [27].

While some authors like HERCKO et *al.* [11] identifies four essential components of Industry 4.0, others scholars agree that there is a bigger picture of it.

1.3 The Objective of This Paper

This paper intends to focus the discussion on the principal requirements to switch to the Industry 4.0 and uses a system dynamics framework to analyses how the different component of Industry 4.0 are linked together. To mark the transition to the purpose of the paper, the literature about Industry 4.0 comprised various studies aiming different scopes. Schmidt et *al.* [21] provides empirical information on the potentials of use Industry 4.0. Wang et *al.* [27] present a smart factory framework including industrial network, cloud, supervisory control terminals with smart shopfloor objects such as machines, conveyors, and products in the context of Industry 4.0. More recently, Tjahjono et *al.* [25] discussed the impact of Industry 4.0 on the whole supply chains. Yang [18] conducts research which aims to review the contents of Industry 4.0, its scope and finding. However, little attention has been given to the link between the components of Industry 4.0 and how they influence each other and therefore the Industry 4.0 as a system.

This paper is organized as follows: Section 2, introduces the fundamental structure of Industry 4.0. In Section 3, we describe the design principal and technologies requirements for Industry 4.0. In Section 4, we present the system dynamic modularization and the causal-loop diagram. Later on, a system dynamic framework for implementation of Industry 4.0 proposes in this section. Lastly, Section 5 provides the conclusions and future research directions.

2. The Basic Components and Concepts of Industry 4.0

Hermann et *al.* [12] take it upon themselves to find out the main components of the Industry 4.0. After a thorough search in the literature based on keywords such as IoT and most frequently searched concepts related to the subject, they come up with four main components of Industry 4.0. CPS, IoT, Smart Factory, and the Internet of Services (IoS) are the most common four terms cited in academic research publications that represent the basics components of the Industry 4.0

2.1 Cyber-Physical System

In 2008, Edward A. Lee [16], defined CPS as follows: "CPS are the integration of computational and physical processes. Entrenched computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice verse". That combination of the physical and virtual world consists an essential component of Industry 4.0 [10]. CPS include compute, and storage capacity, mechanics and electronics, and are based on the Internet as a communication medium. The essence of CPS is the system, and the primary objective of CPS is to measure the state information of physical devices and ensure the secure, efficient, and intelligent operation on physical devices [17].

Three phases characterize the development of CPS.

- Identification: In manufacturing, identification plays an essential role as it is the basic language used by the machine to communicate. RFID tags as the first generation of the identification technologies are used for unique identification and tracking by mean of an electromagnetic field.
- Integration of sensor and actuator: The second generation of the CPS, sensors are equipped with a limited range of functions. They allow the machine to control its movement and sense changes in the environment. However, their use was limited and communication between them, impossible.
- Development of sensors and actuators: CPS third generation are able to store and analyze data, are equipped with sensors and are connected to the network. The machines are now able to store, analyze data, and exchange information.

2.2 Internet of Things

According to Kagermann [10], the integration of the IoT and IoS in the manufacturing process initiated by the fourth industrial revolution.

IoT is built upon on the cloud computing and networks of data-gather sensors; it offers a mobile, virtual, and instantaneous connection. It consists of objects with embedded technologies that enable them to sense and send data for a specific purpose. IoT allows "things" and "object" as RFID, sensors, mobile phones integrate into unique links, which can work together with other objects to achieve a common goal. IoT's vision is to connect the physical world with the virtual one and facilitate communication between all entities. As identified by Atzori et *al.* [1], IoT can be realized in three paradigms: internet-oriented (middleware), things oriented (sensors) and semantic-oriented (knowledge).

2.3 Internet of Service

The IoS makes services, tradable goods by creating an infrastructure using the internet to offer and sell services. Brought together, service consumers and providers can trade services and engage in business interaction which is an enabling technology for the IoS vision [22]. It is the customer's gateway to the manufacturer.

Within these business networks, organizations work together to deliver a service to consumers. For example, a servicebased value network may include the research, development, design, production, marketing, sales and distribution of a particular service. All these phases work interchangeably to add to the overall worth of service. Value is created from the relationship between the company, its customers, intermediaries, aggregators, and suppliers.

On the IoS, the underlying IT perspective provides a global description of standards, tools, applications, and architectures available to support the business perspective.

The IoS can offer value-added services by various suppliers. Suppliers can communicate to users as well as consumers and are accessed by them via various channels [5]. The value-added service allows a new way of dynamic variation of the distribution of individual value chain activities. It is conceivable that this concept will be transferred from single factories to entire value-added networks in the future. Factories may go one step further and offer particular production technologies instead of just production types.

2.4 Smart Factory

The heart of Industry 4.0 in conceptual term is the Smart Factory. The Smart Factory is a factory that context-aware assists human and machines in the execution of their tasks. Everything revolves around it to make the business model. The smart factory is also referred to as key advantages Industry 4.0 [24]. Smart factories are defined as factories and machinery to assist people to fulfill their tasks. This objective is fed on the basis of information obtained online, so is every moment possible to ascertain the status of the device. Systems working in the background achieves, so-called Calm-systems and context-aware mean that the system can take into consideration context information like the position and status of an object. These systems accomplish their tasks based on information coming from physical and virtual world [12].

3. Design Principles and Characteristics of Industry 4.0

In Industry 4.0, CPS made of connected systems of software, sensors, machines, workpieces, and communication technologies monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions [14]. The communication with one another, humans and machine assured this had been achieved with centralized controllers. Figure 1, by Baur and Wee [4], depicts eight value drivers and 24 dependent industry levers in Industry 4.0. The Industry 4.0 system include: a modular structure for increased flexibility; interoperability, where communication between entities are seamless, seamlessly; virtualization, with a strong emphasis on simulation and decentralized decision-making; real-time capability for fast response; and service orientation that gives customers practical guidance for self-service [20].

Major shifts are required within the organizational structures, practices, and systems in order to make Industry 4.0 work properly. Those shifts include new forms of data management, IT architecture and data management and so forth. All those requirements in Industry 4.0 must follow a design principle, aiming at ensuring that all manufacturing processes are computerized and supporting companies in identifying possible Industry 4.0 pilots suitable to be implemented. The literature about the exact number of keys principles is not uniform. Hermann et *al.* [12] identifies 4 major keys principles of Industry 4.0, while Six keys principles remain the results of Vogel-Heuser et *al.* [26]. Gilchrist [8] supports the same idea of 6 keys principles to be the design of Industry 4.0. In the context of this study, we adopt the six key principles as shown in Table 1.

3.1 Interoperability

Interoperability is an essential enabler of Industry 4.0. It implies that all components are capable of connecting, to communicate and operate together via the IoT including humans, smart factories, and the relevant technologies [8]. The Interoperability of Industry 4.0 requires specific principles to guarantee the complete process of accuracy and efficiency. Eight principles are appropriate for Industry 4.0 to be interoperable: accessibility, multilingualism, security, privacy, subsidiarity, the use of open standards, open source software, and multilateral solutions [18].

Figure 1: Industry 4.0 value drivers and levers by Baur and Wee [4]

Table 1: Design principles of each Industrie 4.0 component

Industry 4.0 component	CPS	IoT	Internet of services	Smart factory
Interoperability	X	X	X	X
Virtualization	X	-	-	X
Decentralization	X	-	-	X
Real-time capability	-	-	-	X
Service Orientation	-	-	X	-
Modularity	-	-	X	-

3.2 Virtualization

Simply put, there must be a virtual copy of everything. It implies that CPS is able to monitor physical processes and create a virtual copy of the real world through simulation.

In case of failure, a human can be notified. In addition, all necessary information, like next working steps or safety arrangements, are provided [9]. Hereby, humans are supported in handling the rising technical complexity

3.3 Decentralization

Decentralization refers to the ability of CPS to independently come up with decisions and carry out their dedicated functions without deviating from the ultimate organizational goal. This can only be changed in the event of interferences or conflicts with the intended goals, which may require some tasks to be handled at other levels. Decentralization also creates a more flexible environment for production. In fact, the concept is characterized by greater customization of products in flexible manufacturing environments, as in industries dealing with mass production while the quality assurance for the entire process remains important.

3.4 Real Time capability

Industry 4.0 relies on doing things in real time. Real-time data collection, storage, and analysis are required for a smart factory, to enable the online decision making. The production process, the data collection, and the feedback system should follow the online monitoring requirements. While the status of the plant is continuously tracking and analyzing, the plant can get a response to the machine failure and reroute products to another machine.

3.5 Service Orientation

Production must be oriented for customers. Customers must be able to connect efficiently through the IoS to create products based on their specifications. The services of companies, CPS, and humans are available over the IoS and can be utilized by other participants. Internal and external services are going to be required by the smart factories. That explains why the IoS is essential to Industry 4.

3.6 Modularity

Smart factories in order to easily adapt to changing circumstances and requirements need to be flexible. That can be realized by replacing or expanding individual modules. Therefore, modular systems can be easily adjusted in case of seasonal fluctuations or changed product characteristics. For example, production systems, and even conveyor belts that are modular and agile allow a change in production. Producers can, therefore, ensure that individual products lines can be replaced, modified, expanded, without noticeable disruption to other products or production process.

4. System Dynamics Modularization

Forrester in 1997 [7] defines Industrial Dynamics as "the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success ox the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy".

System Dynamics (SD) is a discipline of researching on system information feedback and solving the problems integrated into the system. It holds the characteristics and pattern that define a system depend on its internal dynamic feedback structure and interactions of its parts [6]. The models developed through a system dynamic approach aims to present, defines and analyze how complex systems work. Therefore, their primary goal is to understand how specific behaviors affect the system and how to predict consequences over time

4.1 Implementation the Industry 4.0 with System Dynamic model

In this section, we develop a framework that summarizes the characteristics and requirement of Industry 4.0 regarding systems dynamics principles. The proposed framework organizes the major factors influencing Industry 4.0 into four sections. The framework is intended to create a platform that showcases another view on Industry 4.0 and emphasizes the importance of the relations and influence between components on reaching the full potential of Industry 4.0.

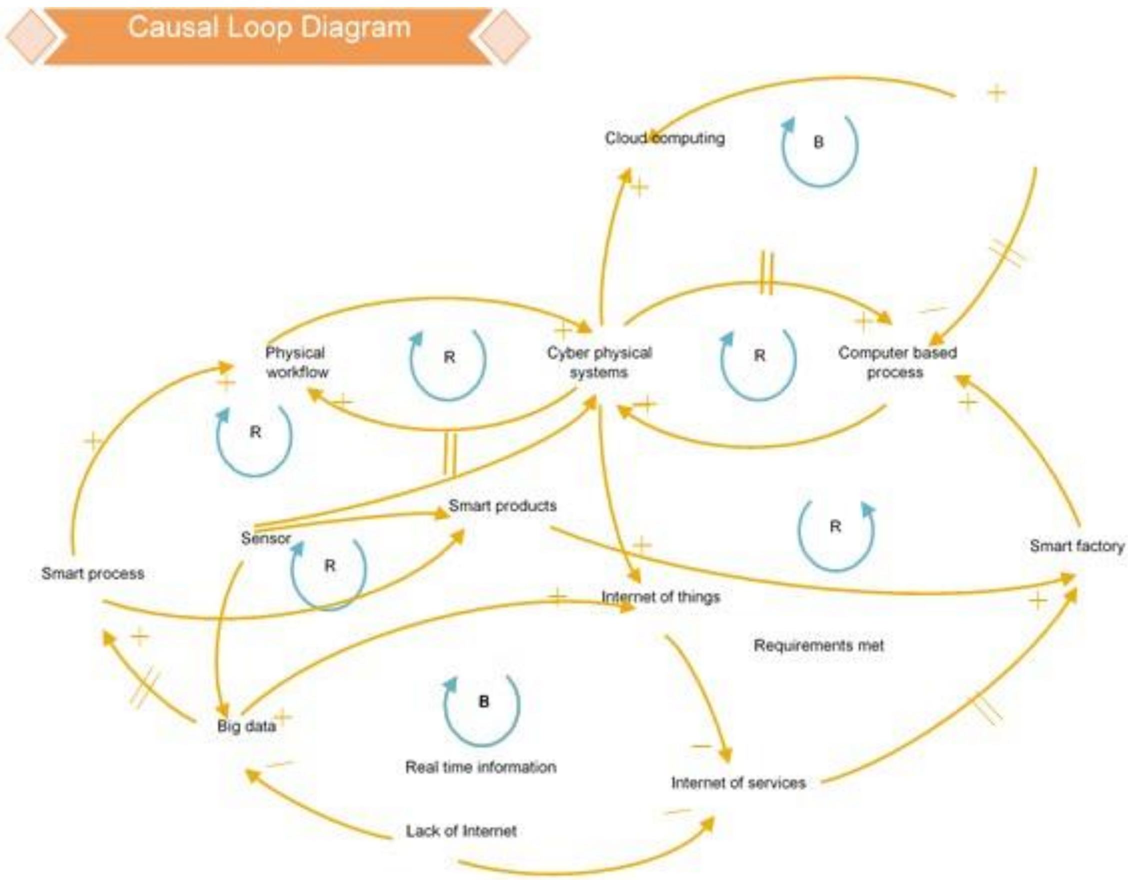
Casual-Loop Diagram The causal loop diagram (CLD), is an essential tool in system dynamics developed by Dr. Jay
Forrester. It is used, to develop an understanding of complex systems. Every arc in causal loop is marked by () or (+). The mark (+) indicates that if the first variable is changed, then the second variable will be changed in the same direction. The mark () indicates that if the first variable is changed, the second variable will be changed in the opposite direction [2].

In this paper, the causal diagram of Industry 4.0 consists of seven loops divided into 5 reinforcing loops and two balancing loops. To describe this diagram as shown in Fig. 1.

The five reinforcing loops are: smart process, smart products, CPS, computer based process, smart factory. The two balancing loops are cloud computing connection, and the real time information loop.

CPS consists into two components which are the physical work-flow, and the computer based process system. Between the CPS and it physical side, there is a reinforcing loop. The physical work-flow influenced positively the CPS. And any malfunction of it has an indigence on the functioning of the CBS. Therefore, it exists as well a reinforcing loop between the CBS and its computerized side, that's represents its second part because it can influence positively and negatively the status of the CBS.

The sensor-smart products loops has a reinforcing loop that can be explained by the fact that smart products rely on sensor real time data to figure out if they fit the requirements of the customers. The sensor needs information the smart



products to be updated continuously. Consequently, any wrong message from the sensor has a bad incidence on the smart products and one important loop is the internet of service -Big data loop. Internet of services rely on full time internet connection to work. One of its key support is the Internet of Things which allows all objects to be connected in real time.

Between the smart factory and CPS there is a reinforcing loop. Smart factory is a big component of industry as much as the CPS.As all the components are linked through the IoT, the smart factory performance influence positively the CPS as negatively depending on if it is performing adequately or not. Therefore, there is a reinforcing loop between them.

The lack of internet influences negatively the creation of big data. With no big data, Internet of things will affect negatively the internet of services. On the contrary, with more stable internet connection, big data is generated, and internet of services are positively influenced to generate more more big data. There it exists a balancing loop between big data-Internet connection and internet of things.

The second balancing loop is between cloud computing and computer based process of the CPS. The cloud computing relies on good connection to be efficient. A poor connection will impact negatively the usefulness of the cloud computing and lead to a lack of productivity of the computer based process side of the CPS. That justifies a balancing loop between them.

5. Conclusion

As a conclusion and future research direction, we attempted to have a broader vision on the requirements for industrial development and intelligence manufacturing. These requirements are barely indicated in literature with analytic context and are known as the new obligations for next step toward smart manufacturing. Following are some of highlighted topics in this chain.

- Supply Chain Management
- Sustainability and Remanufacturing
- Green Smart Manufacturing

Eventually, the fast-growing smart technology for manufacturing requires a Knowledge Management Systems (KMS) in order to support management decision support system. This KMS will identify and analyze research trend gaps and organize a future research agenda for new product development

References

[1] Luigi Atzori, Antonio Iera, and Giacomo Morabito. The internet of things: A survey. *Computer networks*, 54 (15):2787–2805, 2010.

[2] Ahmed Babader, Jun Ren, Karl O Jones, and Jin Wang. A system dynamics approach for enhancing social behaviours regarding the reuse of packaging. *Expert Systems with Applications*, 46:417–425, 2016.

[3] L Barreto, A Amaral, and T Pereira. Industry 4.0 implications in logistics: an overview. *Procedia Manufacturing*, 13:1245–1252, 2017.

[4] Cornelius Baur and Dominik Wee. Manufacturing's next act. *McKinsey Quarterly, Jun*, 2015.

[5] Peter Buxmann, Thomas Hess, and Rainer Ruggaber. Internet of services. *Business & Information Systems Engineering*, 1(5):341, 2009.

[6] Yang Chao and Miao Zishan. system dynamics model of shanghai passenger transportation structure evolution. *Procedia-Social and Behavioral Sciences*, 96:1110–1118, 2013.

[7] Jay Wright Forrester. Industrial dynamics. *Journal of the Operational Research Society*, 48(10):1037–1041, 1997.

[8] Alasdair Gilchrist. *Industry 4.0: the industrial internet of things*. Springer, 2016.

[9] Dominic Gorecky, Mathias Schmitt, and Matthias Loskyll. Mensch-maschine-interaktion im industrie 4.0zeitalter. In *Industrie 4.0 in Produktion, Automatisierung und Logistik*, pages 525–542. Springer, 2014.

[10] Kagermann Henning. Recommendations for implementing the strategic initiative industrie 4.0. 2013.

[11] J Hercko, E Slamková, and J Hnát. Industry 4.0: New era of manufacturing, 2015.ˇ

[12] Mario Hermann, Tobias Pentek, and Boris Otto. Design principles for industrie 4.0 scenarios. In *System Sciences (HICSS), 2016 49th Hawaii International Conference on*, pages 3928–3937. IEEE, 2016.

[13] L Heuser, Z Nochta, and NC Trunk. Ict shaping the world: A scientific view, 2008.

[14] Siddhartha Kumar Khaitan and James D McCalley. Design techniques and applications of cyberphysical systems: A survey. *IEEE Systems Journal*, 9(2):350–365, 2015.

[15] Heiner Lasi, Peter Fettke, Hans-Georg Kemper, Thomas Feld, and Michael Hoffmann. Industry 4.0. *Business & Information Systems Engineering*, 6(4):239–242, 2014.

[16] Edward A Lee. Cyber physical systems: Design challenges. In *Object oriented real-time distributed computing (isorc), 2008 11th ieee international symposium on*, pages 363–369. IEEE, 2008.

[17] Jie Lin, Wei Yu, Nan Zhang, Xinyu Yang, Hanlin Zhang, and Wei Zhao. A survey on internet of things: Architecture, enabling technologies, security and privacy, and applications. *IEEE Internet of Things Journal*, 4(5): 1125–1142, 2017.

[18] Yang Lu. Industry 4.0: a survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, 6:1–10, 2017.

[19] Raj Rajkumar and Insup Lee. Nsf workshop on cyber-physical systems, 2006.

[20] Samuel Mensah Sackey and Andre Bester. Industrial engineering curriculum in industry 4.0 in a south african context. *South African Journal of Industrial Engineering*, 27(4):101–114, 2016.

[21] Rainer Schmidt, Michael Möhring, Ralf-Christian Härting, Christopher Reichstein, Pascal Neumaier, and Philip Jozinovic. Industry 4.0-potentials for creating smart products: empirical research results. In´ *International Conference on Business Information Systems*, pages 16–27. Springer, 2015.

[22] Christoph Schroth and Till Janner. Web 2.0 and soa: Converging concepts enabling the internet of services. *IT professional*, 9(3), 2007.

[23] Klaus Schwab. *The fourth industrial revolution*. Crown Business, 2017.

[24] Weiming Shen and Douglas H Norrie. Agent-based systems for intelligent manufacturing: a state-of-the-art survey. *Knowledge and information systems*, 1(2):129–156, 1999.

[25] B Tjahjono, C Esplugues, E Ares, and G Pelaez. What does industry 4.0 mean to supply chain? *Procedia Manufacturing*, 13:1175–1182, 2017.

[26] Birgit Vogel-Heuser and Dieter Hess. Guest editorial industry 4.0–prerequisites and visions. *IEEE Transactions on Automation Science and Engineering*, 13(2):411–413, 2016.

[27] Shiyong Wang, Jiafu Wan, Daqiang Zhang, Di Li, and Chunhua Zhang. Towards smart factory for industry 4.0:
a self-organized multi-agent system with big data based feedback and coordination. *Computer Networks*, 101: 158–168, 2016.

Manufacturing Innovation on Processing Polygon with Traditional Lathe

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Abstract

The mill-turn multi-tasking machine can cut asymmetric and complex workpieces, but it can only change the form of four-axis milling processes, so the efficiency is not improved. This study does not change the structure of traditional lathes. The traditional lathes add a simple power turret and it can cut the approximate polygon. The power tool turret, which uses a cutting tool, has a rotating function and co-rotating with the workpiece. The traditional lathes are a proper distance and a rotation with certain proportions, the workpiece axis and turret axis can cut out the approximate line of the curve shape. The traditional lathes have a correct ratio of the rotational speed and the length of cutting tool, turret axis, and the workpiece axis have appropriate distances, we can cut out the needed regular polygon approximation. Turning a regular polygon is an approximation.

Keywords: Polygon, traditional lathe, one-time processing.

1. Introduction

The lathe has a larger radius of cutting rotation. Under other conditions are equal, the relative speed of lathe is faster between cutting tool and the workpiece, so the cutting of lathe is usually more efficient than other cutting machine tools such as planers, milling machines, etc. The lathe machine tools are widely used in the machinery manufacturing and it is one of the common machine tools. Factories usually use lathe for cutting. The lathe is convenient, simple to operate, highly efficient, and has a low price but it is mainly used for machining cylindrical or symmetry of parts.

General lathes only have X and Z axes. The turning and milling machine adds Y-axis and C-axis. The turning and milling machine is powerful and can cut asymmetrical and complex workpieces. The turning and milling machine is similar to the four-axis cutting function of the cutting center machine, and the four-axis milling machine is changed into a machining form, but the efficiency is not improved.

Cutting efficiency is determined by the volume removed per unit time. With the same feed rate and feed rate, the cutting speed can be determined by the relative speed between the tool and the workpiece. The radius of rotation of the lathe is determined by the size of the workpiece and is generally greater than the radius of the tool. The turning radius of the lathe is large, and the relative speed between the tool and the workpiece is large under the same rotating speed. Generally, the cutting efficiency of a lathe is higher than other cutting machines, such as milling machines and planers. This is one of the reasons why cutting usually use lathes as much as possible.

Polygonal shape turning is now widely used in the industry, and it is widely used, such as screws and nuts. The general turning and milling machine can process the polygonal shape, but it adopts the function of the milling machine, and slowly grinds one surface and one surface. The turning and milling machine cannot cut the polygon shape at one time, and the efficiency is low.

In order to improve the cutting efficiency, the best way is to process polygon shapes at one time. If the turning and milling machine has a special dedicated turret rotation function and rotates in the same direction as the workpiece, the polygonal shape can be cut out, but this machine is a special machine that is inexpensive.

In order to turn the polygonal shape and improve the cutting efficiency, this paper uses the self-made power turret to actually process on the traditional turning tool. The rotational speed of the turret shaft and the workpiece shaft is in a certain rotation ratio, and the turret shaft and the workpiece shaft take an appropriate distance. With an appropriate tool length, an approximate straight curve shape can be cut and the required approximate polygon can be cut.

2. Literature Review

Professor Chen of the Department of Mechanical Engineering of Far East University had directed two master's theses of Tseng (2012) and Chen (2015). But the content is not perfect. Many simulation theories have not been finally verified (Chen and Pan, 2016).

Modern numerically-controlled mechanical lathes also have the function of milling machines, becoming a CNC turning and milling machine. A variety of processing modes, and the special functions of these models are similar to the addition of the fourth axis to the cutting center (Bono et al., 2008).

The turning and milling machine can control the rotation of the workpiece axis, and the tool X axis and Z axis move, and increase the tool power rotation or even the Y axis can move(Bono et al., 2010; Altintas et al., 2005a, 2005b). Although the turning and milling machine can cut the shape of the polygon, the machining speed is slow and the efficiency is low because the milling machine functions as a milling machine and the workpiece is moved without moving the tool. The general turning and milling machine cannot cut the polygon shape at one time (Neugebauer et al., 2007).

In order to directly turn polygons and improve cutting efficiency, special turning and milling machines have been developed. The special machine will be equipped with a special function of turret rotation. The turret can control the rotary cutting process, and can quickly turn cutting the polygons of the approximate straight edge at one time. The edges of the turned polygon are curved and may be convex or concave.

This paper does not change the structure of traditional lathes. The power tool turret, which uses a cutting tool, has a rotating function and co-rotating with the workpiece. The traditional lathes add a simple power turret and it can cut the approximate polygon.

3. Lathe cutting polygons at one-time processing

The tool turret and workpiece rotation are both counter-clockwise and rotate in the same direction, as shown in Figure 1. The workpiece shaft rotation speed is α, and the tool knife turret shaft speed is β. The workpiece radius is a and the turning tool radius is b. The feed distance is c, and the distance between the tool turret and the workpiece axis is d. Tool center is $P_b(d,0)$, initial tool nose is $P_0(d-b-c,0)=P_0(a-c,0)$, and the rotational speed ratio of β and α is i. We have

$$\beta = i\,\alpha \tag{1}$$

The tool turret and the workpiece both rotate in the same direction and rotate counterclockwise. Assuming that the workpiece is stationary, the equivalent of the turning tool and the turning tool turret rotates clockwise with the rotational speed of α around the center of rotation Q (0,0) of the work tool turret. Then rotate around the center of the turret in the counterclockwise direction with β speed. After the elapse of time p, the angle that is rotated clockwise with respect to the workpiece turning turret is t = α*p. The angle that the tool tip P(x,y) rotates counterclockwise with respect to the center of the turret is i*t=β*p. Then there is

$$(i-1)t=(\beta-\alpha)p \tag{2}$$

$$QE=d\cos t \tag{3}$$

$$EF=d\sin t \tag{4}$$

$$FG=b\cos[(i-1)t] \tag{5}$$

$$PG=b\sin[(i-1)t] \tag{6}$$

$x=QE-FG=d\cos t-b\cos[(i-1)t]$ (7) $y=(EF+GP)=-d\sin t-b\sin[(i-1)t]$ (8)

a:workpiece radius α :workpiece shaft rotation speed $\beta= i\ \alpha$ b:turning tool radius β :tool knife turret shaft speed $d=a+b-c$

c:feed distance $P_b(d, 0)$:tool center $QE=d\cos t$ d: distance between the tool turret and the workpiece axis $EF=d\sin t$

$P_0(d-b-c,0)=P_0(a-c,0)$:knife tip i : speed ratio $FG=b\cos[(i-1)t]$

$PG=b\sin[(i-1)t]$

$x=QE-FG=d\cos t-b\cos[(i-1)t]$

$y=-(EF+GP)=-d\sin t-b\sin[(i-1)t]$

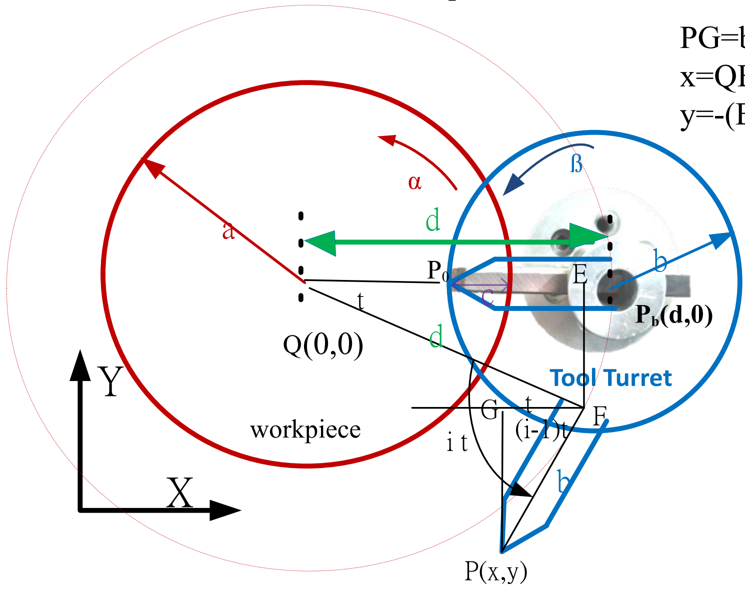

Figure 1. Turning tool nose of counter-clockwise turning tool turret and workpiece

The workpiece rotates one revolution and the turning tool turret rotates i revolutions in the same direction. General i is expressed as a fraction. Considering the cutting of n polygons, there are m turning tools on the turret and evenly distributed. The ratio of the turret speed β to the workpiece speed α is i. Then i is

$$i=\beta/\alpha=n/m \quad (9)$$

The number of sides of a turned polygon workpiece is

$$n=i*m \quad (10)$$

Turret speed is

$$\beta=i*\alpha \quad (11)$$

The trajectory of the tool tip P(x,y) relative to the center Q(0,0) of the workpiece can be established on the turning turret. The equation of the angle t is as follows:

$$P(x,y)=\{ d\cos t-b\cos[(i-1)t], -d\sin t-b\sin[(i-1)t]\} \quad (12)$$

If it is expressed by the time parameter p, the equation is as follows:

$$P(x,y)=\{ d\cos\beta p-b\cos[(\beta-\alpha)p], -d\sin\beta p-b\sin[(\beta-\alpha)p]\} \quad (13)$$

4. Processing Results

The workpiece material is ABS with a diameter of 10.5mm and a radius of rotation of 5.25mm. The rotation radius of the power turret is 60.0mm. The distance between the rotating shaft of the power turret and the rotating shaft of the workpiece is 62.45 mm. The feed radius is 2.8mm. The rotational speed of the lathe is 437.5 rpm and the speed of the turret is 1312 rpm. The speed ratio of the two is i=3 times.

The tool tip to workpiece trajectory equation is

$$\{62.45\mathrm{Cos}[t]-60\mathrm{Cos}[2t],-62.45\mathrm{Sin}[t]-60\mathrm{Sin}[2t]\} \quad (14)$$

The trajectory graphic of the tool tip to the workpiece center shown in Figure 2. A partial enlargement of the trajectory is shown in Figure 3. Turning the actual situation as shown in Figure 4. The controller panel screen is shown in Figure 5. The finished product turning is shown in Figure 6. The turning result measurement triangle side length is 9.6mm as shown in Figure 7.

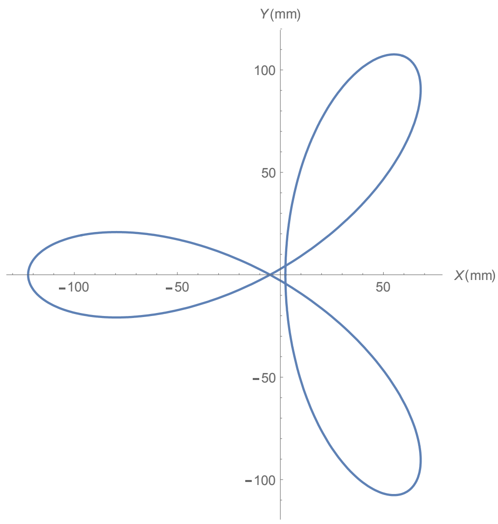

Figure 2. Turning tool tip to workpiece center trajectory graphic d=62.45mm, b=60.0mm, i=3

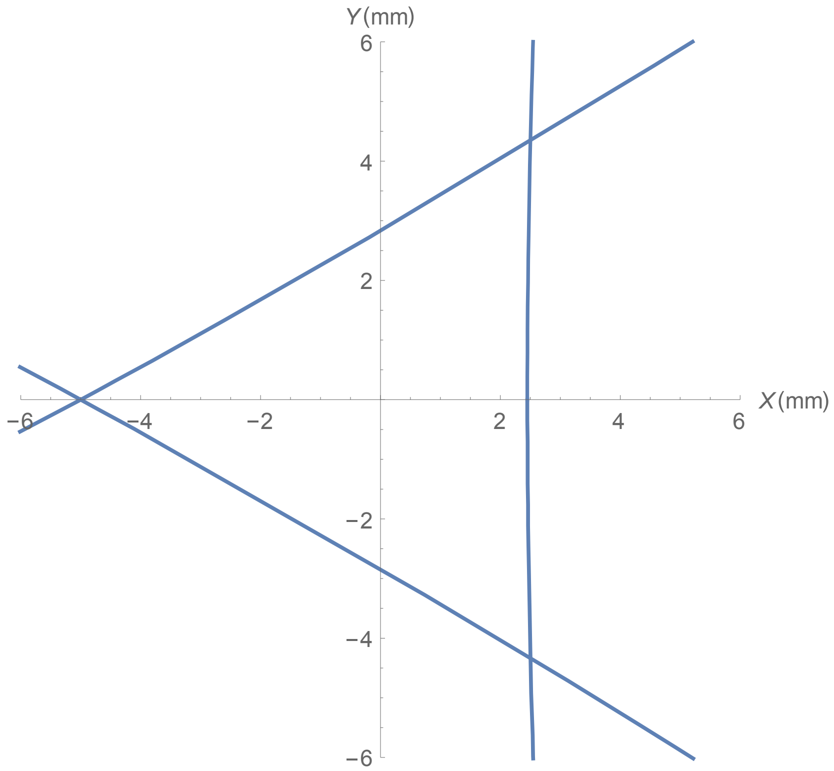

Figure 3. Local zoom trace d=62.45mm, b=60.0mm, i=3

Figure 4. Actual turning situation

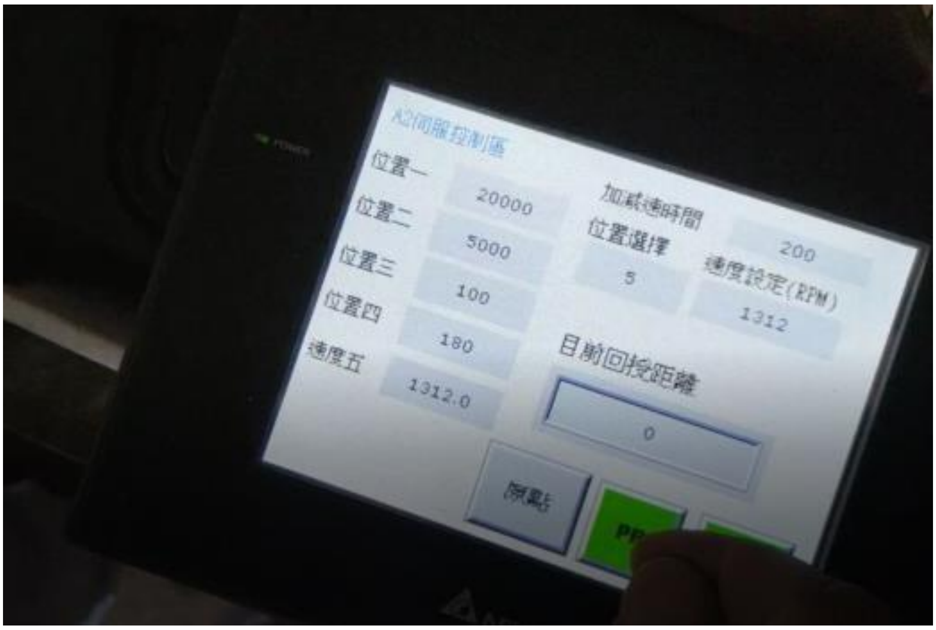

Figure 5. Controller panel screen

Figure 6. Turning the finished product d=62.45mm, b=60.0mm, i=3

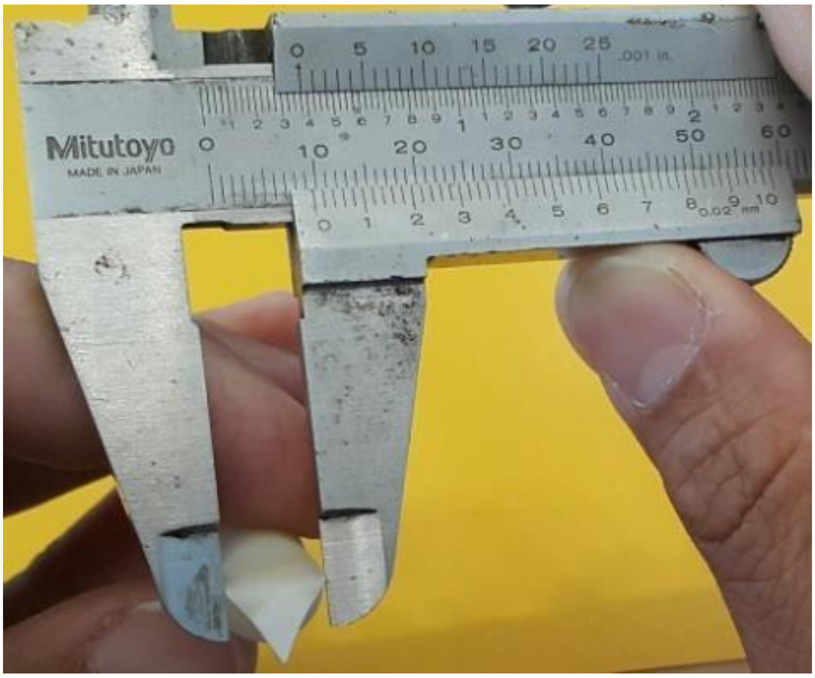

Figure 7. Finished product measurement trilateral side length is 9.6mm

5. Conclusion

The first use of homemade power turrets, combined with traditional lathes to cut polygons. In this paper, self-made power turrets are installed on the most common equipment, inexpensive, widely used traditional lathes, and the actual machining and cutting of polygonal shapes are satisfactory.

▪Reference

Altintas, Y. and Cao, Y., Virtual Design and Optimization of Machine Tool Spindles, *CIRP Annals - Manufacturing Technology*, 2005, 54(1), 379–382.

Altintas, Y., Brecher, C., Weck, M. and Witt, S., Virtual Machine Tool, *CIRP Annals-Manufacturing Technology*, 2005, 54(2), 115–138.

Bono, M.J. and Kroll, J.J., Tool setting on a B-axis rotary table of a precision lathe, *International Journal of Machine Tools and Manufacture*, 2008, 48(11), 1261-1267.

Bono, M.J., Seugling, M.R., Kroll, J.J. and Walter, W.N., An uncertainty analysis of tool setting methods for a precision lathe with a B-axis rotary table, *Precision Engineering*, 2010, 34(2), 242-252.

Chen, T.J., Design and manufacturing of regular polygon turning mechanisms and optimization, Master's Thesis, Far East University, 2015.

Chen, W.F. and Pan, Z.Z., A research of optimal polygon turning, *ICCPE&ICI*, Kenting, Taiwan, 2016, Paper ID: C268.

Neugebauer, R., Denkena, B. and Wegener, K., Mechatronic Systems for Machine Tools, *CIRP Annals - Manufacturing Technology,* 2007, 56 (2), 657–686.

Tseng, N.A., Researches of polygonal shape and helical surface using lathe machining, Master's Thesis, Far East University, 2012.

Innovative Improvement on Milling Machine for One-time Processing Polygon Model

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Abstract

It is generally necessary to purchase a dedicated special CNC turning-milling machine to cut approximately regular polygons at a time. However, the equipment is expensive, making the manufacturers who need this processing function daunting. This paper added a simple power turret without changing the mechanism of the milling machine. Using a certain speed ratio between the turret and the workpiece and its relative position, a model for machining the polygon at one time of the milling machine is established. This paper investigates the high efficiency of milling machines to fabricate approximately polygonal workpieces at a time. This paper uses the milling machine processing characteristics with the speed detection device to measure the workpiece speed. Adjusting and strict control of the rotational speed of the turret, change length, with the number and location of the cutting tool, in addition to a regular polygonal outer milling approximate, other various changes can be milled rectangle, parallelogram shape and so on.

Keywords: milling machine, rectangle, one-time processing.

1. Introduction

Milling machine is a common machine tool in machining and is one of the most widely used machine tools in mechanical manufacturing and repairing plants. Milling machines can produce complex workpieces, but cutting efficiency is not high. How to improve the cutting efficiency of milling machines has always been a subject worthy of study.

The milling radius of the milling machine is the radius of the milling cutter, which is usually less than the machining radius of the object. This is one of the reasons why the milling machine's cutting efficiency is not as good as that of the lathe. The difference between the cutting center machine and the milling machine is that the cutting center machine has multiple tools and a tool change mechanism, and the milling machine has the function of a cutting center machine with only one knife. The milling machine has only one knife, so it cannot be called a cutting center machine, but the milling machine can mill complex objects like the compressor blades, propeller blades, complex curved surfaces and the like in the same way as the cutting center machine. These functions are not comparable to other machine tools such as lathes and planers.

Milling machines are common, powerful and inexpensive. If you can add special fixtures such as a power turret, you can mill polygonal objects at one time. These functions will be more powerful, and the cost can be acceptable to most manufacturers. In this paper, the first time on the milling machine, a self-made power turret, milling and processing polygon shape objects, can greatly improve the milling efficiency.

2. Literature Review

In recent years, approximate polygon milling has become increasingly popular in the industry. However, special machine tools with turret rotation special features must be purchased to mill approximate regular polygons. Although the efficiency is high, the equipment is expensive. Manufacturers who need to process this function, such as smaller factories in screws and nuts, can only be deterred because of insufficient funds (Chen, 2015a). The study of polygons is dominated by turning (Chen, 2015a; Chen, 2015b; Chen, 2016a; Chen, 2016b; Chen, 2017; Hwang, 2014; Tseng, 2012; Wang, 2013). It is rare to use a milling machine to cut a polygon at a time. In many articles, the approximation of polygon cutting is limited to simulation and no actual cutting verification is seen. Not to mention the measurement test of finished products after processing.

This article will conduct in-depth research and integration of the imperfections of Chen (2015a). The most important thing is to improve the cutting polygon power turret mechanism and fixtures including controlling the number of revolutions of the linear motor and verifying the actual cutting and simulation. This article is not a simple simulation calculation.

In order to be applicable to the cutting of the power rotary turret installed on any conventional milling machine and numerically controlled milling machine, an instrument for measuring the rotational speed must be added. The number of coordinated rotations of the power tower can be adjusted at any time. It is suitable for the different speeds of any conventional milling machine and CNC milling machine and the error of the machine marked speed.

This article does not need to buy a dedicated machine, only the instrument to measure the speed, the power rotary turret, the simple clamp and the good linear motor speed controller. It is still the first to enhance the powerful functions of cutting a variety of polygons in any conventional milling machine and CNC milling machine.

3. One-time milling of polygons

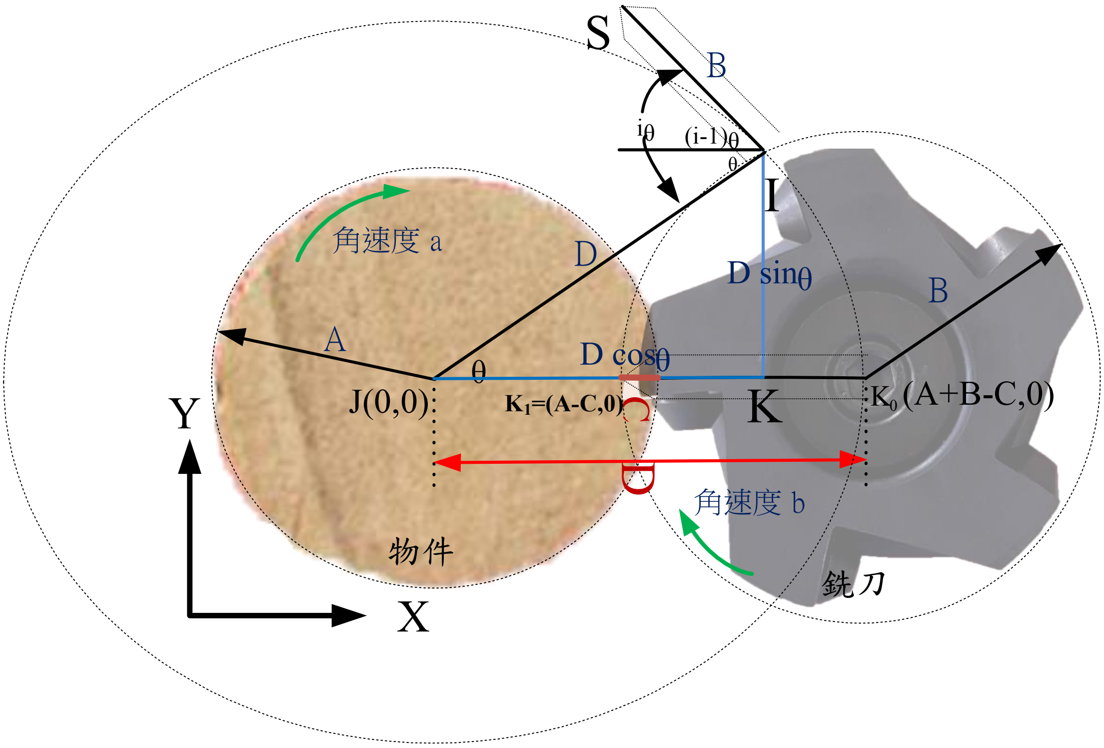

Figure 1. Diagram of the rotation of the turret and the object in the same direction

If the cutter turret and the object rotate clockwise and rotate in the same direction, as shown in Figure 1. The angular velocity of the object is a, and the angular velocity of the milling cutter turret is b. The radius of the object is A, the radius of the milling cutter is B, and the distance of the infeed is C. The parallel distance between the axis of the turret and the axis of rotation of the object is D=A+BC. The axis of the milling cutter tower is K_0(A+B-C,0). Assume that the initial position of the cutter nose is K_1(A-C,0). Rotate speed ratio is i, a turret rotating at a multiple of the rotational speed of the object. The equation of the rotate speed ratio i is as follows:

$$b=i*a \tag{1}$$

As shown in Figure 1, the object rotates in the same direction as the turret of the milling cutter, and both rotate clockwise. The turret axis and the object axis run at a certain speed ratio i. When the object rotates one circle, the turret of the milling cutter rotates i-turns in the same direction. In general, i cannot be an irrational number that must always be expressed as a fractional number. If the milling machine is milled as an n polygon. Considering the milling of polygons, there are k milling cutters on the turret and evenly distributed. The ratio of the turret rotation speed b to the object rotation speed a is i. The relationship between the number of cutters k and the n-edge of the object is i=b／a=n／k. The number of sides of the milled polygon object is n=i*k. The turret speed is b=i*a.

The radius of gyration of the object is A, the radius of gyration of the milling cutter tip is B, and the parallel distance between the axis of the turret and the axis of the object is D. If it is assumed that the object is not moving, it means that the turret rotates around the axis of the object, and the rotation direction is counterclockwise. The rotation speed is a. The milling cutter rotates clockwise around its own axis K_0 at a speed of b and also revolves around the axis J of the object. The object rotation angle is the parameter θ. The value of θ can be positive or negative. Both the turret and the object rotate clockwise. When it is assumed that the object is not moving, the direction of the revolution of the turret relative to the object is counterclockwise. At this time, the value of θ is positive. The movement of the cutter's turret axis coordinates is K_0(A+B-C,0) and the milling cutter's tool tip coordinates is K_1(A-C,0), as shown in Figure 1. Set the distance between the tool tip and the center of the turret to be B. The distance between the center of rotation of the object and the center of the turret is D. Assume that the object is stationary, which is equivalent to the tool tip revolving around the center of the tool at the center of the tool at a rotation speed, and then rotating at b rotation speed. After time t, θ = at, iθ=bt, (i-1)θ=(b-a)t, JK=Dcosθ, IK= Dsinθ. At this point, the trajectory of the tool tip relative to the object on the milling cutter turret can be established. The tool tip position S equation is as follows:

$$S=\{D\cos\theta-B\cos[(i-1)\theta],\ D\sin\theta+B\sin[(i-1)\theta]\} \tag{2}$$

S(X, Y) is represented by the following formula:

$$X=D\cos at-B\cos(b-a)t \tag{3}$$

$$Y=D\sin at+B\sin(b-a)t \tag{4}$$

4. Milling example results

Milling material is ABS. The object has a diameter of 12.4 mm and a radius of rotation of 6.2 mm. The length of the two knives is different as shown in Figure 2. The radius of rotation of the cutter is 51.65mm and 52.65mm, that is, the length of the cutter is B=51.65mm and 52.65mm. The rotation axis of the object and the milling cutter tower are 56.45 mm, that is, the parallel distance between the turret axis and the object axis is D=56.45 mm. The feed rate is 2.4 mm, the milling machine object speed is 1497 rpm, and the milling cutter turret speed is 2994 rpm. The speed of the turret is twice the speed of the milling machine, ie b: a = 2. The cutter length is different and the number of cutters is 2 in total.

$$\mathrm{D}=56.45\mathrm{mm};\ \mathrm{B}=51.65\mathrm{mm};\ \mathrm{b}=2a; \tag{5}$$

The track position of the milling tool tip relative to the center of rotation of the object is

$$\{4.8\mathrm{Cos}[t],108.1\mathrm{Sin}[t]\} \tag{6}$$

Figure 2. Two lengths of different milling cutters

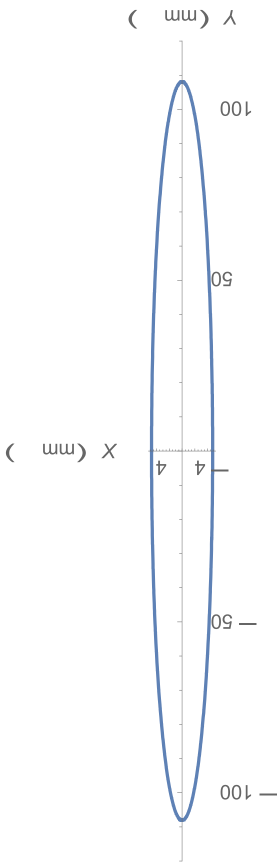

Figure 3. Rotary speed 2 times cutter tip trace B=51.65mm，D=56.45mm

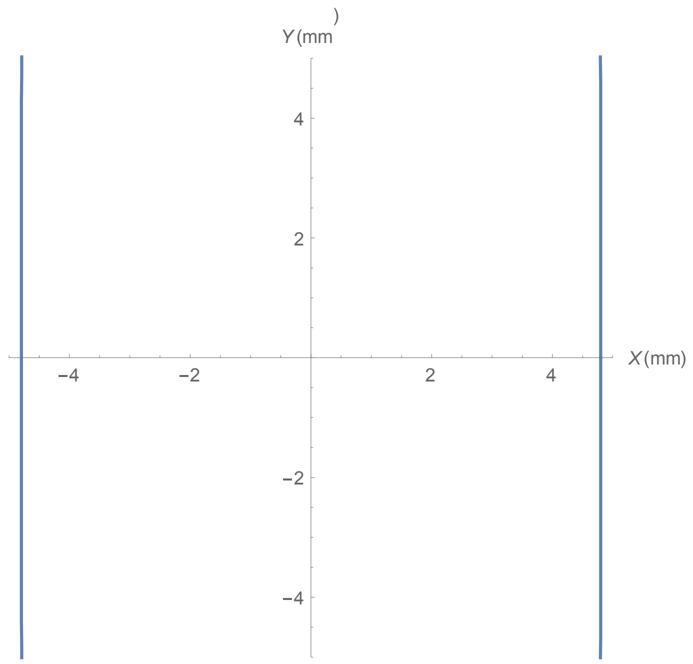

Figure 4. Rotary speed 2 times cutter tip zoom path diagram B=51.65mm，D=56.45mm

The available trace is shown in Figure 3. A partial enlarged view is shown in Figure 4. Another milling cutter data is as follows:

$$\mathrm{D} = 56.45\mathrm{mm};\ \mathrm{B} = 52.65\mathrm{mm};\ \mathrm{b} = 2a; \tag{7}$$

Using the rotation formula, rotate 90 degrees, the path position of the cutter tip is

$$\{-D\mathrm{Sin}[at] - B\mathrm{Sin}[(b-a)t], D\mathrm{Cos}[t\alpha] - B\mathrm{Cos}[(b-a)t]\} \tag{8}$$

The track position of the milling tool tip relative to the center of rotation of the object is

$$\{-107.1\mathrm{Sin}[t], 3.8\mathrm{Cos}[t]\} \tag{9}$$

The available trajectory is shown in Figure 5. A partial enlarged view is shown in Figure 6.

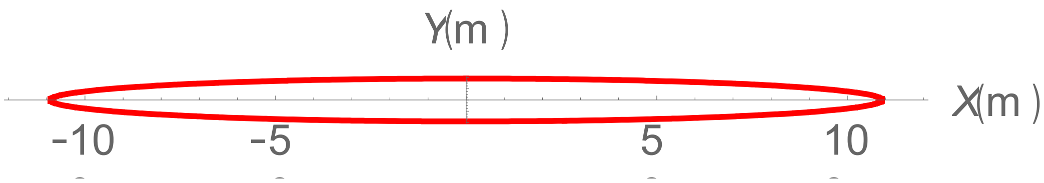

Figure 5. Rotary speed 2 times cutter tip trace B=52.65mm，D=56.45mm

Figure 6. Rotary speed 2 times cutter tip zoom path diagram B=52.65mm，D=56.45mm

Figure 3 and Figure 5 can be combined to obtain Figure 7. Figure 4 and Figure 6 can be combined to obtain Figure 8. The actual processing of the measured object speed is 1497 rpm as shown in Figure 9. The finished product after machining a rectangular edge at a time is shown in Fig. 10. Finished product measurement the rectangular edge length is 9.6mm*7.8mm.

Figure 7. Rotary speed 2 times cutter tip trace B=51.65mm、52.65mm，D=56.45mm

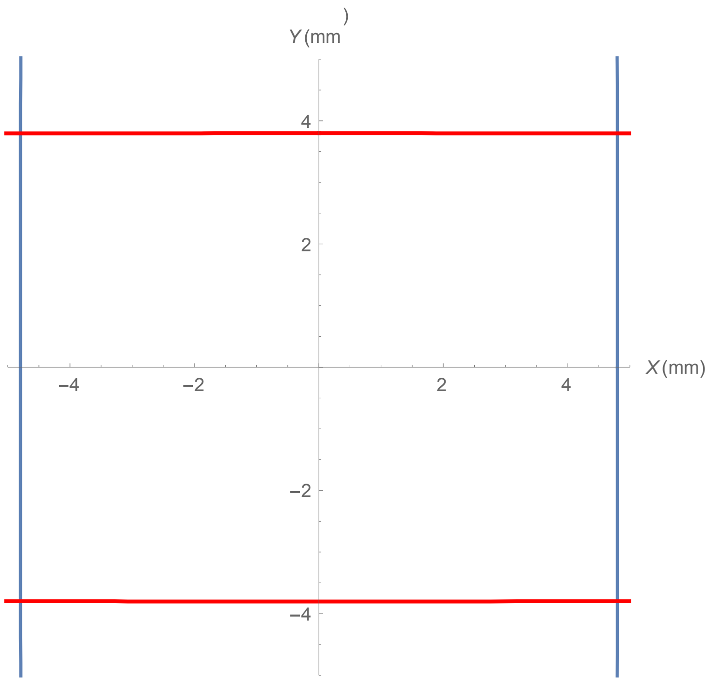

Figure 8. Rotary speed 2 times cutter tip zoom path diagram B=51.65mm、52.65mm，D=56.45mm

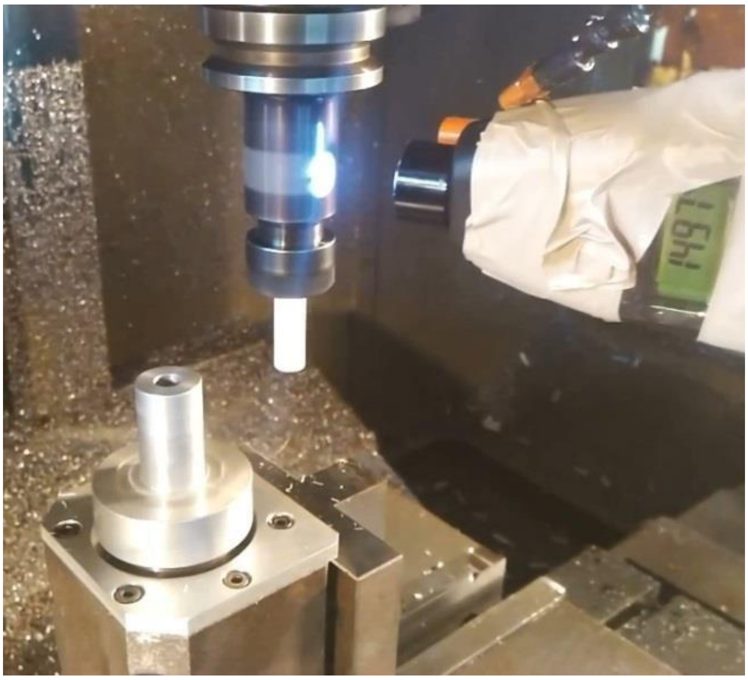

Figure 9. The actual processing of the measured object speed is 1497 rpm

Figure 10. Finished drawing after rectangular cutting

5. Conclusion

This paper discusses the polygon processing of a milling machine. The unequal rectangles are actually machined once. This article uses a speed measuring instrument to instantly correct the speed. The speed of the milling cutter tower and the object can be maintained at a certain ratio. One-time milling completes shapes such as regular polygons and rectangles.

▪Reference

Chen, T.J., Design and manufacturing of regular polygon turning mechanisms and optimization, Master's Thesis, Far East University, 2015a.

Chen, W.F. and Chang, J.T., The optimizing design of regular polygon turning, the 32th National Conference on Mechanical Engineering of CSME, 2015b, Paper number: 2219.

Chen, W.F. and Pan, Z.Z., A research of optimal polygon turning, *ICCPE&ICI*, Kenting, Taiwan, 2016a, Paper ID: C268.

Chen, W.F., Pan, Z.Z. and Chen, T.J., Design and Error Analysis on Turning Polygon, the 33th National Conference on Mechanical Engineering of CSME, 2016b, Paper number: 1527.

Chen, W.F., Liu, C.C., Huang, Y.L. and Chen, T.J., Design and Simulation of Power Mechanism with Polygon Turning, the 34th National Conference on Mechanical Engineering of CSME, 2017, Paper number: 10396.

Hwang, J.H., Chen, W.F., Chen, T.J. and Tseng, N.A., A research of mill-turn multi-tasking machine on polygon turning, the 31th National Conference on Mechanical Engineering of CSME, 2014, Paper number: 00557.

Tseng, N.A., Researches of polygonal shape and helical surface using lathe machining, Master's Thesis, Far East University, 2012.

Wang, F.S., Chen, W.F., Chang, J.T., Yeh, C.S. and Tseng, N.A., Research on polygon turning, the 30th National Conference on Mechanical Engineering of CSME, 2013, Paper number: 1697.

Innovative Problem Solving on Straightener Stick Design and Model Making

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Abstract

Round steel is not a straight bar when it is rolled from a hot rolling mill. It is necessary to pass through the two stick surfaces of the straightener to straighten the round steel. The two stick surfaces are symmetrical. The axis of the two stick surfaces has an angle with the axis of the circular steel. Usually two sticks are arranged up and down, one stick is fixed below, and the top stick is movable and can move up and down. This paper uses 2D envelope and 3D envelope theory, coordinate transformation, normal equidistant surface, curved spiral, spiral binding wire meshing contact surface space technology, a helical line of contact engagement surface and step of the method to solve the formula. The detailed procedures for the theory, design, and calculation of the straightener stick were established. The stick solid design and 3D print model making of the leveler were performed with different data.

Keywords: envelope, normal equidistance, straightening machine, hot rolling mill.

1. Introduction

In the field of mechanical manufacturing, gear movement and transmission of various types of mechanisms, machining of forming tools, grinding of grinding wheels, and even multi-axis machining of tools generally conform to the conjugate theory. The two conjugate surfaces have a common contact point, there is a common normal at the contact point, and the relative velocity cannot be a component of the line direction at the contact point. The relative velocity of the contact point cannot be in the direction of the line, in other words, it cannot be slipped. The two objects are in contact at this moment, and the next moment of contact is still inseparable and not relevant. Another way of saying it must conform to envelope theory. The contact points of the two objects are the same at each moment of contact, and the slope of the contact points is also the same. The location of the next moment is different, and the contact points are naturally different. However, the two objects have the same contact point at this time, and the contact point has the same slope.

Mechanical manufacturing uses a lot of spiral surfaces. All the rotating surfaces are widely used, for example, the finished products on the lathe and the tools on all kinds of milling machines are rotating surfaces. Rotary surfaces and cylindrical surfaces are all special examples of spiral surfaces.

The parametric equation of a general space curve has one parameter. The parametric equation of the surface has two parameters. The parametric equation of an entity has three parameters. A family of curves consists of a combination of curves, one parameter more than the curve usually has two parameters. A family of surfaces is a combination of surfaces. There is usually one more parameter than surface. There are three parameters. Due to the different choice of parameters, the same surface can be represented by different equations.

If both objects are rotating, the normal of the momentary contact point will intersect with the axis of rotation of the two objects. These theories seem simple. In conjunction with the physical characteristics of the mechanism's motion, coupled with coordinate transformation, complex calculations can solve practical problems. The results must also be compensated if necessary to match the actual situation. It is often necessary to solve many very complex nonlinear equations. Only in this way can there be a large number of designs for the design and processing of different machine shapes.

Envelope and inverse envelope theory are used in mechanical manufacturing and mechanism design. For example, the design and manufacture of various tools are applied to envelope theory (Chen, 2002a; Chen, 2002b; Chen, 2004; Lai, 2002). In this paper, the envelope theory and application (Chen, 1998; Su, 1998) are used to design the stick surface of the straightening machine, and the 3D printing technology is used to verify the actual product.

2. Stick surface straightening machine design

Hot rolling mills are not straight bars when rolling round steel. Round steel requires a straightened machine to straighten. The straightening machine has two sticks. The axis of the two stick surfaces has an angle α with the axis of the circular steel, and the two stick surfaces are symmetrical. Two sticks are arranged up and down, one stick is fixed below, and the top stick is movable and can move up and down.

A normal isometric surface is a curved surface formed by taking all the points in the positive or negative directions at each point of the surface. The equation for the surface is $\mathbf{r}(u,v)$. The equation for a surface is such that the normal unit vector at any point above it is n.

The normal unit vector n is

$$\mathbf{n} = \frac{\mathbf{r}_u \times \mathbf{r}_v}{\left|\mathbf{r}_u \times \mathbf{r}_v\right|} \tag{1}$$

$$r_u = \frac{\partial r}{\partial u} \text{ , } r_v = \frac{\partial r}{\partial v} \tag{2}$$

There are two normal isometric surfaces with a surface distance h, and the equation is:

$$\mathbf{r}_h = \mathbf{r} \pm h\mathbf{n} \tag{3}$$

A curve on the X, Z plane, the parameter equation is:

$$C = \begin{cases} x = f(v) \\ z = g(v) \end{cases} \tag{4}$$

The rotation angle of the curve around the z axis is u, the radius of the turn rotation surface is f(v), and the equation of the rotation surface is:

$$r(u,v) = \{f(v)\cos u, f(v)\sin u, g(v)\} \tag{5}$$

Rotary plane plus translation along the z-axis bu, that is spiral motion, spiral surface equation is:

$$r(u,v) = \{f(v)\cos u, f(v)\sin u, g(v) + bu\} \tag{6}$$

It is known that the radius r of the round steel material, the included angle α between the stick axis and the axis of the round steel product, and the vertical distance A between the stick axis and the axis of the round steel product are as shown in Figure 1. The relationship between the two sticks and the cylindrical entity is shown in Figure 2.

The equation P for a cylindrical radius r is:

P{x,y,z}={r Cos[θ], r Sin[θ],z} (7)

x=r Cos[θ]
y=r Sin[θ]
z=z (8)

$$R_\theta = \frac{\partial R}{\partial \theta} = \{-rCos\theta, r\sin\theta, 0\} \tag{9}$$

$$R_z = \frac{\partial R}{\partial z} = \{0,0,1\} \tag{10}$$

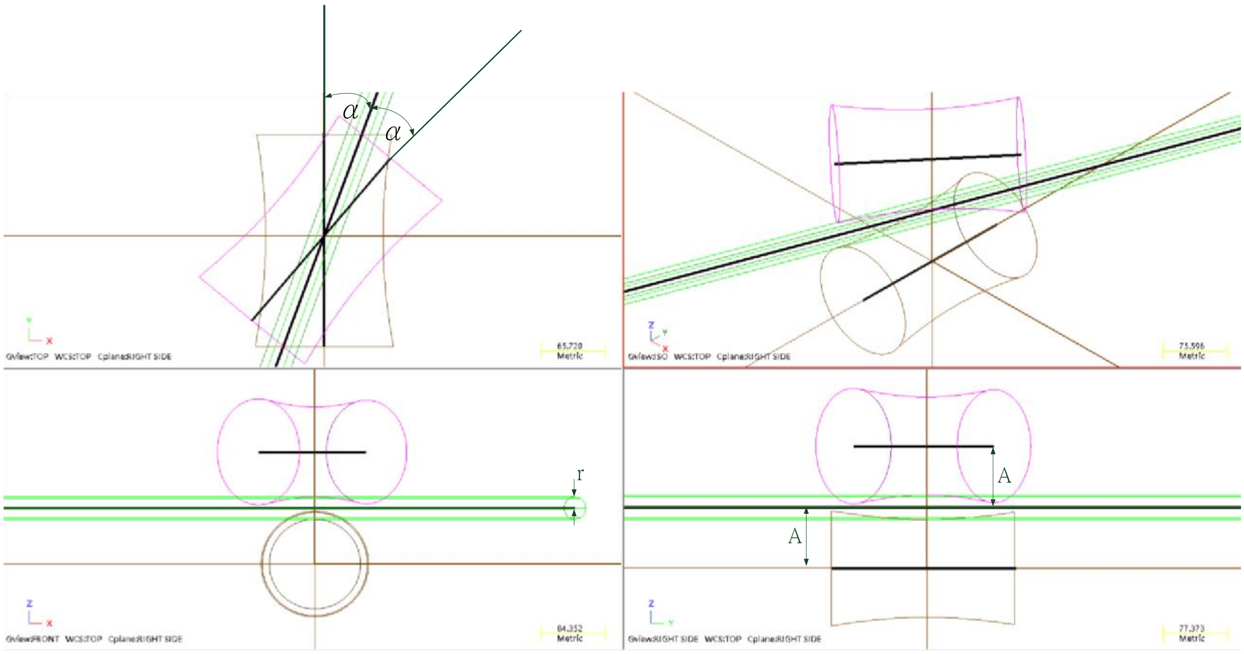

Figure 1. The relationship between the axis of two sticks and the cylindrical axis

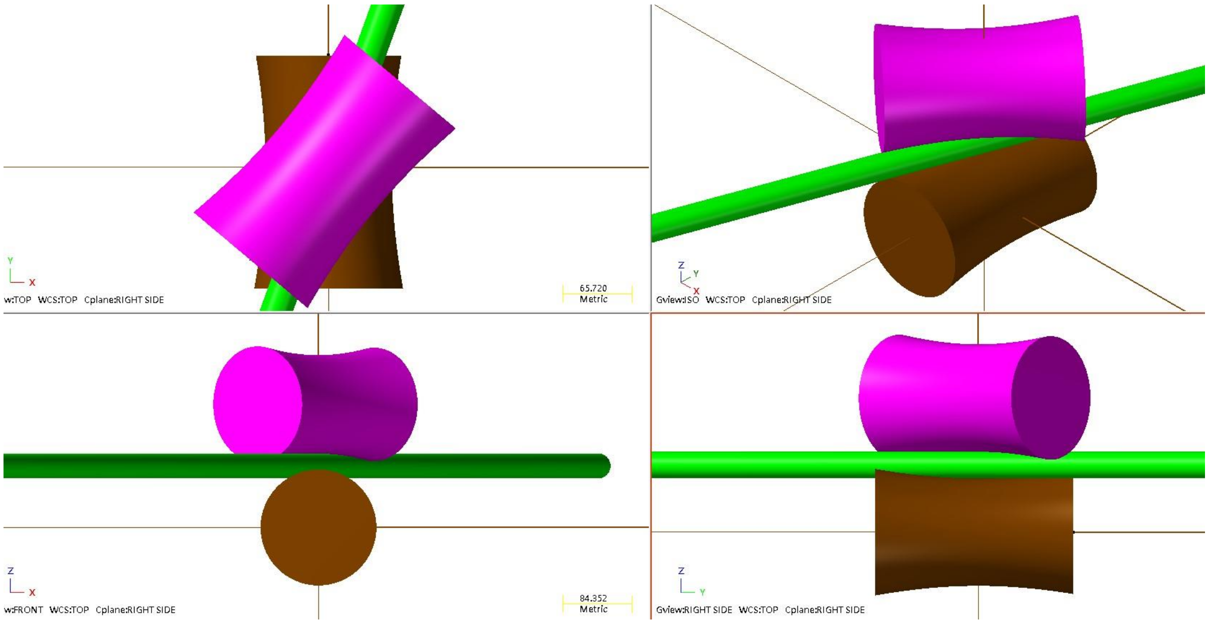

Figure 2. Two sticks and cylindrical entity diagram

The normal vector of a cylindrical surface is:

$$n=R_\theta \times R_z = \frac{\partial R}{\partial \theta}\times\frac{\partial R}{\partial z} = \{-rCos\theta, r\sin\theta, 0\}\times\{0,0,1\} = \{rCos[\theta], rSin[\theta], 0\} = \{x, y, 0\} \quad (11)$$

If the stick coordinates is {x1, y1, z1}. The relationship between the stick and the circular steel coordinate transformation is:

x1=x-A
y1=y Cos[α]-z Sin[α]
z1=y Sin[α]+z Cos[α] (12)

The cylindrical surface of the round steel is in contact with the stick surface and a contact line is available. Each contact P(x,y,z) has a normal vector n= $\{x, y, 0\}$. The stick face is a rotating surface. The normal at any point on the rotating surface is coplanar and intersects with the instantaneous axis. The axis of the stick surface is a straight line that passes the O_1(A,0,0) point and has a unit vector $k = \{0, \sin\alpha, \cos\alpha\}$. Then the O_1P=W equation is:

W={r Cos[θ]-A, r Sin[θ], z} (13)

$$\text{n1} = \text{Cross}[k, \text{W}] = \{z\text{Sin}[\alpha] - r\text{Cos}[\alpha]\text{Sin}[\theta], -A\text{Cos}[\alpha] + r\text{Cos}[\alpha]\text{Cos}[\theta], A\text{Sin}[\alpha] - r\text{Cos}[\theta]\text{Sin}[\alpha]\}] \quad (14)$$

The envelope equation complies with: The envelope equation conforms to the contact line conditions as:

$$\text{F=Dot[n1, k]} = r(z\text{Cos}[\theta]\text{Sin}[\alpha] - A\text{Cos}[\alpha]\text{Sin}[\theta]) = 0 \quad (15)$$

$$\theta = -\text{ArcCos}\left[\frac{A\text{Cos}[\alpha]}{\sqrt{A^2\text{Cos}[\alpha]^2 + z^2\text{Sin}[\alpha]^2}}\right] \quad (16)$$

$$x = r\text{Cos}[\theta] = \frac{rA}{\sqrt{A^2 + z^2\text{Tan}[\alpha]^2}} \quad (17)$$

$$y = r\text{Sin}[\theta] = \frac{rz\text{Tan}[\alpha]}{\sqrt{A^2 + z^2\text{Tan}[\alpha]^2}} \quad (18)$$

Get the stick section equation as:

$$\{\text{x1,y1,z1}\} = \{-A + \frac{Ar}{\sqrt{A^2 + z^2\text{Tan}[\alpha]^2}}, -z\text{Sin}[\alpha] + \frac{rz\text{Sin}[\alpha]}{\sqrt{A^2 + z^2\text{Tan}[\alpha]^2}}, z\text{Cos}[\alpha] + \frac{rz\text{Sin}[\alpha]\text{Tan}[\alpha]}{\sqrt{A^2 + z^2\text{Tan}[\alpha]^2}}\} \quad (19)$$

The distance between the shape of the stick and the axis of rotation is:

$$R1=\sqrt{x1^2+y1^2} \tag{20}$$

The stick shape equation is:

$$\{z1,R1\} \tag{21}$$

The stick shape is rotated 360 degrees around the axis to get a stick solid body.

3. Straightener stick entity example production

A=65mm, α=45 degrees, r=5mm, the stick profile can be obtained as shown in Figure 3. The left and right sides take the Z axis 200mm, 20 intervals, and a total of 41 points. Transfer point data to CAD and establish stick axis as shown in Figure 4. The establishment of the stick entity is shown in Figure 5. Produce and reduce by 4 times with 3D printing can get complete and up and down two sticks and cylinder entities as shown in Figure 6.

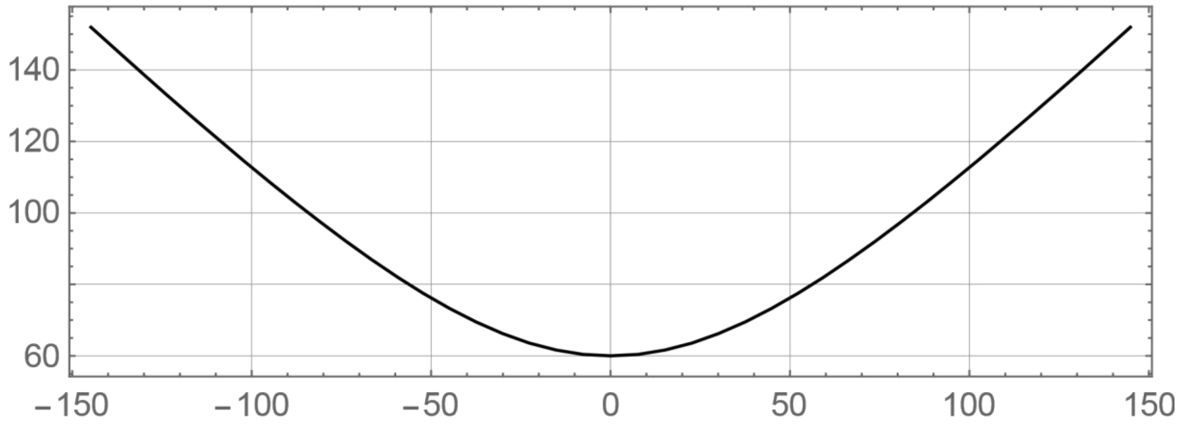

Figure 3. The stick profile A=65mm, α=45 degrees, r=5mm

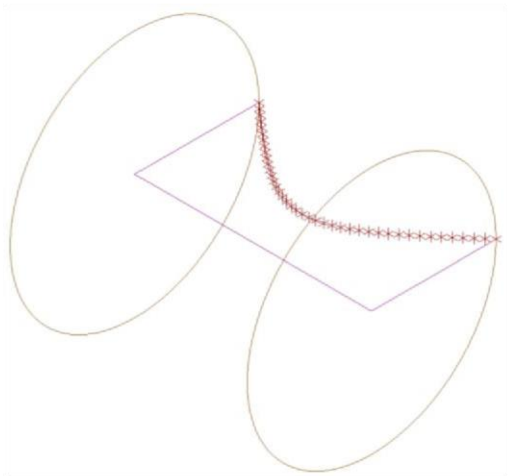

Figure 4. The sampling points and stick axis

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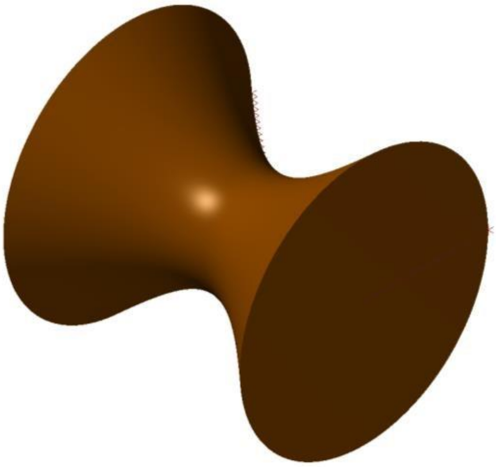

Figure 5. The stick entity

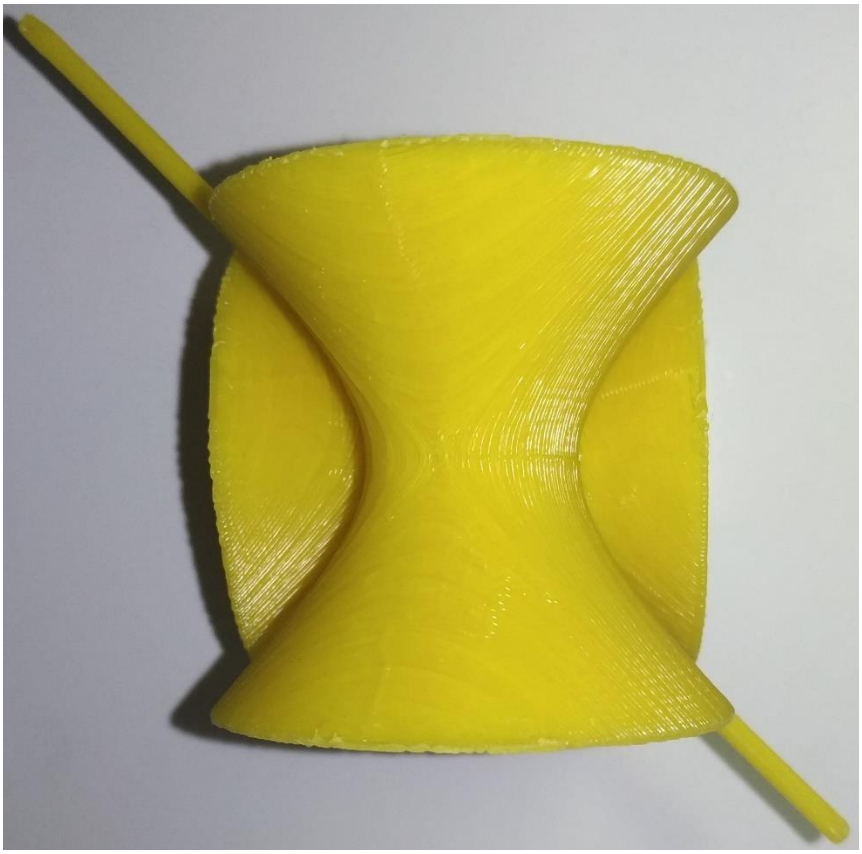

Figure 6. Up and down two sticks and cylinder entities

4. Conclusion

Known surface families are often used in mechanical manufacturing for enveloping. Or invert the envelope, and the contact line and the surface in the surface family are obtained by the known envelope. In practical calculations, it is necessary to coordinate with other physical conditions and coordinate transformation, and complicated nonlinear calculations can solve practical problems. In this paper, the theory and technology of envelope, coordinate transformation, normal equidistant surface, spiral surface and spiral surface space meshing contact line are used. This paper establishes the procedure and method for solving the spiral surface meshing contact line. It is applied to the design and calculation theory of stick solids in straighteners. Based on actual data, the physical design, drawing, and 3D printing of the straightener were performed.

▪Reference

Chen, C.K., Tang, Y.Y. and Wu, H.G., Differential Geometry and Its Application in Mechanical Engineering, Harbin Institute of Technology Press, 1998

Chen, W.F. and Lai, H.Y., A comprehensive engineering model for the design, Manufacture and Assembly of Helical Carpenter Shapers, *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, 2002a, 216, 1493-1504.

Chen, W.F., Lai, H.Y. and Chen, C.K., Design and NC machining of concave-arc ball-end milling cutters, *Advanced Manufacturing Technology*, 2002b, 20, 169-179.

Chen, W.F., A precision design for computer numerical machining models of involute-generator revolving cutters, *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, 2004, 218, 517-531.

Lai, H.Y. and Chen, W.F., Precision design and numerical control machining of tapered ball-end milling cutters, *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, 2002, 216, 183-197.

Su, B.Q., Hua, X.N. and Yu, Y.L., Introduction to Practical Differential Geometry, Science Press, 1998

Virtual reality applications in new product development for improving product safety

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Abstract

Virtual Reality (VR) is currently applied in different stages of new product development process for increasing productivity and production lead-time in high technology manufacturing industries (e.g., automotive industry) before releasing the finished products to markets. Medium and low technology manufacturing industries are facing several problems on product safety, short product development time, small batch and high variety of market trends. Product safety is seldom documented in the VR applications. This paper studies the opportunities of applying VR to evaluate potential hazard and improve product safety in various stages of new product development process in consumer products manufacturing industries. This paper discusses (i) current product safety condition in consumer product industries, (ii) virtual reality characteristics, (iii) virtual reality applications in high technology industry, (vi) three product-recall cases of consumer products in three major stages of new product development in the US.

Keywords: Virtual Reality, product safety, product recall, new product development

1. Introduction

Manufactures pay substantial efforts to improve product safety in new product development process for enhancing their product competence and value as most customers are willing to spend money on safer products “Bai, L., Zhang, H. (2004)”. Manufacturers with different technology levels are looking for emerging technologies to upgrade their production and safety management systems to improve the operation technique. High technology manufacturers like automotive manufactures, they involve over thousand pieces of components/modules for each finished product and high manufacturing cost in new product development process. They have been using the virtual reality system to control the product cost and productivity, since 1990’s “Lawson, G., Burnett, G., (2015)”. Conversely, medium and low technology manufacturers like consumer product manufactures, they involve less than hundred pieces of components/modules and low manufacturing cost in new product development process. Labor-intensive and low machinery technology are being used to meet the market trend under small batch and high variety condition, product safety could be influenced when any deviations of labor and machinery are found “Berry, W. L., & Cooper, M. C. (1999)”. In the past 50 years, the United States (US) is the largest consumer markets in the world, the United States Consumer Product Safety Commission (CPSC) indicates that total recalled cost in the US is more than US $700 billion each year and the recalled consumer products include household products, toys and others “Menon, et. al. (2014)”.

This paper begins with an overview of virtual reality. Applications of virtual reality in manufacturing industry will then be introduced. Current new product development process problems and recall cases are also described. Product-recall cases for each major new product development stages (including conceptual design stage, production stage and inspection stage) in the US and possible virtual reality applications are also described in this paper.

▪1.1 Virtual Reality

Virtual reality is not a brand new technology in manufacturing industries. In the past three decade, research projects on applications of virtual reality in new product development and manufacturing studies to increase productivity in different manufacturing industries, like aviation and automotive industries, were carried out. Actually, virtual reality system consists of four fundamental technologies: (1) Input devices include keyboards, electronic glove and joysticks to interact the virtual objects and operation environment, so as to simulate the working behavior; (2) Output devices include standard high-resolution display to immerse the operator in the virtual environment “Figure 1” “Mujber, et. al. (2004)”; (3) Resolution involves the graphics rendering system that generate the high resolution image; (4) Database construction and maintenance system include the data source for building the input three dimensional graphic and maintaining detailed information to simulate the operation environment as real as possible “Brooks, F. P. (1999)”. There are some advantages of virtual reality applications. Firstly, it helps operators to familiar with the workstations and works for improving productivity in real production; Secondly, it evaluates the virtual operation results and modifies the operation procedures; Thirdly, it reduces the lead time of allocating the operation procedures and machinery movement.

Figure 1. Fully immersive VR environment "Mujber, et. al. (2004)"

2. Virtual Reality applications in Manufacturing Industries

Automotive industry was one of the first batches "Brooks, F. P. (1999)" of virtual reality applications in the new product development processes from conceptual design, digital prototyping to mass production stages "Figure 2" so as to maintain the core competences in the past decade "R. Stark et al. (2010)".

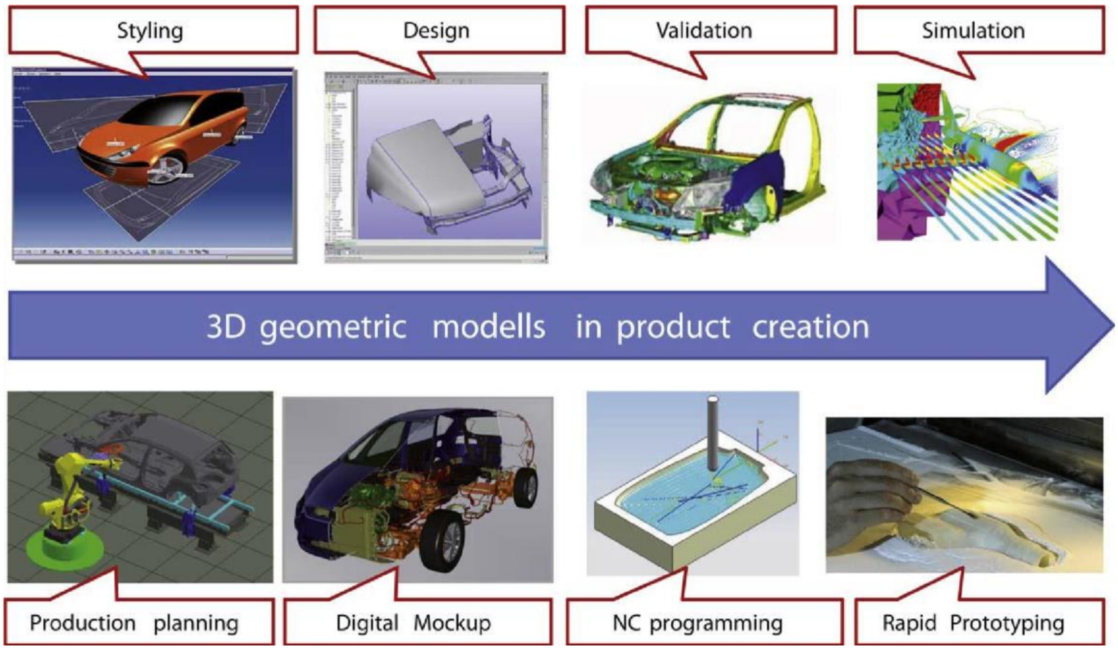

Figure 2. Virtual technologies for product creation "R. Stark et al. (2010)"

There are three main reasons such as quick product response of new product, high customer demand of product quality and competitive manufacturing cost, to try some emerging technologies like virtual reality in the automotive industry “Lawson, G., Burnett, G., (2015)”.

In conceptual design stage, aesthetic and functionalities of new car models are modified frequently to fulfill the market trend and company strategy before making physical or digital prototyping “Fiorentino et al., (2002)”. Changing aesthetic design is not only influencing the scale of the major outer part like doors or bumper, but also affecting the dimensions of other inner mechanical components and electronic modules like engine module. As a result, a huge amount of redesign time and cost could be involved for each round of modification process. Thus, automotive industry involves a higher product cost than consumer products; the early stage of new product development could influence around 70% of the total product cost “Shao, F., Robotham, A.J., Hon, K., (2012)”. Therefore, virtual reality is the possible solution to shorten the redesign lead-time, reduce the modification cost and minimize the design errors.

In prototyping stage, building several versions of physical prototype are unavoidable practices during new product development in the automotive industry, automotive companies build several numbers of physical prototype for demonstrating the unique technologies and modern aesthetic in the automotive exhibition, and testing the fundamental functionalities on the testing track and laboratories. At early stage of prototype stage, virtual reality is being applied to fabricate different versions of digital prototyping, at the same time instead of single version of physical prototyping at each time in order to pull up the development schedule and save a huge amount of prototyping cost “Kulkarni et al., (2011)”. Thus, product designer simply uses the three-dimensional software to modify the outer major parts and inner modules in the digital prototype rapidly.

In assembling stage, automotive manufacturers are innovative pioneers to apply the assembly and disassembly operations in virtual reality environment “Qiu et al., (2013)”. Before planning the assembly procedures and designing the jigs and fixtures methods in mass production, manufacturers integrate the existing product design software with virtual reality application to create the virtual operation environment and identify any potential assembly problems. Since large scale of robotic arms and electronic spot-welding machines are applied in the physical assembly process, virtual reality assists the manufacturers to identify the ideal critical operation path for production; decrease the preparing time for reallocating any machinery and enhance product quality in production “Lee et al., (2001).

Original Equipment Manufacturer (OEM) companies like Jaguar Land Rover, which integrates the virtual reality in new product development. Jaguar Land Rover established the Virtual Innovation Centre (VIC) in the headquarters at United Kingdom to develop some new virtual reality technologies such as Cave Automatic Virtual Environment (CAVE) and ergonomic-based systems to simulate the product design performance in conceptual and identify the appropriate assembly methods and potential human factors before mass production respectively.

3. Virtual Reality Applications in product safety

▪3.1 Checking product safety in conceptual design stage

In consumer product industry, project designer always uses free hand sketching and computer-aided design (CAD) and computer-aided manufacturing (CAM) software “Zeugebauer, R., et al. (2011)” to present the conceptual idea of new product to different stakeholders “Figure 3” in new product development process “R. Stark et al. (2010)”.

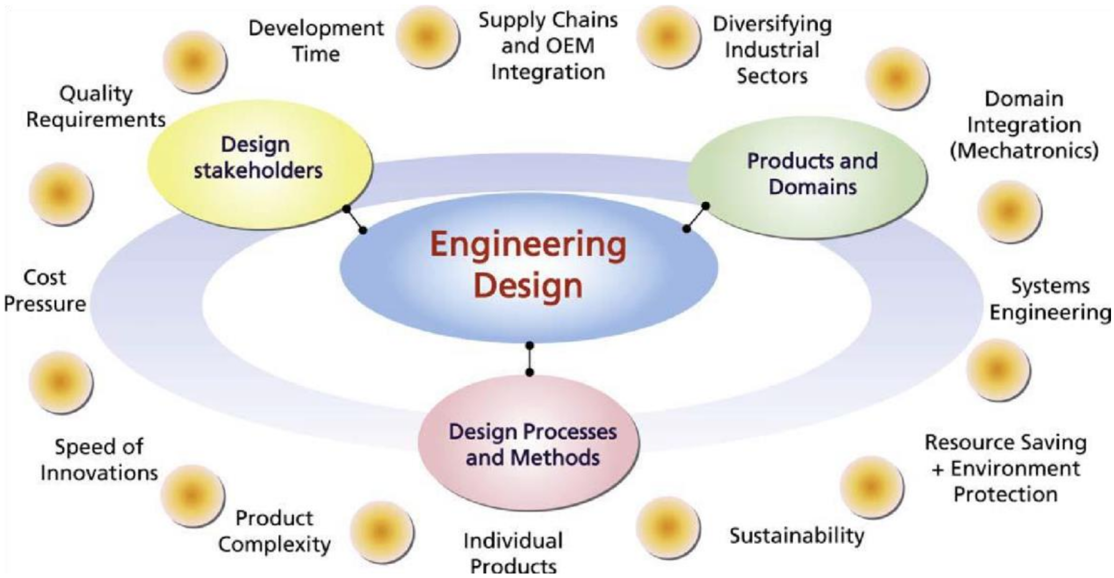

Figure 3. Competition drivers in engineering design “R. Stark et al. (2010)”

Different stakeholders have different consideration criteria to the conceptual design, internal sales and marketing team mainly foci on the product aesthetic and present the digital or physical drawing for promoting the product in the market; engineering team mostly concerns about the feasibilities of product safety, structure and function in future production. Therefore, several versions of conceptual designs are created to fulfill the majority requirements in different timeslots of new product development. This design practice consumed developing time for changing conceptual design back-and-forth, development cost are also increased for reviewing different versions repeatedly. The most important is that potential safety hazards are not identified promptly.

For example, the Home Depot Product Authority recalled bout 64,200 units of the Home Decorators Collection 3-Light and 4-Light Comotti Vanity Fixtures “Figure 4” in the US in June 2017 “Home Depot (2017)”. Design problem was found in this case as the light shades of the home decorators collection 3-light and 4-light comotti vanity fixtures can detach and fall, posing laceration and burn hazards. The company has received 108 reports of shades falling, including one report of a laceration to the head that also involved a laceration and burn to the arm and one report of a laceration to the leg. This product was complied with the luminaire safety standard UL 1598 and CPSC requirements before launching to the market.

Figure 4. Home Decorators Collection 3-Light and 4-Light Comotti Vanity Fixtures "Home Depot (2017)"

Virtual reality could be used to analyze some major potential risks in the virtual product in the conceptual design stage. When product designer creates the preliminary digital three dimensional drawings in the computer, virtual product could also be developed for sales and marketing team to choose the appropriate materials and design; engineering team to clarify the manufacturability and quality assurance team to assess the potential risks through the virtual reality kit set. The performance of virtual reality system could be applied with some special features such as thermal heat and loading features inside the sensitive glove, teammate could visual some warning signals in the screen and feel different temperature in the glove when hotspot and sharp edge areas are found. Potential customers could also be invited to simulate the using behaviors and comment on the virtual new product through virtual reality system in order to prevent any safety problems.

▪3.2 Structure verification in production stage

In pilot and mass production, assembly process is a compulsory manufacturing process to assemble all relevant components and complicated modules together as finished products. Industrial engineering team usually applies the concurrent engineering methods, from planning the manufacturing process, prioritizing the assembly procedure, developing jig and fixture, to training the shop floor workers, in order to utilize the limited resources, minimize the assembly time and cost, and maintain the product safety at high standard. While product contains complex assembly structure and diversification with small batch size, short production lead time and worker fluidity, which is the market trend "Tůma, Z. et al. (2014)" in manufacturing industries, product safety could be affected accordingly.

For example, the Graco Children's Product Inc., recalled about 26,000 units of Safety 1st and Beatrix Potter "Designer 22" infant car seats/carriers. "Figure 5" in the US in February 2002 "CPSC, (2002)". This product may have missing components on the base or seat. The components are metal hooks and "U" bars that are used to attach the carrier to the base. If the hardware is missing, the carrier may not be securely attached to the base. In the event of a sudden stop or crash, the carrier may detach from the base possibly resulting in serious injury or death "Graco, (2002)". The Graco has four reports of the handle releasing and no injuries were reported. This product was complied with the US toy safety standard FMVSS 213 and CPSC requirements before launching to the market.

Figure 5. Safety 1st and Beatrix Potter "Designer 22" infant car seats/carriers "Graco (2002)"

Virtual reality could be implemented to improve the assembly problems such as missing components and misassemble in the assembly process. Product designers could provide basic dimensions and functional requirements of each component to process designers after confirming the product design. Afterward, process designers could work with the industrial engineers to prioritize the virtual assembly method for each critical components or modules, and then develop the corresponding jig and fixture in the virtual assembly environment. The shop floor supervisors could comment on the manufacturing aspects such as operational time study, accessibilities, mechanical reachability and ergonomic applications to the virtual reality system "M. Weyrich, Paul Drews (1999)". At the end, frontline workers could simulate the complicated assembly process and familiar with the critical assembly process through the interactive graphic simulation before working on the physical production line.

▪3.3 Performance validation in inspection stage

In traditional manufacturing industries, inspection system is well-developed in mass production. Quality assurance (QA) identifies the potential assembly problems in the quality inspection plan, quality controller (QC) follows such plan to conduct onsite inspection and evaluate any defects in the production process and warehouse before shipping finished goods to the customers. However, different types of defects could be found in the market and customers can be suffered due to the product safety problem.

For example, the Little Tikes recalled about 540,000 units of 2-in-1 Snug'n Secure pink toodler swings "Figure 6" in the US in February 2017. The plastic seat can crack or break, posing a fall hazard to the infant. The Little Tikes has received about 140 reports of the swing breaking, including 39 injuries to children including abrasions, bruises, cuts and bumps to the head. Two of the reported injuries included children with a broken arm "Little Tikes (2017)". This product was complied with the US toy safety standard ASTM F963 and CPSC requirements before launching to the market.

Figure 6. Little Tikes 2-in-1 Snug'n Secure pink toddler swings "Little Tikes (2017)"

Virtual reality could be applied to enhance the QC inspection knowledge and technique in order to minimize the similar problems in future. Base on the reliability testing results in the pilot production, virtual reality system could be used to develop the virtual product, QA and QC could use the system to familiar with the product structures, assembly method and critical components, they could also simulate the inspection process and spot out any potential hazards before conducting the physical inspection in the production plant.

4. Conclusion

This paper reviewed the current product safety conditions in consumer products, virtual reality characteristics, virtual reality applications in manufacturing industries and some US major product-recall cases in three stages of new product development process. It is noticed that current new product development process could be integrated with emerging technologies like virtual reality to evaluate the potential hazards in production before launching consumer products to the market.

▪Reference

Bai, L., & Zhang, H. (2004, August). Singapore consumer product safety scheme. In Electromagnetic Compatibility, 2004. *EMC 2004. 2004 International Symposium* on (Vol. 1, pp. 150-152). IEEE.

Berry, W. L., & Cooper, M. C. (1999). Manufacturing flexibility: methods for measuring the impact of product variety on performance in process industries. *Journal of Operations Management*, 17(2), 163-178.

Brooks, F. P. (1999). What's real about virtual reality?. *IEEE Computer graphics and applications*, 19(6), 16-27.

CPSC, NHTSA, and Dorel Juvenile Group Inc. Announce Recall to Repair Infant Car Seats/Carriers, 2002.https://www.cpsc.gov/Recalls/2002/cpsc-nhtsa-and-dorel-juvenile-group-inc-announce-recall-to-repair-infant-car

Fiorentino, M., De Amicis, R., Monno, G., Stork, A., 2002. Space design: a mixed reality workspace for aesthetic industrial design. *In: 1st International Symposium on Mixed and Augmented Reality. Darmstadt, Germany*, 30 October- 1 November 2002. IEEE, New York, pp. 86–94.

Graco'sSnugRide Infant Car Seats, 2002. https://www.gracobaby.com/en-US/product-recall-details?gbprd=CS02INFCSR

Home Depot Recalls Home Decorators Collection 3-Light and 4-Light Comotti Vanity Fixtures, 2017 https://www.cpsc.gov/Recalls/2017/design-solutions-international-with-home-depot-recalls-light-fixtures

Kulkarni, A., Kapoor, A., Iyer, M., Kosse, V., 2011. Virtual prototyping used as validation tool in automotive design. In: Chan, F., Marinova, D., Anderssen, R.S. (Eds.), MODSIM2011, *19th International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand. Perth, Australia, 12-16 December 2011. pp. 419–425.

Lawson, G., Herriotts, P., Malcolm, L., Gabrecht, K., Hermawati, S., 2015. The use of virtual reality and physical tools in the development and validation of ease of entry and exit in passenger vehicles. *Appl. Ergon*. 48, 240–251.

Lee, W., Cheung, C., Li, J., 2001. Applications of virtual manufacturing in materials processing. J. Mater. Process. Technol. 113 (1), 416–423.

Little Tikes Recalls Toddler Swings Due to Fall Hazard, 2017 https://www.cpsc.gov/Recalls/2017/Little-Tikes-Recalls-Toddler-Swings

Memon, M. S., Lee, Y. H., & Mari, S. I. (2014). A Model for optimizing traceability of product in a supply chain based on batch dispersion. In Logistics Operations, *Supply Chain Management and Sustainability* (pp. 101-114). Springer, Cham.

Mujber, T. S., Szecsi, T., & Hashmi, M. S. (2004). Virtual reality applications in manufacturing process simulation. *Journal of materials processing technology*, 155, 1834-1838.

Neugebauer, R., Wittstock, V., Meyer, A., Glänzel, J., Pätzold, M., Schumann, M., VR tools for the development of energy-efficient products, *CIRP Journal of Manufacturing Science and Technology*, 208-215 (2011).

Qiu, S., Fan, X.,Wu, D., He, Q., Zhou, D., 2013. Virtual human modeling for interactive assembly and disassembly operation in virtual reality environment. *Int. J. Adv. Manuf. Technol*. 69 (9–12), 2355–2372.

Stark, R., Krause, F. L., Kind, C., Rothenburg, U., Müller, P., Hayka, H., & Stöckert, H. (2010). Competing in engineering design—The role of Virtual Product Creation. *CIRP Journal of Manufacturing Science and Technology*, 3(3), 175-184.

Tůma, Z., Tůma, J., Knoflíček, R., Blecha, P., & Bradáč, F. (2014). The process simulation using by virtual reality. *Procedia Engineering*, 69, 1015-1020.

Weyrich, M., & Drews, P. (1999). An interactive environment for virtual manufacturing: the virtual workbench. *Computers in industry*, 38(1), 5-15.

Systematic Identification for Workforce and Competency Requirements for Testing, Inspection and Certification Sectors

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Abstract

The adoption of competency model and systems for identification and evaluation has become the good practice in many organizations in recent years. Competency development and management are widely regarded as vital tools to enhance competitiveness for organizations as well as for growing industries. As the world is in transition that we are being pulled in different directions by the challenges of globalization and the dynamic and ever-changing technologies, innovative product development, global supply chains, product safety and traceability are some of the main issues that are being concerned by society. In this regard, one of the growing industries – Testing, Inspection and Certification (TIC) play a vital role to guarantee of quality and credibility dealing with the global challenges. The testing, inspection, certification (TIC) is providing services to the companies operating across various industrial verticals for the purpose of improving the productivity, efficiency, manufacturing process for manufacturers to meet with the globally recognized standards, regulations and policies set by government to improve the quality of the product. In view of the importance of testing, inspection and certification, the workforce and competency requirements for the testing and certification are discussed by using systematic identification approach.

Keywords: System Identification, Competency Standards, Testing and Certification, Unit of Competency,

1. Introduction

The testing, inspection, certification (TIC) industry enjoys some key advantages. Operators generally deliver higher margins and require relatively lower capital expenditure than other business services sectors. And financial performance is typically underpinned by excellent revenue visibility, due to longer-term contracts and framework agreements – supplemented by regulation. These sound fundamentals ensured the TIC sector remained strong in the market. However, the lack of global certification standards and lack of skilled personnel. With the increase in the import and export and globalization, the product testing and quality standards are increasing but some of the factors such as difference in the quality and testing and lack of global certification standards restrain the growth of Testing, inspection and Certification market on a global scale. Many countries like India, and in Middle East are experiencing the lack of skilled personnel. Out of the large labor force in India, only 5% are the skilled workforce and many of them are without any professional skills.

With this, competency development and management are the critical instruments to increase competitiveness for TIC sector. Nowadays, the concept of competencies has been adopted to for the identification, selection and development of the expertise in organizations. A competency model is a set of success factors, and includes the key behaviors required for excellent performance in a particular role. Furthermore, the competency model can be used to identify the required competencies which employees need to improve performance in their current job or to prepare for other job. TIC practitioners can utilize competency-based approach to improve themselves, their team as well as the organizational performance. Hence, applying competency models is now a leading strategy used by TIC stakeholders to identify and develop employees' competencies.

2. Testing, Inspection and Certification Sectors

TIC help verify that products are compliant with a market's regulatory requirements and are safe for consumers. They enhance the quality assurance of products, minimise the chance of recalls, returns, complaints, and reduce financial risks to suppliers, traders, and retailers. According to the new research report "Testing, Inspection, and Certification (TIC) Market by Service Type (Testing, Inspection, Certification), Sourcing Type (In-house and Outsourced), Application (Consumer Goods & Retail, Agriculture & Food, Chemicals), and Geography - Global Forecast to 2023", the testing, inspection and certification (TIC) market is expected to be worth USD 247.94 billion by 2023, at a CAGR of 5.02% from USD 184.77 Billion in 2017. The growth of this market is mainly driven by harmonization of standards, growing consumption of goods in emerging countries, increasing incidents of product recalls globally, surge in global counterfeiting and piracy activities, and imposition of rigorous government regulations and standards across various sectors.

It is worth to note that increasing outsourcing of TIC services is expected to emerge as a key opportunity for companies in the global testing, inspection and certification market over the forecast period. Many large firms are increasingly outsourcing TIC services because the increased regulations make it costly to conduct test in-house, thereby helping the firms to reduce the overall cost of testing. Demand for outsourcing TIC services to third-party vendors is increasing for applications such as consumer goods and manufacturing owing to the capital-intensive nature of in-house TIC activities.

TIC market for transportation application was also hold the largest share in 2016. The transportation industry is subject to a variety of stringent regulations, standards, and legislations. The transportation application includes automotive, marine, aerospace and defence, and rail. These industries are required to continually meet the highest levels of safety and reliability tests for the safety of passengers and assets. With this, technical knowledge and skills are essential to support the development of the TIC sectors to cope with the manpower demand. Hence, there is a need to review the skill competency requirement by the TIC stakeholders as well as the competency standards for TIC sectors.

3. Competency Standards for TIC

Competency standards have been established in a number of countries, including the United Kingdom (QAA, 2014), Europe (EQF, 2014) and Australia (AQF, 2013). The requirements of these standards vary according to the conditions set by the government agency. Similarly, the Qualifications Framework under the Education Bureau of the Hong Kong government has developed the Specification of Competency Standards of the testing, inspection and certification industry in 2014. The Specification of Competency Standards (SCS) is regarded as a set of core competencies for the identified work functions with specifications on integrated outcome performance for the industry. These competency standards are the industry requirements for the skills, knowledge and attributes required to satisfactorily perform a job at a certain qualification level. According to the QF in Hong Kong, the qualification levels are designed in a seven-level hierarchy, which ranks level 1 as the lowest and level 7 as the highest. Various skill functions are presented as units of competencies (UoCs) in the SCS. The QF elaborates that UoCs are competency based, contextual and outcome criteria referenced. Each UoC represents an inseparable, self-contained set of competencies required to perform a specific task. The UoCs can be grouped into building blocks for serving different purposes. The SCS consists of 242 UoCs which are distributed in 7 major functional areas at various QF levels. TIC stakeholders make use of the distribution to evaluate, identify or develop employees' competencies in terms of testing operations, testing quality management, inspection operations, inspection quality management, certification operations, certification quality management and operation management.

Table 1
Distribution of Unit of Competencies (UoCs) at different levels

Functional Area	**QF Level**							**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	
Testing Operations		6	29	63	45	8		**151**
Testing Quality Management				2	3	3		**8**
Inspection Operation			2	7	10			**19**
Inspection Quality Management				1	5	1		7
Certification Operation				3	11	4		18
Certification Quality Management				3	4	2		9
Quality Management		2	3	8	9	8		30
Total		**8**	**34**	**87**	**87**	**26**		**242**

It is noted that “Testing Operations” contributes the majority of the functional area of UoCs with a range of QF levels (from Level 2 to Level 6). In addition, the UoCs consists the majority of QF levels in both Level 4 and Level 5.

Figure 1 Different functional areas for TIC sectors

Further review has been conducted for the SCS that the job functions vary with different QF level. More technical knowledge is required for higher QF levels. Table 2 illustrate the job function of the UoCs consisting in the testing operation.

Table 2
Job function of Unit of Competencies (UoCs) at different QF levels for Testing Operation

QF Level	Job function for the Unit of Competencies	Examples
2	Sampling	Collect routine site samples
3	Sampling Handling	Pre-condition test samples
4	Test Method Development and Operation Planning	Perform stability and mechanical tests
5	Test Method Development and Operation Planning	Perform evaluation tests
6	Test Method Development and Operation Planning	Validate laboratory information management system

4. Recognition of Prior Learning (RPL)

Although the functional area in TIC industry can be identified by referring to the SCS, this is only served the basic framework for the evaluation of individual's competency. To identify what skill sets are required for a particular job competency, it is worth to review the clusters of units of competency in Recognition of Prior Learning (RPL) under Qualification Framework mechanism. RPL is an assessment process that assesses an individual's formal, non-formal and informal learning to determine the extent to which that individual has achieved the required learning outcomes, competency outcomes, or standards for a certain qualification. The major purpose of setting up a Recognition of Prior Learning (RPL) mechanism under the Qualifications Framework (QF) is to enable employees of various backgrounds to receive formal recognition of the knowledge, skills and experience already acquired. It facilitates employees with learning aspirations to know what competencies they have acquired through experience or previous training in the industries, so that they can determine their starting point for learning and progression and reduce duplication in training for the same skills. The RPL mechanism operates basing on the Specification of Competency Standards (SCSs) formulated by the TIC industry. There are 51 RPL clusters which indicate what skill sets required for the particular competency. Table 3 illustrate two examples of RPL clusters out of the 51 clusters.

Table 3 RPL Clusters for TIC industry

RPL Cluster	QF Level	UoC Codes	Unit of Competency
Measurement Uncertainty (Physical Testing)	4	105768L4	Estimate and report measurement uncertainty
		105871L4	Apply statistical calculations to measurement data
Sample Handling	3	105777L3	Pre-condition test samples

To confirm a TIC practitioner attaining the competency in "Measurement Uncertainty", he/she should be capable to estimate and report measurement uncertainty, apply statistical calculations to measurement data. Similarly, a TIC practitioner is competent in "Sample Handling" as long as he/she is able to demonstrate the capability in handling pre-condition test samples.

5. Model of Systematic Identification for Competency Requirements for Testing, Inspection and Certification Sectors

It is used to indicate this careful review and identification process which is usually used synonymously but which has a more specific meaning relating to the combining and quantitative summarising of results from a number of studies. The systematic identification process for competency requirements includes five stages:

1. Establishment of mission and goals
2. Identification of competency by SCS functional areas
3. Identification of competency by UoCs of RPL clusters
4. Assessment and evaluation
5. Skill gap identification

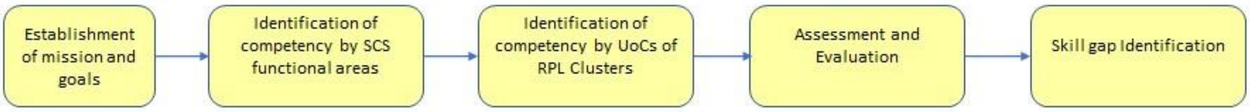

Figure 2 Systematic Identification Process Model for TIC Industry

According to conceptual framework in Figure 2, the components in the Systematic Identification Process Model can be further interpreted as:

1. Establishment of mission and goals – To setup the goal by defining the purpose of conducting competency identification
2. Identification of competency by SCS functional areas – To identify the functional areas according to SCS
3. Identification of competency by UoCs in RPL clusters – To identify the skill competency of T&C practitioner according to RPL clusters
4. Assessment and evaluation - To assess and evaluate the individual's performance with the competency requirements of TIC.
5. Skill gap identification – To identify any skill gap exist and to identify the required competencies which employees need to improve performance in their current job or to prepare for other job.

7. Conclusions

Based on the model, the workforce and competency requirements for TIC can be identified by utilizing SCS and RPL clusters as the competency standards.

In short, the systematic identification model is capable to support:

- Human resources management and development: for employers to design their in-house or internal training to individual employees or to use the SCS as yardsticks for identifying personnel with suitable skills and knowledge for recruitment or promotional purposes

- Education and training for individual continuous improvement: SCS provides the learning outcomes (required competencies at various QF levels) and assessment criteria for TIC practitioners to evaluate themselves as well as to identify any skill gap exist. They can conduct further study or training to learn the skills in order to bridge the skill gaps. The adoption of the systematic identification can sustain competitiveness and facilitate workforce development for the TIC sectors.

▪Reference

Australian Qualifications Framework Council. (2015) *Australian Qualifications Framework*. Australian Qualifications Framework Council.
Available from: www.aqf.edu.au/wp-content/uploads/2013/05/aqf-2nd-edition-january-2013.pdf

European Qualifications Framework (EQF) (2012). *The European Qualifications Framework for Lifelong Learning*. European Qualifications Framework

Quality Assurance Agency for Higher Education (QAA) (2014) *The quality code*. UK: Quality Assurance Agency for Higher Education.
Available from:www.qaa.ac.uk/en/Publications/quality-code-brief-guide.pdf

Wise Guys Reports (2018). "Testing, Inspection and Certification (TIC) Market 2018 Global Trend, Segmentation and Opportunities Forecast To 2025."

Hong Kong Council for Testing and Certification. (2017). "Report of the Hong Kong Council for Testing and Certification 2016-2017."
Available from: http://www.hkctc.gov.hk/en/doc/HKCTCAnnualReport_2016-17_Eng.pdf

Hong Kong Qualification Framework (HKQF). (2016) *Comparability Study of the Hong Kong Qualifications Framework and the European Qualification Framework for Lifelong Learning.* Hong Kong: Hong Kong Qualification Framework.

Certification Scheme for Virtual Reality based Stroke Rehabilitation Devices

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Abstract

Virtual Reality (VR) Technology is rapidly developing and applied in different application. The most common applications are game and entertainment. In the recent years, VR technologies are applied to tertiary education, electrical and maintenance (E&M) training and rehabilitation. In the areas of rehabilitation, VR technologies are applied to help stroke survivors relearn skills lost. Liked many other health-related devices, there is no well-recognized product certification schemes to cover such products. It is a room for the industrialists and researchers to develop the product certification scheme for health-related devices.

Keywords: Product certification, stroke rehabilitation, Virtual Reality.

1. Introduction

Stroke is one of major leading causes of death in the developed countries. In the United States of America, stroke is the fifth leading cause of death and may cause the serious disability for adults (Stroke 2018). In Hong Kong, stroke is the fourth leading cause of death kills with about 3000 people per year (Stroke 2016). Figure 1 shows the top ten of leading cause of death in Hong Kong. It is noticed that around 66% of persons can survive and require rehabilitation. Rehabilitation aims to let patients to live independent and to keep best possible quality of life. Rehabilitation will help survivors to learn the skills, including the coordination of leg movements in order to walk or carrying out the activities (Post-Stroke 2018). The rehabilitation exercises were normally designed and teach to the survivors by the physiotherapists. However, the problem of shortage of physiotherapists is serious. The Hong Kong SAR Government indicated that Hong Kong could see a shortage of 933 physiotherapists by 2030 (The Standard 2018).

Some researchers are investigating alternative ways to help the survivors, such as Virtual Reality (VR) technology. In this paper, we will discuss applications of Virtual Reality and the lack of product certification scheme for VR-based rehabilitation devices.

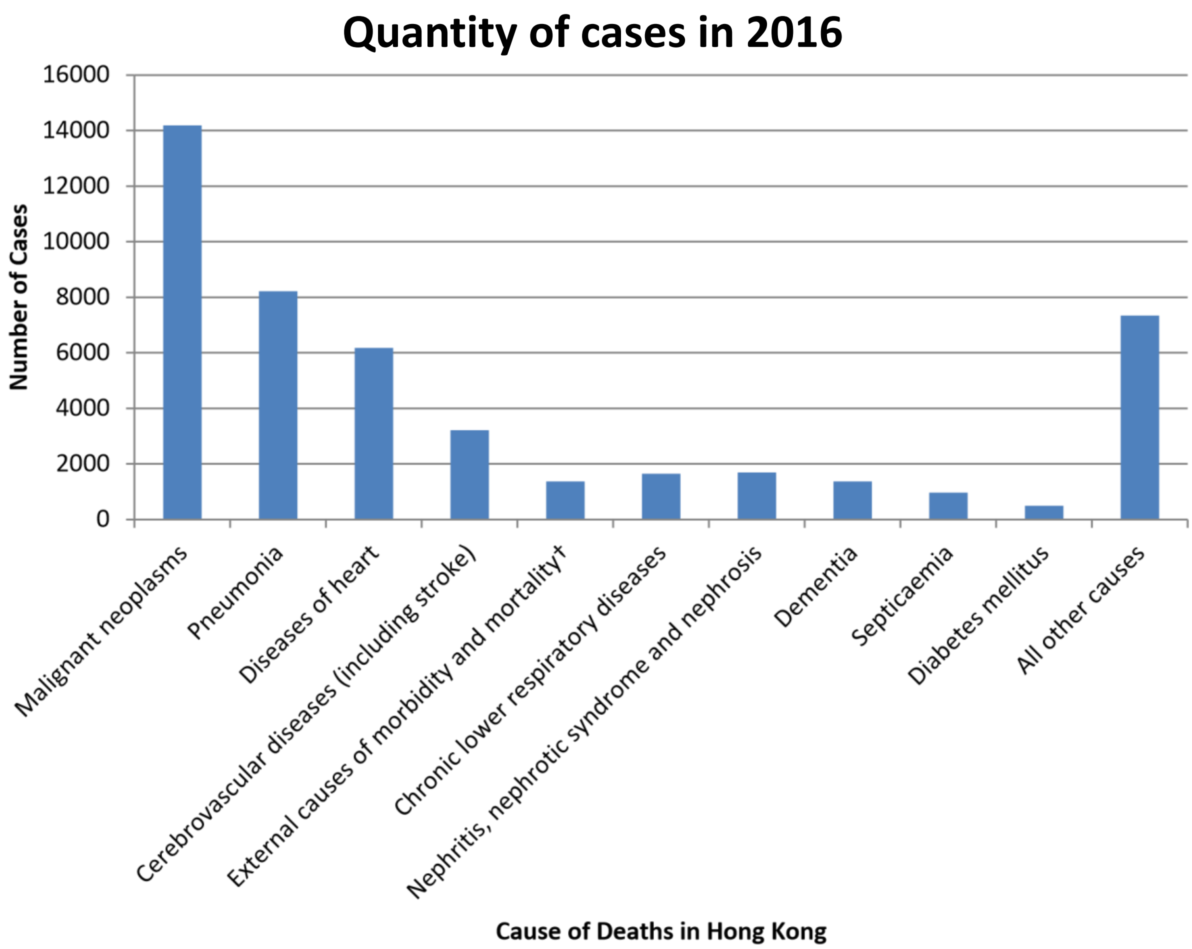

Figure 1: Top 10 Causes of Death in Hong Kong (2016)
(Source: http://www.strokefund.org/eng/stroke_part2.php/)

2. Applications of Virtual Reality Technology

Virtual Reality provides a high-end user graphical interface that involves real-time simulation and interaction through multiple sensorial channels, such as visual, audial, touch, smell and taste VR technology, has been developing over several decades. It was used for medical, flight simulation, motor simulation, product design and military training purposes since 1970s. Meanwhile, NASA established their Jet Propulsion Laboratory by using the Virtual Reality Technology (Nelson, Ted 1982). The VR Technology becomes popular in many areas, such as entertainment and product design (Burdea & Coiffet, 2003).

One of the hottest applications of Virtual Reality Technology is to provide trainings, such as virtual laboratory for distance education in chemistry. The educators developed the scenes and allowed the students to carry out the experiments without using danger and hazardous substances in order to protect the teachers and students (Georgiou, Dimitropoulos and et. al, 2007). Railway companies developed simulators to allow the operators to learn how to handle the emergency situations and investigating the personal safety at railway stations (Cozens, Neale, and et. al, 2003). Pro-Act (Electrical Engineering) of Vocational Training Council developed a VR system to train how to maintain and repair elevators and lifting system in Hong Kong.

Since 2000, David Jack and his research team started to study the application of VR-Enhanced Stroke Rehabilitation. It aims to re-train the stroke-survivors to modify their neural organization and recover the functional motor skills. He found that the VR technology has the potential to replace the traditional rehabilitation (David, Rares and et. al, 2001). Another researching team led by Gustavo Saposnik had similar conclusions, they used the Wii gaming tools with VR technology and apply to the stroke survivors and conclude that the VRWii technology was feasible and safe to the survivors (Saposnik, Teasell and et, al, 2010). However, K. Laver had different viewpoints and concluded that there was limited evidence to sayVR is beneficial to improve survivor's the motor skills compared with the same dose of conventional therapy (Laver, George and et, al, 2012).

3. Importance of Product Certification schemes in newly developed technology

In the last section, we found that the use of VR-based Stroke rehabilitation may lead to different results. Like other newly different products, it is important to give evidence to customers and users that the product is feasible, effective and safe. The prices may need to be increased once the product was being certified (Roheim & Wessells, 2001). Nowadays, the Food and Drug Administration (FDA) of the United States and other medical administration departments of other countries do not have such mandatory product certification scheme for the VR-based rehabilitation devices. The industrialists and researchers have a room to develop the voluntary certification scheme for the VR-based rehabilitation devices. The certification scheme could be not only covering safety issue, it can also cover the functionality, performance and reliability of the products.

Theoretically, any industrial, trade or research organizations can follow the requirements of ISO/IEC 17067: 2013 to develop product certification scheme. The standard specified the fundamentals elements of product certification and guidelines for product certification schemes. The most common product certification scheme was to cover the construction materials. The typical product certification involves (1) testing; (2) inspection; (3) design appraisal; (4) assessment of products; and (5) other determination activities, such as system audit.. The certified products will be labelled with unique code of product certification scheme.

4. Development of Product Certification Scheme

ISO/IEC 17067: 2013 is the latest edition of the standard in guiding organizations to establish their product certification scheme. Before the organization started to develop the scheme, they shall consider the scope of scheme carefully, including the type of products included in the scheme. The technical team shall be formed with a group of the expertise in such area.

Typical requirements of a product certification scheme are (1) the international, national or trade standards and normative documents shall be evaluated to form the technical and general requirements of the products; (2) the activities appropriate to the certification scheme shall be included, such as audit, testing and inspection; (3) other requirements shall be met by the certification applicants, such as requirement of quality management system (QMS) and process control procedure; (4) whether the conformity assessment bodies are included in the scheme are to be accredited, participate in peer assessment or qualified in another manner; such as laboratory, inspection bodies or certification bodies; (5) the information shall be supplied to the certification bodies for product certification process; (6) product certification marking with the unique traceable code assigned to the certified products. (7) handling of client's complaints; (6) documentation system; (7) maintenance of certification scheme and (8) surveillance procedure (ISO/IEC 17067).

After the scheme is formulated, the certification bodies and regulatory bodies could adopt the scheme and promoted to the public. ISO/IEC 17065 is an international standard to include the both general and technical requirements for bodies certifying products, processes and services (ISO/IEC 17065).

5. Conclusion

Virtual Reality Technology is developed rapidly and might be used in the Stroke rehabilitation. However, the reliability and effectiveness are questionable. Similar to other newly innovative products, it is recommended to adopt product certification scheme in order to prove the safety, effectiveness, reliability and performance. This paper describes the importance and development elements of a typical product certification scheme.

▪Reference

Burdea Grigore, C., & Coiffet, P. (2003). Virtual reality technology. John Wiley & Sons.

Cozens, P., Neale, R., Whitaker, J., & Hillier, D. (2003). Investigating personal safety at railway stations using "virtual reality" technology. Facilities, 21(7/8), 188-194.

Georgiou, J., Dimitropoulos, K., & Manitsaris, A. (2007). A virtual reality laboratory for distance education in chemistry. International Journal of Social Sciences, 2(1), 34-41.

ISO/IEC 17065: 2012 Conformity assessment -- Requirements for bodies certifying products, processes and services

ISO/IEC 17067: 2013 Conformity assessment -- Fundamentals of product certification and guidelines for product certification schemes

Jack, D., Boian, R., Merians, A. S., Tremaine, M., Burdea, G. C., Adamovich, & Poizner, H. (2001). Virtual reality-enhanced stroke rehabilitation. IEEE transactions on neural systems and rehabilitation engineering, 9(3), 308-318.

Laver, K., George, S., Thomas, S., Deutsch, J. E., & Crotty, M. (2012). Virtual reality for stroke rehabilitation. Stroke, 43(2), e20-e21.

Nelson, Ted (1982). Report on Siggraph '81". Creative Computing, March 1982

Post-Stroke 2018. Post-Stroke Rehabilitation
Available at: https://stroke.nih.gov/materials/rehabilitation.htm [Accessed 2 July 2018].

Roheim, C. A., & Wessells, C. R. (2001). Product certification and ecolabelling for fisheries sustainability (No. 422). Food & Agriculture Org..

Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., ... & Bayley, M. (2010). Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: a pilot randomized clinical trial and proof of principle. Stroke, 41(7), 1477-1484.

Stroke 2016. Death Rates by Leading Causes of Death 2016
Available at: http://www.strokefund.org/eng/stroke_part2.php
[Accessed 2 July 2016].

Stroke 2018. Stroke Home
Available at: https://www.cdc.gov/stroke/index.htm [Accessed 2 July 2018].

The Standard 2018. Shortage of physios sparks warning
Available at: http://www.thestandard.com.hk/section-news.php?id=184119 [Accessed 2 July 2018].

Research on Establishing Maturity Model of Organizational Innovation Management System

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Abstract

A company that pursues sustainable development should be able to consistently launch successful new products. Continuous innovation has become one of the key success factors of innovation-oriented companies. Companies must be able to design an innovation management system that is appropriate for the organization and become an innovative organization. This study used SMEs as the research object, first established an evaluation index system for the organization's product innovation management system from the perspective of literature research, and then applied the hybrid multi-criteria decision-making method to establish the impact of the evaluation index of the product innovation management system on the network association map. Based on the CEN/TS 16555-1 international standards, the innovation management system interrelated factors influence the relationship-level performance evaluation model to support innovative organizations to establish innovative leadership and innovation culture. Then, a performance radar chart is used to present the innovation management system performance of the case organization, and finally a suitable improvement plan is proposed by influencing the network association diagram (system structure model) so as to continuously improve the organization's innovation management capabilities. Following the latest European innovation management standards, this research helps and supports our clients to develop and innovatively maintain a systematic structural model of a system's innovative management practices. Establishing such a management system can make companies more innovative and achieve greater success through innovative products and services.

Keywords: Innovative Organizations, Innovation Management Systems, Hybrid Multi-Criteria Decision-Making Methods

建構組織創新管理系統成熟度模型之研究

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摘要

一個追求可持續發展的企業應該能夠持續地推出成功的新產品。持續創新產品已經成為創新導向型企業的關鍵成功因素之一。企業必須能設計一個適合於組織的創新管理系統，進而成為創新型組織。本研究以中小企業為研究對象，首先從文獻探討中建立了組織的產品創新管理系統評估指標體系，接著應用混合式多評準決策方法建立產品創新管理系統的評估指標的影響網絡關聯圖，建構基於 CEN/TS 16555-1 國際標準的創新管理系統關間因素之相互影響關係級績效評估模型，以支援創新型組織建立創新領導與創新文化的建立。然後以績效雷達圖呈現個案組織的創新管理系統績效，最後藉由影響網絡關聯圖(系統結構模型)提出合適的改善方案，以持續改善組織的創新管理能力。遵循最新的歐洲創新管理標準，本研究幫助和支持我們的客戶開發和創新維護一個系統的創新管理實踐的系統結構模型。建立這樣一個管理系統，可以使企業變得更具創新性，並透過創新產品和服務獲得更大的成功。

關鍵字**:** 創新型組織、創新管理系統、混合式多評準決策方法

1.組織創新管理系統成熟度模型的發展

創新管理系統(IMS)是一個新的主題，可以使組織發展壯大，創造更多的利潤。創新不僅僅是產生下一個偉大的創意，而是涉及到實施新構思的方式，以及如何塑造創新文化以維持創意。因此，實施這樣的管理系統可以使組織機構在產品、服務、流程、組織設計和商業模式創新方面更具創新性，取得更大成功和競爭優勢。

1.1.標準化創新管理系統

創新管理體系的目的是為導入、開發和維護系統的創新管理實踐提供指導，以提高組織的創新能力，從而在創新方面取得更大的成功（CEN 標準，2013）。創新管理系統標準化則支持創新管理關鍵成功因素的建立和創新管理能力成熟度模型的建構。

1.1.1.創新管理系統

創新管理系統包含若干相互關聯的組成部分：探索客戶需求和市場趨勢，根據新的洞察力以及組織的願景和目標採取策略行動;並管理和控制採取的開發和向市場推廣創新的所有活動（Morris，2011; Tuominen 等，1999; Sundbo，1997）。此外，Van de Ven（1986）強調，為創新設計的組織需要整合管理整個價值鏈創新所需的基本職能、組織單位和資源。根據這一推理，CEN 標準（2013）指出，創新管理系統應包括提高組織創新能力所需的所有活動，從而增加組織持續創新的機會。Anthony 等人（2014 年）強調，創新管理系統的建立是特定創新(ad hoc innovation)和持續創新工坊(continuous innovation factory)之間的重要聯繫，這個聯繫之間的層級可以提供組織建構創新管理成熟度的框架。

從這些文獻可以得到一個結論，成功的創新管理系統(IMS)為組織提供了一個端到端(end-to-end)的過程，其特徵在於構想的辨識和實施，以實現創新成果。雖然存在許多創新管理方法，但是一個好的系統是關於實現和有方法的構想管理。一般來說，IMS 需要包含五個關鍵階段：第一階段：確定構想 the identification of ideas 第二階段：細化或定義潛在的機會(refinement or definition of potential opportunities) 第三階段：發現或進一步證明概念(discovery or conduct of further proof of concept) 第四階段：開發或實施前的活動(development or pre-implementation activities) 第五階段：交付給予價值 (delivery to confer value)

同樣重要的是，五個階段的每個階段都是“歸檔(archive)”未來重新評估思想的機制，刪除不相關的構想，並在組織內傳達創新過程。

組織建立 IMS 可以獲得下列的主要好處：

- 透過創新提高組織的成長、收入和利潤；
- 給您的組織帶來新的思維和新的價值；
- 透過更好地瞭解未來市場需求和可能性，積極捕捉價值；
- 有助於識別和減輕創新風險；
- 深入組織的集體創造力和智力；
- 從與合作夥伴的合作中獲取創新的價值；
- 激勵員工參與組織，並促進團隊合作。

創新管理系統應該是一個整合多方專業、技術與管理的全面性解決方案，其運作的原則通常在於：

- IMS 能夠作為內外在創新團隊及組織所處的開放式創新環境中各個不同協作單位之間的共通語言。

- IMS 能夠促進組織內外成員達成明確的創新共識，使得創新的理念與作法充分跟組織的營運宗旨和目的結合在一貣。
- IMS 在大家擁抱共同的創新願景的同時，能進一步讓組織實現創新的策略、政策、目標與績效指標，為創新管理注入系統性的力量。
- IMS 有效整合、協同內部各項創新專案的技術與行政資源，並且有效掌控各個專案的優先順序與風險，確保創新專案的成本效益。
- IMS 提供整個組織有關創新發展的結構化職責劃分與工作授權，同時讓組織的創新管理能進入持續改善的迴饋。

創新管理系統會影響組織的創新績效。MoisesMir(2016)等人對標準化創新管理系統（standardized innovation management systems, SIMS）對企業創新能力、創新績效和企業績效的影響提供了新的分析，這對創新管理文獻的貢獻是前所未有的。這項研究的重點是標準的 UNE 166002，是全球首批國家認證的 SIMS 之一。這是世界上第一個已經達到足夠的接受程度的 SIMS 之一，可以進行實證研究。為了分析其對企業的影響，該研究使用關於主要維度的假設來開發和分析關係模型[1]。

1.1.2.標準化創新管理系統

英國於 2008 年 4 月發布新版 BS 7000-1:2008-創新管理指南。該指南專門針對創新和有競爭力的產品的設計和開發提供指導，以滿足客戶在長期的未來需求和期望。英國政府的重點：提高創新能力，以經濟效益。該指南條文 3.18 定義了創新管理系統是一個正式的基礎設施，包括組織管理創新的目標、策略和過程、組織結構和價值。

西班牙 AENOR 於 2008 年 11 月發貣 CEN / TC 389“創新管理(Innovation Management)”。並在 2013 年 7 月首次發布：CEN / TS 16555-1 創新管理系統文件[2]。我們在本書第八章「創新型組織持續創新的支持保證」中，已經討論了歐盟發展的標準化創新管理系統 CEN/TS 16555 (CEN/TS IMS)的發展。

[1] MoisesMira, MartíCasadesúsa and LucHonorePetnjib (2016), The impact of standardized innovation management systems on innovation capability and business performance: An empirical study, *Journal of Engineering and Technology Management*, Volume 41, July–September 2016, Pages 26-44.

[2] CEN / TS 16555-1 技術規範為建立和維護創新管理系統（IMS）提供指導。它適用於所有公共和私人組織，不論其部門、類型或規模。本檔就以下方面提供指導：瞭解組織的背景；建立最高管理層的領導和承諾；成功的創新規劃；確定和培養創新驅動因素/驅動因素；發展創新管理過程；評估和改進創新管理體系的績效；瞭解和使用創新管理技術。透過使用這個檔，組織可以提高他們對 IMS 價值的認識，建立這樣一個系統，擴大他們的創新能力，最終為組織和相關方創造更多的價值。注：本文件中概述的創新管理系統遵循 PDCA 結構（計劃 - 執行 - 檢查 - 行動），因此可以將其整合到組織中現有的其他標準化業務管理系統中，例如， EN ISO 9001，EN ISO 14001 等。

CEN/TS 16555 為組織建立和維護一個創新管理系統(IMS)提供了標準化指導，適用於所有政府與私人組織，無論組織類型或組織規模。

CEN / TS 16555-1：2013 的條文(3.2）對創新管理系統 InnoMS 的定義：一組組織的相互關聯或相互作用的要素，以建立創新政策和目標，以及實現這些目標的過程。InnoMS 是一系列過程組組合而成的系統。

CEN / TS 16555-1：2013 是七個技術規範系列中的第一個部分，它們追求以下維度：

- 制定創新策略和願景；
- 建立一個組織和文化來促進創新；
- 導入最合適的創新流程；
- 使用方法、技術和工具來促進創新；
- 關注和衡量創新成果。

基於這些維度，CEN/TS 16555-1 為組織提供了以下指導：

- 瞭解組織的內外部環境背景；
- 建構高階管理的領導統禦與承諾；
- 規劃創新的成功；
- 辨識和培育創新之推動/驅動因素；
- 發展創新管理過程(創新通道)；
- 創新管理系統績效的評估與改善；
- 理解與運用創新管理技術。

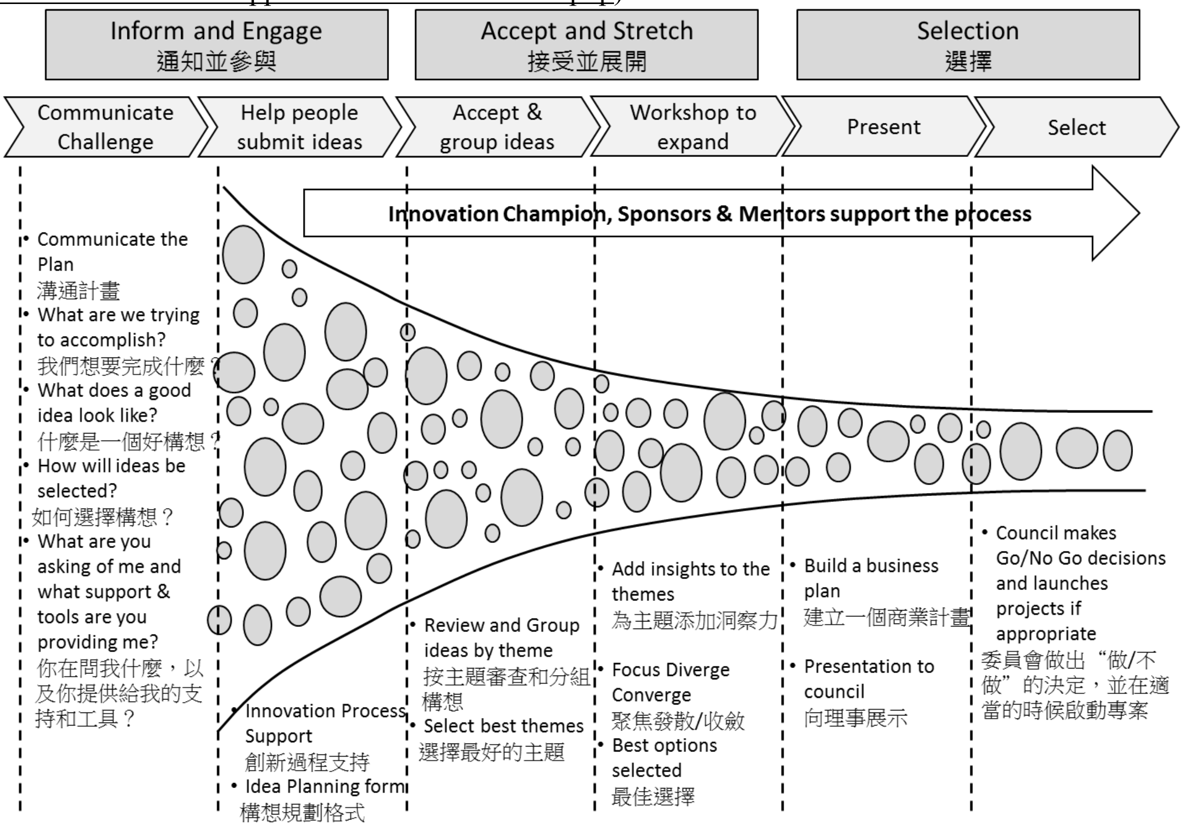
CEN/TS 16555-1 主要目的是幫助組織提高創新能力，為利害關係者創造更多價值的目標。因此，我們可以應用 CEN/TS 16555-1 的這些指導原則來建立組織創新能力評估等級，成為創新管理系統的成熟度模型。這幾個指導中，發展創新管理過程是最主要與創新產品開發相關的組成部分。

1.2.組織創新管理過程

組織創新管理過程(或稱為創新通道)已經成為許多企業運營的重要組成部分，因為認識到創新措施的重要性已經變得越來越普遍。儘管如此，許多公司確實訥圖對創新和創新採取堅實的態度，但實際上很少有公司把它作為一個單一的功能集中在一貣。相反地，他們似乎孤立地進行了許多獨立的創新活動，例如腦力激盪會議，訥點專案和活動，與市場的模糊交流，只是不斷地交叉，最終會聚到一貣。雖然這在過去有些效果，但是完成這個重要任務還不是理想的方式。相反，要做到這一點，最好的辦法是有一套創新活動，將這些創新活動整合成一個過程並融入到企業的正常循環中。組織的創新成功規劃能力、創新領導與創新策略能力和辨識組織環境能力都會影響創新管理過程能力。

創新管理過程(創新通道)透過過濾器、閘門和規則的過程來使創意/構想能夠被評估 — 建立構想管理系統 (Idea management system)來評估產生的構想。在構想過程的每一個階段，構想要麼通過過濾器，要麼通過閘門，或者不能達到推進的標準。構想可能會被歸檔（例如，如果當時沒有正當理由）或者可能會繼續進行到另外的階段。關鍵目標是產生與當前業務情況相關的大量構想，以實現新的增長。

圖 1 所示的創新管理流程可以我們幫助擴大創新構想思維流入創新通道（符合您的長期業務策略）。另外，我們可以透過創新執行方法論來識別創新的盲點和限制因素。創新管理流程中的策略驅動創新框架定義了 3 個規劃視角（包括當前業務的成本控制、鄰近客戶的增量增長以及新的市場擴張）。該框架還確定了 10 個創新類別（跨越策略、過程、產品和交付）。 綜合的結果是 30 個維度，可以產生您的創新漏斗的想法。收穫最好的構想就是創新管理流程的魔力，在這個創新管理流程中還定義了正確的階段標準，以提高合格的構想，並抵制對價值較低的構想的投資。
(http://www.desai.com/our-approach/innovation-funnel.php)



圖

1: 組織創新管理流程(創新管理通道)

此外，構想管理系統 (Idea management system)在組織中越來越普遍。構想管理系統可被視為"捕捉、檢查、培育和發展在組織內創意/構想的形式化方法"。透過實際部署，企業意識到現有構想管理系統存在各種缺陷。低度的交互溝通和知識交流導致了創意/構想開發者的特別高的工作量，並且提出了太多的想法。為了克服這些缺陷，Bansemir, Bastian and Neyer, Anne-Katrin (2009)的分析表明，企業需要一個支援多學科和團隊協作的互動式創新管理系統 (interactive innovation management system)，並包含不同的社交軟體應用程式，以增加交互溝通和知識交流。越來越多大型組織實施構想管理系統，其目的是充分利用其內部員工的知識交流和創造力，從而收集和成熟盡可能多的創新構想。

在探索和發展創新管理過程和互動式創新管理系統中，組織也可以開始探索成熟度模型(Maturity model)，希望能利用它分級過程成熟度，也讓組織先評估自身狀況，選擇適合的創新管理方案解決問題，持續精進組織的創新管理成熟度。

CEN/TS 16555-1 的創新漏斗(創新通道) 包括框架和洞察力的產生、構想管理，創新專案的開發、創新結果的保護和利用以及市場導入。如圖 2 所示。其中，評估主要是確定評估指標（財務和非財務）、監測方法、評估準則，以確保 InnoMS 的適應性(suitability)、充足性(adequacy)和效益(effectiveness)。

改善是確定並應用矯正措施，刺激學習和持續改善。

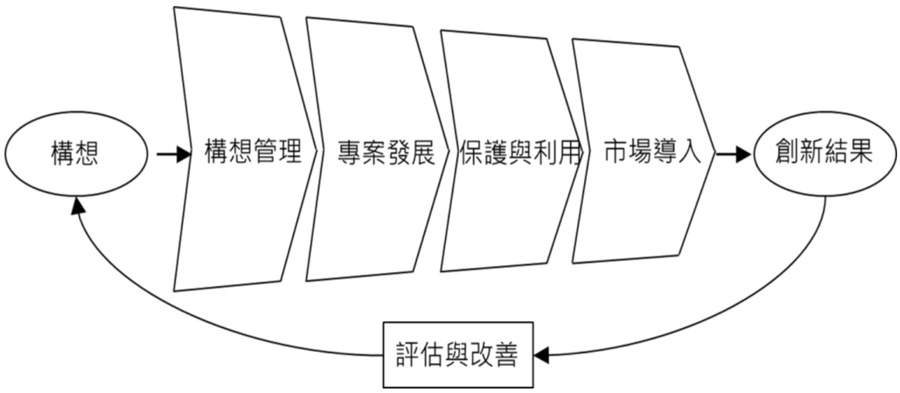


圖 2：CEN/TS 16555-1 的創新漏斗

2..組織創新管理成熟度模型

創新管理通常將高成本與高失敗率相結合。可以透過對組織創新能力的評估來處理由此產生的風險。為此，最近的研究已經開發了創新能力成熟度模型（Innovation Capability Maturity Model, ICMM）。ICMM 背後的想法是檢查一個組織如何發展新的構想。達到的成熟度水準決定了該組織能夠實現其理念的影響力，從而創造創新。

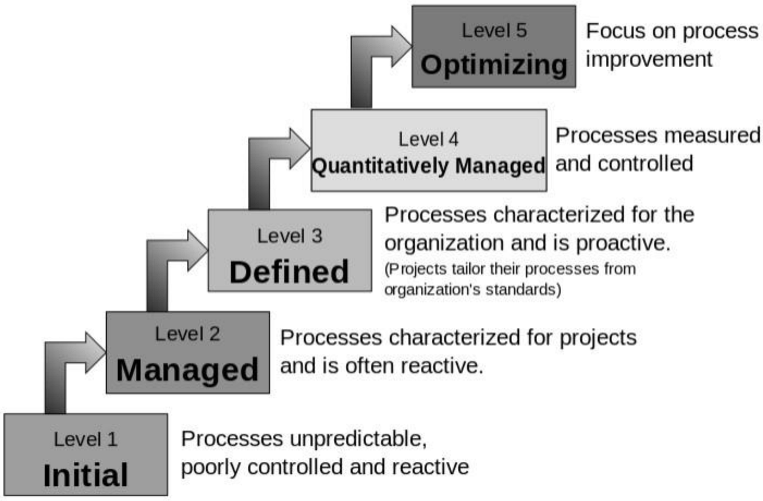
2.1. 能力成熟度模型

能力成熟度模型（CMM）原先是支援軟體開發過程的開發模型。CMM 是軟體工程研究所（SEI）開展的研究成果，由美國國防部（DoD）資助。第一個版本是在 1991 年發布的。為了拓寬應用領域並改進模型的整合，CMMI Product Team (2002)已經在 2002 年發布的能力成熟度模型整合（CMMI）中推進。為了評估過程域的成熟度，CMMI 定義了五個成熟度等級(見圖 3)：

- 初始(Initial)：過程不可預測，控制不佳和被動。
- 管理(Managed)：針對專案特點的流程，往往是被動的。

- 定義(Defined)：為組織所特有的流程，並且是主動的。
- 定量管理(Quantitatively Managed)：測量和控制流程。
- 優化)Optimizing)：關注過程改進。

這些層級區分被動過程領域和主動過程領域，並將其與來自某些實例（如單個專案，組織，管理要求和品質管理）的目標進行比較。這種方法已經被幾位作者提出來創建創新能力成熟度模型（ICMM），以用於創新管理。



(REF: https://en.wikipedia.org/wiki/Capability_Maturity_Model_Integration)

圖 3: CMM 成熟中各層級的特點

2.2.Essmann 的創新能力成熟度模型（ICMM v2）

在國外創新管理能力成熟度模型研究文獻中，Essmann H., Preez, N. du. (2010)的創新管理成熟度模型是被學者引用最多的創新管理能力成熟度模型，該模型將 CMM (Capability Maturity Models)模型引人到創新管理能力成熟度模型的構建中。其建造的模型的成熟度分為五個等級，即臨時性創新、已定義的創新、支持性創新、整合創新和協同創新。Mann, D. (2012)在其組織創新能力的研究中將組織的創新能力發展過程分為五個階段。Tse, K. M. (2012)以蘋果公司案例和 CMM 模型構建了創新能力成熟度模型，該模型分為五個等級，即離散級、已建立級、策略級、優化級和適應級。

Essmann, H. (2009)的 ICMM v2 是創新管理能力成熟度方法中引用次數最多的轉移。它作為博士論文的一部分進行了研究，並定義了五個成熟度等級的結構：見圖 4 所示。

- 特別創新(Ad Hoc innovation)：日常業務消耗，產出不一致，不可預測。
- 定義的創新(Defined innovation)：需要創新確定和定義，產出不一致，但可追溯。
- 支持創新(Supported innovation)：實施的做法、程式和工具，一致的產出保持市場佔有率。
- 協調一致的創新(Aligned innovation)：整合和一致的活動和資源，產出是一致區分的來源。
- 協同創新(Synergized innovation)：活動和資源同步，產出提供持續的競爭優勢。

為了確定組織當前的成熟程度，已經開發了問卷。與 CMM 類似，這些層級評估一個組織從商業的角度來看，如何精心制定和調整他們的創新能力。此外還考慮了研究部門產出的影響。

除了之前描述的 ICMM v2 之外，還有其他作者對創新能力成熟度進行了評估：

•Darell Mann(2012)的模式區分了播種(seeding)、支援(championing)、管理(managing)、策略(strategized)和冒險(venturing)這五個層次。

•Tse(2012)基於蘋果案例(Apple case)研究的 ICMM 也提到了 CMM，它由五個層次組成：離散的(discrete)、已建立的(established)、戰略的(strategic)、優化的(optimized)和適應性的(adaptive)。

Benjamin Knoke 指出，這些模式具有相似的結構，並且被全面地解釋，但是卻顯示出較少的科學闡述。因此，CMM 和 ICMM v2 的結構是 ICMM 協作方法的關鍵輸入。

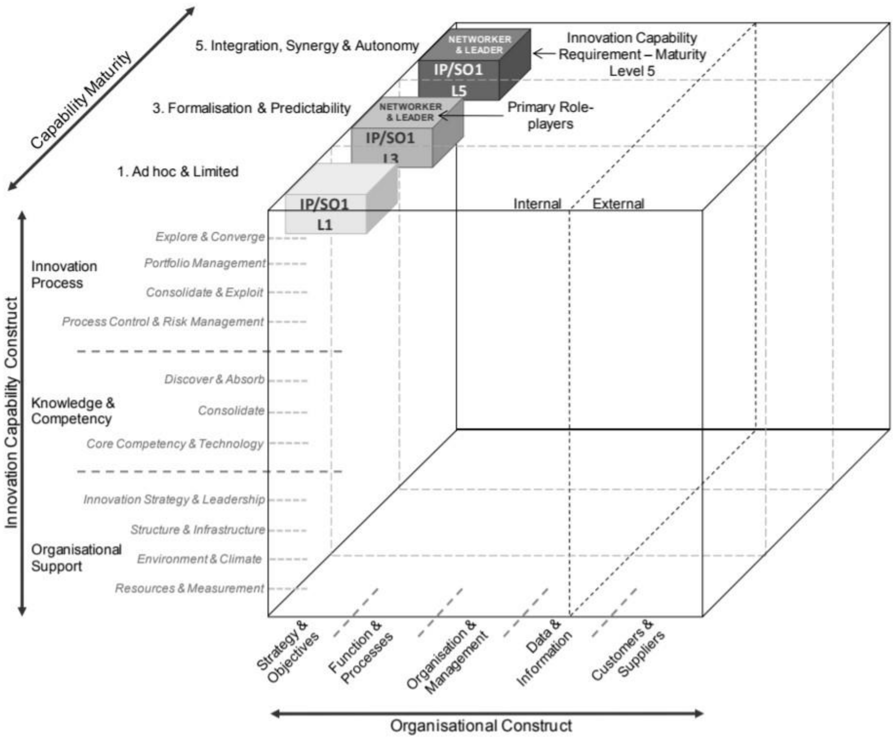


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圖 4: ICMM v2 框架-能力要求和主要角色扮演者的示例

2.3. CMMI 協同創新治理協同創新治理(collaborative innovation governance)是組織實現開放式創新的基礎。協同創新管理(或網絡創新管理)的成熟度可以與單個組織的維度相似。共同的維度是（i）變更管理(Change management)，（ii）溝通(Communication)，（iii）人力資源(Human resources)，和（iv）技術(Technology)。

（v）合作(Cooperation)的另外一個方面是為了體現合作管理成功的要求，透過合作來發展創意。目前，這些維度代表了結構化模型的第一種方法，並可能在模型開發的進程中被改變。他們被選中是因

為他們被證明與創新管理有關[3]。 然而，這種關係造成了它們之間的依賴關係，必須予以考慮。例如，接受組織間層面的新觀點是成功溝通層面的一部分，也是滿足協同合作的關鍵問題[4]。

Benjamin Knokez 發展出協同式 ICMM 的第一個版本是透過擴展 CMM 的五層結構來構建的，另外還有一個層面來確定網絡作為一個同質組織的程度。這四個級別的網絡符合性定義為：

- 單一組織(Single organization)：網絡中表現最好的單一組織獲得的最高層級的創新能力成熟度。
- 網絡意識(Network awareness)：網絡中所有相關創新者都意識到的最高層級的創新能力成熟度。
- 網絡同意(Network consent)：所有相關創新者同意在網絡內部實現創新能力成熟度水準。
- 網絡奉獻(Network dedication)：網絡中所有相關創新者獲得的最低層級的創新能力成熟度。

結合 CMM 的五個層次，可以創建一個圖形，如圖 5 所示。最大程度的網絡一致性將導致一條水準線，最低程度至少會產生一個步驟圖。Benjamin Knokez 指出，網絡一致性的水準類似於一個簡單而有效的擴展來評估網絡協同創新管理能力的成熟度。必須進一步的研究是將基於案例研究和二維模型的闡述。未來的研究目標是完善一個調查問卷來評估一個網絡的現狀，並提供指導改進的指引。協同創新管理面臨的挑戰源於網絡中業務目標和策略的多樣性。阻礙組織之間交流和跨越這些選擇的組織間障礙也需要進一步的研究。

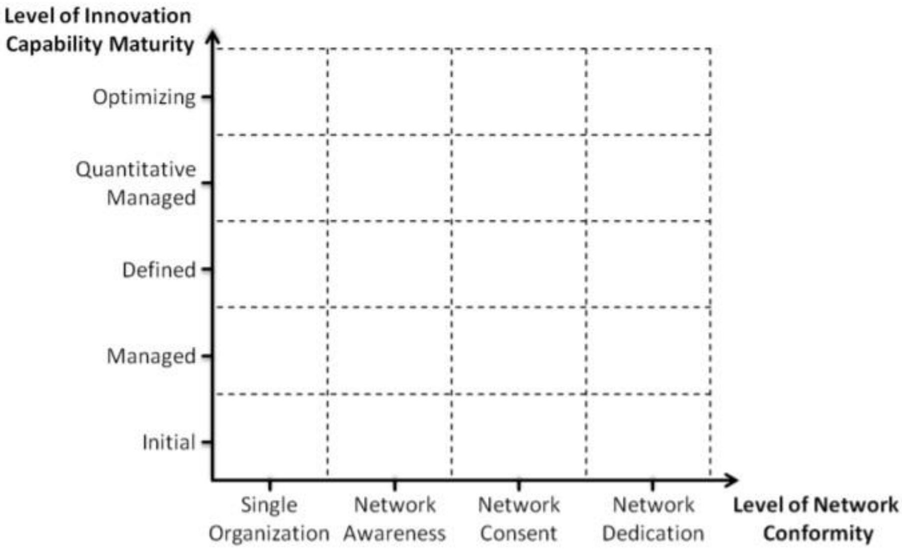

圖 5: 創新和網絡能力成熟度

3.基於歐盟創新管理標準的成熟度模型

創新管理成熟度模型(Innovation Management Maturity Model, IMMM)具有諮詢性質，並沿著一條軌跡促進創新的增長和發展。組織可以使用自己的流程、工具、指標和其他內部實踐的組合，這些組織

[3] Burns, T. E., Stalker, G.M.: The Management of Innovation, University of Illinois (1961)
[4] Mâsse, L.C. Moser, R.P. Stokols, D., Taylor, B.K., Marcus, S.E., Morgan, G.D., Hall, K.L., Croyle, R.T., Trochim, E.M.: Measuring Collaboration and Transdisciplinary Integration in Team Science, American Journal of Preventive Medicine, 35, 151-160 (2008).

內的實踐在其特定的背景下是有意義的。事實上，創新的大多數方面可以用相對統一的指導方針進行詳細描述、制定和實施，但它們總是根據組織實際的需求量身定做。到目前為止，還沒有一個成熟度模型可以真正共用的認可詞彙。

3.1. 歐盟創新管理系統標準

3.1.1.創新管理系統的關鍵因素評估指標

組織建立創新管理成熟度的最大挑戰就是關鍵因素的確定或評估指標體系的建構。許多文獻都在探討這些創新管理評估指標的合理性與完整性。Amanda E. M. 等人(2015)以廣泛的文獻綜述為基礎，重點闡述了對組織創新能力至關重要的因素。確定了編制創新管理系統的九個因素：組織情境管理、創新戰略、創新文化、創新績效測評與管理、協作與溝通、知識產權與知識管理、資源管理、前端創新流程，以及後端創新流程[5]。這項研究的主要發現是，創新管理系統關鍵因素之間的相互作用已經被確定，這進一步支援了對創新管理實踐（創新管理系統）採取更全面的方法的需要。

組織情境管理 (Organizational Context Management)。隨著全球化競爭環境的變化，傳統的客戶與供應商之間的忊衡正在轉向以客戶為中心。客戶是考慮將組織創新投資與市場需求聯繫貣來的關鍵因素。然而，關於創新型組織內外部環境的資訊並不僅僅是由客戶洞察力所覆蓋，而且還需要考意味著新商機的政治或技術變革（CEN 標準，2013）。因此，為了提高組織創新能力，並從創新中獲得更大的成功，組織需要製定組織情境管理的系統實踐。

創新戰略 (Innovation strategy)。成功的創新型組織將創新和資源集中到確定的需求，從而實現公司的短期、中期和長期目標。 這意味著創新型組織需要一個創新策略作為一個框架，指導組織從確定的需求，系統化且持續的方式實現商業化創新(commercialised innovations)。

創新文化 (Innovation culture)。在創新的實踐上，創新型組織持續創新更多的是策略的和人力資源管理過程，而不是技術創新，組織文化需要在解決組織創新能力時加以管理。組織的創新成功與組織文化或更具體的創新文化有密切相關。

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[5] Amanda E.M., Palmovist and Patrik E. U. (2015), *Exploring the Design and Use of Innovation Management Systems in Swedish Organisations*, Department of Technology Management and Economics, Chalmers University of Technology.

創新績效測量 (Innovation Performance Measurements)。與涉及投資業務的其他任何部分一樣，創新也需要進行衡量以便進行管理。 此外，創新績效測量的結果應該作為一個學習過程，以持續不斷提高創新型組織的創新能力。

協作與溝通 (Collaboration and Communication)。員工與公司之間的溝通促進了資訊流動，這對創新活動是至關重要的。當人們與他人互動時，高品質構思的數量和這些構想的傳播都會增加。在這一推理中，可以認為合作與交流是促進創新的動力，因此需要加以管理，以提高組織的創新能力。

資源管理 (Resource Management)。創新型組織的創新性反映在組織所擁有的能力上。能力這個術語是指人的能力，以及如何調整、整合和重新組織技能和資源。因此，需要解決資源管理問題，特別是策略性人力資源管理，以提高組織創新能力。

知識產權與知識管理 (IP and Knowledge Management)。創新型組織面臨的另一個挑戰是如何把握創新帶來的價值。為了適應創新的回報，組織需要排斥他人模仿創新。為了保證排他性，知識產權(intellectual property rights, IPR)可以保護組織的商品和實踐。然而，知識是一種非排他性的商品，因此增加了其他公司"搭便車(free-riding)"對組織創新的風險。 因此，要成功創新的組織需要把重點放在知識產權和知識管理上，充分利用創新工作的回報。

前端創新流程及後端創新流程 (Front-end Innovation Process and Back-end Innovation Process)。許多學者認為，需要一個明確的創新過程來實現創新成功。創新的過程是在許多文獻中有不同的定義；然而在大多數情況下，這個過程被定義為一系列事件或活動。一般而言，創新過程由三個階段組成：發明、開發和實施(invention, development, and implementation)。根據這個推理，創新過程可以由兩個階段來定義：前端創新流程和後端創新流程。這一定義旨在解決為尋找新商機，開發創新以及最後將創新商業化而採取的行動。

3.1.2.歐盟創新管理評估指標

2013 年 5 月，歐洲標準化協會頒布了創新管理標準。一個創新管理系統(IMS)包括為產生創新所需的所有活動，主要內容包括下列關鍵因素：組織所處的環境、創新領導力和策略、為獲取創新成功所做的規劃、創新推動/驅動因素、創新管理流程、創新管理系統績效評估、創新管理系統改進和創新管理技術等構成要素。

歐盟創新管理的概念模型如圖 6 所示。本研究基於歐盟創新管理系統的條文建立創新管理系統的關鍵因素或評估指標體系。圖中的創新過程或創新通道可以是組織適合的創新管理過程。圖 7 是本研

究使用的研發創新通道管理，包括：創造力，策略智慧、技術跟監、內外部能力分析、構想篩選、創新專案、創新專案組合、智慧資產保護，以及創新成果應用等程式活動。簡述如下。

創造力*(Creativity)*。創造力是透過原創思想產生新構想的過程。沒有偉大的構想，業務創新就不算是甚麼。但是創意/構想可能難以按計劃進行。因此，它需要一個穩定的手法來管理創造性的過程，並以高效的方式向前推進。管理創造力需要不同的方法以管理組織內其他功能。管理活動應限制在協助與創造力有關的架構和機制，而非創造力過程本身。產生創意/構想的過程對於更廣泛的持續性創新管理流程是不可或缺的。所以應該將其置入組織政策中，並藉由組織的領導力以制裁及輔助，其需被所有工作人員和其他利害關係人所接受。

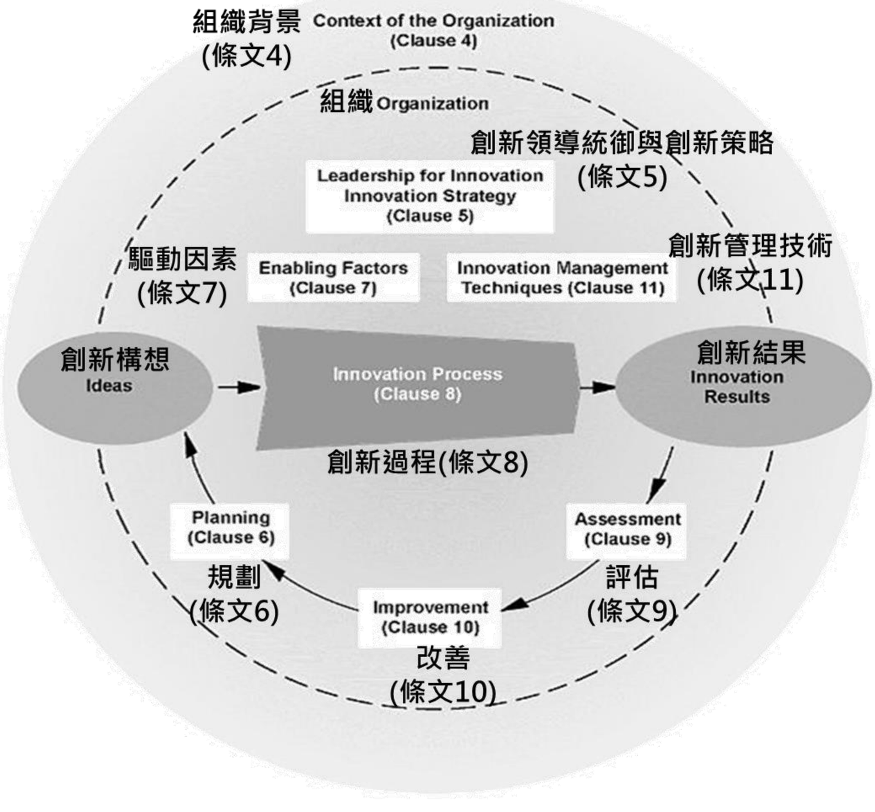

圖 6:歐盟創新管理系統的概念模型(資料來源: CEN/TS 16555-1:2003)

策略智能*(Strategic intelligence)*。策略智慧在創新管理中有著舉足輕重之地位，因其有助於連結組織的願景與策略。舉例來說，如 CEN/TS 16555-1 所描述，在開展創新策略或專案時，策略智慧提供與組織相關的經濟、技術、科學、規範、法律、財務、商業、競爭性、顧客，社會及環境方面議題之情報及遠見。策略智慧是一個決策支援系統或支援決策工具，支持決策者制定決策。策略智慧系統的主要程式包括：識別策略智慧需求、蒐集資訊、分析與評估資訊(即資訊分析與解釋、分析方法與工

具、策略智慧系統之結果、結果之存放與未來利用)。策略智慧系統是組織創新管理系統中一個關鍵部分。策略智慧管理過程涵蓋一般組織經營及包含 3 個主要的必備過程以達成策略智慧目標：策略智慧管控過程、策略智慧實施、策略智慧系統支援資源。

技術跟監*(Technology watching)*。技術跟監與競爭情報是兩個相互關聯的過程，都是以提高組織/公司競爭力為導向。技術跟監是收集外部資訊、分析資訊並將其轉化為知識的、有組織的、選擇性的和持續的方式，以便預測變化並確保較少的風險決策。當新產品、新技術、新競爭對手出現時，將嚴重威脅到組織各項業務的順利運行。不同行業的經驗證明，由於新技術的突然出現，組織乃至整個行業都可能陷入困境。這就是為什麼組織必須始終關注最新的技術和產品進入市場，以預測和利用新的機會。在此背景下，技術跟監和競爭情報是組織獲得科技領域外部威脅和機會的主要工具，並將收集到的資訊轉化為知識和決策工具。同時，組織在創新過程中，特別是針對技術創新，必須先蒐集相關資訊，跟監並瞭解最新技術的發展情況，以及相關技術專利的資料，避免侵犯到別人的技術專利，或保護自己的技術專利。

內外部能力分析*(Internal and External capability analysis)*。一家公司的內部能力和外部合作關係有助於產品、服務和流程的創新。組織透過內外部能力分析，以確保被選出的創意/構想實現的可行性。例如，SWOT 分析是透過評估公司內部的優勢和劣勢來提高創新專案整體成功的過程，同時也考察公司在創新過程中可能面臨的外部機會和威脅。

構想篩選*(Idea screening)*。構想篩選是一個用於評估創新產品構想、策略和市場趨勢的過程。構想篩選標準被用於確定與整體商業目標的相容性，以及這個構想是否會提供可行的投資回報。 不符合這些標準的構想通常是丟棄的。構想篩選是評估和對比創新構想法以獲得最有前途的業務的過程。並不是每個構想都與你的公司有關。為了從不太好的構想中篩選出一個好的構想，應該遵循一定的準則，如技術問題、戰略適應性和一些市場機會。由於可用資源的稀缺性，很難同時開發多種新產品。透過成功的構想篩選流程，有助於將整個創新產品開發過程集中在取得成功的可能性更高的構想上。構想篩選過程有助於將不相關的構想的數量減少到可以進一步轉化為原型(prototype)的便利數量。目的是消除構想的數量，而不會放棄潛在的構想。在構想篩選過程中，組織必須關注以下問題：目標客戶是否將受益於產品？目標市場的規模和增長預測是什麼？

創新專案*(Innovation project)*。創新專案是一個涉及產品和服務創新的專案，涉及創新(innovation)和創新性(innovativeness)的各個方面。透過構想篩選程式獲得的構想將形成創新專案。當團隊共識出現

最終的構想準備要思考如何執行創新專案時，需要有一個完整的機制逐一檢查創新專案計畫的完整性。創新專案管理要為組織領導者和決策者提供了一整套靈活的、有紀律的和轉型的工具和流程，以提高創新機會成果，實現持續創新專案的成功。

創新專案組合*(Innovation project portfolio)*。做正確的創新專案對公司的成功至關重要; 因此，組織應該努力優化創新專案組合管理（IPPM）。在創新通道中，有兩個以上的創新專案同時進行時就必須應用創新專案組合管理方法。如果將 IPPM 的績效同時視為投資組合帄衡、戰略調整和價值最大化的綜合體系，就可以更好地理解 IPPM 的績效。有效的 IPPM 是三個結構的結果：IPPM 方法的使用、IPPM 設計和專案特性[6]。IPPM 的重要性日益突出，因為組織一方面需要源源不斷的成功創新專案，另一方面還要優化稀缺資源的配置。IPPM 幫助組織為新的創新專案分配資源並實現組織的創新目標。因此，創新專案組合被用來最大化創新專案的投資價值。

智慧資產保護*(Intellectual assets protection))*。智慧資產係指個人或組織所擁有來自於構想或才智創作之部份智慧資產。為輔助組織創新過程而發展之槓桿與工具，智慧資產之有效管理和保護，是組織發展、助長和保護競爭力的先決條件。智慧資產管理之目的在於支援創新策略及保護因其所產生之成果。智慧資產管理因而支援、提升和增進創新過程之成果。組織頇透過鑑別及追溯智慧資產來啟始智慧資產管理過程，然後制定如何處理此類已鑑別智慧資產之管理決策。這些決策取決於智慧資產的種類。智慧資產管理過程頇持續監控並與創新過程在管理上互相連結。隨著創新專案和創新專案組合所產生出來的智慧資產都要進行有效管理和保護。

創新成果應用*(Innovation comes application)*。新構想的成功開發對於組織至關重要，創新成果能夠改進流程，將新的改進產品和服務推向市場，提高效率，最重要的是提高盈利能力。創新成果的應用主要是將創新結果商品化，將創新產品導入市場，提供客戶價值並為企業創造利潤。商業化(或商品化) 是將新產品或生產方法引入市場的過程或週期。新產品的實際推出是新產品開發的最後階段，其中最多的錢將用於廣告、促銷和其他營銷努力商業化的三個關鍵方面：(1)思想階段(Ideation stage) - 必頇看到許多構想，以獲得一個或兩個產品或業務可以長期持續；(2)業務流程階段(Business process stage) - 這是一個階段性的過程，每個階段都有自己的關鍵目標和里程碑；(3)參與階段(Engage stage) - 早期涉及關鍵利害關係者（包括客戶）至關重要。

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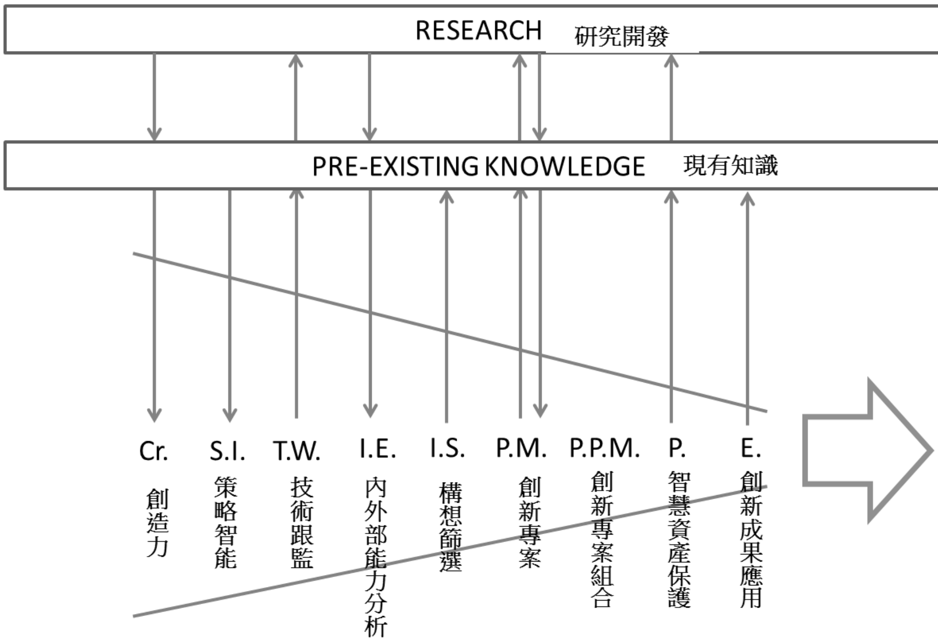
[6] M. Lerch (2012), Innovation Project Portfolio Management: A Qualitative Analysis, IEEE Transactions on Engineering Management (Volume: 60, Issue: 1, Feb. 2013)



圖

7: R&D&I 通道管理

3.2. 基於歐盟創新管理標準的創新管理能力或成熟度模型

有研究文獻針對創新管理能力成熟度進行不同觀點的研究，企目標都是要建構成熟度模式以提供組織實施創新能力評估。安景文等人(2006)的「企業技術創新能力成熟度評價指標體系研究」中闡述了企業技術創新能力成熟度的概念和評價方法，經過對創新能力指標進行相關分析優化指標，建立了操作性很強的企業技術創新能力成熟度評價指標體系，並選擇 DEA 方法對創新能力成熟度進行評價。趙林捷、湯書昆(2007)在「一種新的技術創新管理工具—創新管理成熟度模型研究(IMMM)」 的研究中，基於 CMM 成熟度模型，構建了一個包括發展模型、分析模型和評估模型等三個模型在內的技術創新管理成熟度模型(IMMM)。

王斌(2008)的「製造業企業技術創新能力成熟度模型研究」論文探討如何對製造業企業技術創新能力進行評估和定位；建立了製造業企業技術創新能力成熟度模型，將製造業企業的技術創新能力的提升過程分為五個等級，分別為初始級、可重用級、已定義級、可管理級和優化級，並對各個等級的關鍵過程域和關鍵實踐進行了構建。陳玉和、俞其慧(2010)在「企業技術創新能力成熟度探析」研究中依據 CMM 模型創建了五級技術創新成熟度模型。

張潔(2010)在「高新技術企業自主創新管理能力成熟度模型與提升方法研究」博士論文中以創新管理理論為主，結合組織理論、戰略理論以及現代專案管理理論，開展對高新技術企業自主創新活動所需要的自主創新管理能力的研究，分析自主創新管理能力的構成，自主創新管理能力成熟度模型，以及自主創新管理能力成熟度提升方法。在對高新技術企業自主創新管理能力內涵分析基礎上,明確了自主創新管理能力構成，包括：創新戰略管理能力、創新組織結構、創新組織文化、創新知識管理能力、創新計劃管理能力、以及創新變更管理能力六個方面。實證研究發現，這六個變數都與創新績

效正相關。對創新績效影響大小依次是創新組織結構、創新知識管理能力、創新策略管理能力、創新組織文化、創新計劃管理能力和創新變更管理能力。

秦德智和胡宏(2011)的「企業技術創新能力成熟度模型研究」借鑒軟體行業評估軟體發展能力的成熟度模型研究企業的技術創新能力，構建了一個包括發展模型、分析模型和評估模型等三個模型在內的技術創新能力成熟度等級和等級特徵以及每一個等級的關鍵過程域和關鍵實踐，為企業技術創新能力的發展提供了清晰的目標和路徑。其次，根據技術創新過程和關鍵過程域，基於全面性、客觀性、可操作性原則，設計了一套技術創新能力成熟度評價指標體系，並且運用模糊數學理論評價技術創新能力成熟度等級。

姚麗(2015)在她的研究「組織創新能力成熟度模型研究」中，依據歐盟創新管理標準中提到的創新管理理論模型和最佳業務實踐，以 CMMI 模型為工具構建組織創新管理能力成熟度模型。歐盟創新管理標準是國際通用的創新管理最佳業務實踐的集合，依據其控制點構造創新管理能力成熟度模型的創新管理過程域及相應的特殊實踐詳見表 1。該模型的核心過程域由三個關鍵組件構成，即創新領導力及策略、創新推動/驅動因素和創新管理流程。這三個過程域的關係如圖 8 所示。

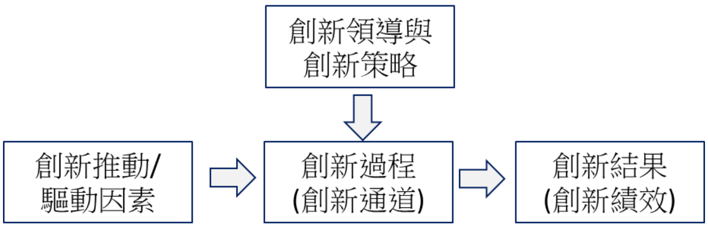


圖 8: 創新管理能力核心過程域

表 2: 創新管理能力成熟度模型的創新管理過程域及相應的特殊實踐

過程域	特殊目標	特殊實踐
創新領導力及策略	1.為創新管理流程實施提供策略方向。 2.透過高層承諾，提供組織創新所需各種資源。 3.培育有利於組織創新的文化。	1.1.制定創新策略。 2.1.制定高層承諾的內容。 3.1.建立創新文化。
創新推動/驅動因素	1.培育組織創新推動/驅動因素。	1.1.定義組織的創新角色和職責。 1.2.確定構建創新體系所需資源。 1.3.保證人員具有履行創新職能的相關能力。 1.4.創新管理意識培育。 1.5.建立創新管理溝通管道。 1.6.將創新管理資訊文件化。 1.7.策略人力資源管理。 1.8.知識產權和知識管理。

創新管理流程	1.確保高品質地實施創新管理流程，並對績效進行評估和改進。	1.1.對創意進行管理。 1.2.創新專案開發。 1.3.對創新活動結果的保護和利用。 1.4.將創新結果引入市場。
	2.對創新流程結果的評估。	2.1.對財務指標和非財務指標的評估。

3.3. 建構創新管理系統能力指標體系

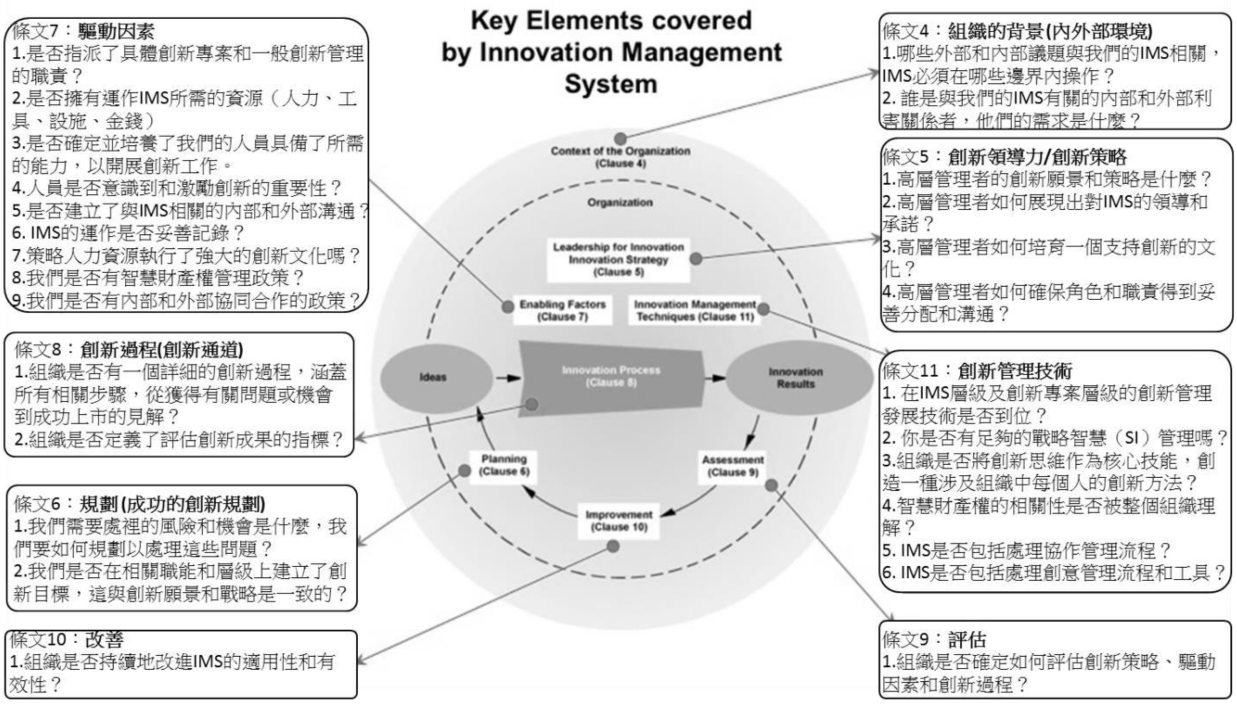
透過國內外創新能力成熟度模型相關文獻之探討，姚麗(2015)指出了現有研究的不足。主要包括下列幾點：(1)創新能力成熟度模型還相對簡單，對於企業創新管理的績效改善和評估的實踐在理論上還缺乏足夠的支撐，成熟度模型還需要細化；(2)創新能力成熟度模型中指標多來源於知識管理和專案管理，與組織實際的組織管理實踐有所脫節，同時也缺乏一個國際性的視角來獲取創新管理領域的最佳業務實踐；(3)現有創新能力成熟度模型的研究多集中於技術創新成熟度研究，而融合技術創新和管理創新於一體的創新管理能力成熟度模型研究還相對較少。

本研究係以 CEN/TS 16555-1 為基礎，建構創新管理系統成熟度模型。本研究依據文獻探討的內容建立組織創新管理系統的評價指標體系，此指標體系是以基於 CEN/TS 16555 的條文和 IPO 模型為基本觀念，基於組織創新管理能力之文獻，將之展開為 6 個構面，組織創新管理系統的關鍵績效指標代表了：辨識組織環境能力、創新領導力與策略能力、成功創新規劃、創新推動/驅動因素、創新管理流程、創新管理技術。

歐洲創新標準對創新管理體系應用了比資訊科技更為細微的觀點，根據歐洲創新標準的第一個文件，創新管理系統定義如下：

“*IMS* =創新管理系統：一套組織的相互關聯或相互作用的組成部分，以建立創新政策和目標，和實現這些目標的過程。”

歐盟創新管理系統 16555-1：2013 中涵蓋的關鍵要素如圖 9 所示。從這圖中可以清楚地看出，這只是檔中所有主題的總結，對創新管理系統（IMS）的描述遠遠超過了最先進的基於資訊技術的系統。為了使創新更加成功，我們需要把它看作是一個整體系統，並以比我們忓常做得更有條理和更有形的方式進行工作。採用一種創新標準，這個標準捕獲了我們所知道的關於創新的許多東西，這是一個更好的辦法，而不是單單在 IT 系統上浪費大量資金。



(資料來源：

http://finnkollerup.com/2015/09/20/use-the-european-innovation-management-standard-as-your-innovation-checklist/)

圖 9 : 歐盟創新管理系統 16555-1：2013 中的關鍵要素

本研究基於 CEN/TS 16555 創新管理系統國際標準所建構的評估指標體系如表所示。

表 2: 基於 CEN/TS 16555-1 創新管理系統評估指標體系

構面層	準則層	說明
(D1) 辨識組織環境能力	組織須確定在外部和內部與其宗旨有關而且影響其達成創新管理系統預期結果之能力的議題。組織須確定創新管理系統之界線與應用，以便建立其範圍。	
	(C1)瞭解組織及其內外部環境的能力	組織須定期審視及分析其外在環境以便辨識當前與未來的挑戰。組織須定期分析其當前與未來創新管理之能力。
	(c2)辨識利害關係人需要和期望的能力	組織須確定與創新管理系統相關之利害關係者，並且辨識其需求、期望、要求。
(D2) 創新領導力與策略能力	高階管理者應建立其組織所要達成甚麼樣創新的創新願景。創新願景應配置成可以實現願景的創新策略。	
	(c3)制定創新策略的能力	此創新願景、策略與政策應在組織內建立文件化資訊、能被量測及在組織內傳達。
	(c4)領導力和高層管理的承諾	高階管理者應展現對創新管理系統的領導統禦與承諾。以確保創新願景、策略、政策及目標能因應創新管理系統而建立，且符合組織的策略方向。

	(c5)培育創新文化的能力	高階管理者應培養能夠輔助創新的組織文化。創新文化應形成一個思維模式，且組織內的每一個人都應為其發展有所貢獻。
	(c6)組織的角色、職責和權利的設計能力	高階管理者應確保在組織內指派與傳達相關職務的責任與職權，並分配責任與職權。
(D3) 規劃創新成功能力	為了維持領導的地位，組織必須持續地主動探索各種創新的機會，因此組織需要具備成功規劃的能力。	
	(c7)處理風險與機會的能力	在規劃創新管理系統的過程中，組織應考量外部與內部的相關議題、利害關係者的需要及期望、創新願景與策略、以及確定需要面對的風險與機會。
	(c8)執行規劃的能力	組織應在相關的部門及層級建立創新目標。創新目標應符合創新願景與策略，並適當地傳達、衡量、監控及更新。
(D4) 創新推動/驅動因素	為了創新管理系統的有效運作，組織必須重視策略性人力資源管理，確定創新的權責及陪樣創新的能力。	
	(c9)定義組織的創新角色與職責	組織應為創新管理系統範圍內的特定創新專案之責任和總體創新管理之責任的兩項主要責任做出定義。
	(c10)確定建構創新體系所需資源	組織應確定並提供創新管理系統的建立、實施、維持、及持續改善所需的資源。 (例如：人力資源、設備、設施、與預算)。
	(c11)保證人員具有履行創新職能的相關能力	組織應確認發展創新活動及相關工作人員所需之必要能力；確保工作人員擁有足以勝任之適當的教育、訓練及經驗；採取行動獲取必要的能力並評估行動之效益；持續改善提高創新績效所需之技術與能力。
	(c12)創新管理意識培育的能力	組織管控下的工作的人員，應受激勵並瞭解創新對組織、創新願景及策略的重要性，並瞭解其對創新管理系統效能做出貢獻的重要性以及改善創新績效所帶來之利益。
	(c13)建立創新管理溝通管道的能力	組織應建立與創新管理系統相關之內部與外部的溝通，並將溝通的內容、何時溝通、跟誰及由誰溝通、溝通管道的提供及預期的回饋等納入考量。
	(c14)將創新管理資訊文件化的能力	組織的創新管理系統應包含組織認定為了確保創新管理系統之效用以及佐證其績效所必需之檔化資訊。
	(c15)策略人力資源管理的能力	創新管理系統應運用策略性的人力資源管理。
	(c16)知識產權和知識管理的能力	組織應對無形資產(包含知識及專業訣竅)以及智慧財產管理訂立政策，並為內部與外部知識和保護的等級與方法提供管理架構。
	(c17) 制定合作政策、培育內外部合作的能力	組織應為內部與外部協同制定政策。與外部組織的協同與聯網可以幫助辨識構想、顧客需要、知識及夥伴以協助解決問題及利用構想。

(D5) 創新管理流程	根據其創新的願景、策略及對應目標，組織應建立詳細的創新過程，涵蓋所有從洞察問題或機會到成功開展的相關步驟。典型”創新通道”的常見構面是：框架與理念的形成、構想管理、創新專案發展、成果的保護與利用和市場導入。	
	(c18)創新架構和直覺產生的能力	創新過程的構面高度仰賴不同的創新型態、組織的類型亦或內部架構，因此有許多不同的進行方式。
	(c19)創意管理的能力	構想管理包含新構想的產出、獲取、評估和選擇。一個有系統的構想管理過程應確定其能確保穩定的新構想源流。
	(c20)創新專案開發的能力	創新專案的發展建議遵循以下方法。例如「階段關卡」過程或者創新思維過程，或者可能結合了兩者。階段關卡的主要益處是其在專案開展時以明確目標和交付物設立詳盡的專案計畫之原則。
	(21)結果的保護和利用的能力	創新活動成果的保護與利用，應以最好的保護方式進行，並於適當時，遵循為利用所訂定的機制與協議。
	(c22)市場推廣的能力	對一個成功的創新來說，其成果預能導入至市場或在過程中實施並為組織創造回饋。
(D6) 創新管理技術	這些技術涉及各種正確發展創新管理和提昇企業創新活動的影響所需的不同層面。這些技術應用在創新管理系統層級，以瞭解背景和策略發展等，也應用在每個創新專案層級，以生產、評估和選擇新構想、發展創新專案、確保成果的保護與利用等。	
	(c23)策略情報管理的能力	創新管理因而需要充分的策略性智慧管理來支援籌備組織、展望未來、定位、影響力或專門技能、自由運用及保護資產的策略性決議。
	(c24)創新思維的能力	創新思維是探索問題與機會的一種反覆而且可以重複的做法，以便辨識明顯較佳的解決方案並預測未來之需求。這是要創造一個動員組織內所有人員的創新途徑。
	(c25)智慧財產管理的能力	智慧財產和智慧財產權意識對所有種類的組織都是必要的，這樣才能管理、保護和利用無形資產、獲得運作的自由以及防制仿造和侵權。
	(c26)協同管理的能力	協同管理能讓組織取得新技術和資源。此外也凝聚組織內不同的群組、改善成功創造力和創新的機會、解決問題及協助開發外部潛能。
	(c27)創造力管理的能力	創造力的成功管理可以藉由一套激發新構想產出以供選擇、發展與實施而成就創新的明確原則。

4.混合式多評準決策方法

本研究應用混合式多評準決策方法建構組織創新管理的評估模式，提供做為組織進行自我評估創新能力的程度，進而提出改善措施，以持續改善組織的創新管理能力。混合式多評準決策方法主要包括三個研究方法與工具，分別簡述如下。建構基於 CEN/TS 16555-1 創新管理系統標準關鍵要素的系統結構模型之程式步驟如下圖 10 所示。

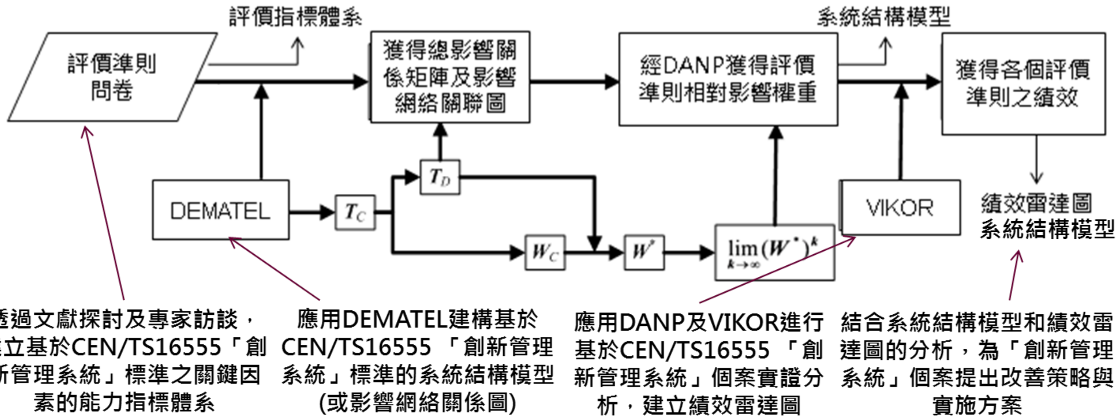


圖10:建構基於 CEN/TS 16555-1 關鍵要素系統結構模型之程式步驟

4.1.決策實驗室分析法

決策實驗與評價實驗室法 DEMATEL(Decision Making Trial And Evaluation Laboratory)是瑞士日內瓦 Battelle 紀念協會（Battelle Memorial Institute of Geneva）於 1971 至 1976 年發展而成，主要是為解決科學與人類事務專案所發展的研究方法，以幫助收集世界問題及獲得世界問題更好的解決。近年來此方法常用於產業界與學術界，應用議題也很廣泛。決策分析實驗法可提高對於特殊問題的理解，藉由層級結構來提供可是別可行的方案(Hung et al., 2006)，此方法可有效的瞭解複雜的因果關聯式結構，並可作為研究各個指標兩兩之間影響關係，利用矩陣及相關數學理論計算出所有指標之間的因果關係及影響的強度。DEMATEL 運算分為五大步驟：

1. 建立直接影響關係矩陣（Direct relation matrix）;
2. 建立初始化直接影響關係矩陣（Initially direct-relation matrix）;
3. 計算正規化直接影響關係矩陣（Normalized direct-influence Matrix）;
4. 計算總影響關係矩陣（Total influence-relation matrix）;
5. 建構評估系統結構模型。

4.2. DANP 方法

Saaty (1996)將層級分析程式法做了進一步研究，提出 ANP，與 AHP 的不同之處在於 AHP 考慮到了各個指標存在內部相依性及相互影響關係，ANP 為 AHP 分析法的通用形式，AHP 則為 ANP 的特例。ANP 的目的在於預測各個指標、目標或方案間精確的內部關係，通過評估模型進行成對比較並得到相互影響的各個指標體系的構面層和具體指標的權重。

4.3. 折衷排序法(VIKOR)

Opricovic (1998)所提出為了能以妥協(compromise)的概念解決評估準則間相互競爭問題的多方案排序方法，以各方案與理想解(Positive-ideal solution)的接近程度作為排序方案的依據，越接近理想解則表示該方案越佳；反之，越接近非理想解(Negative-ideal solution)表示該方案越差。

本研究採用結合 DEMATEL 和 ANP 的混合式多評準決策方法來求取評價系統結構模型各個指標的權重，簡稱為 DANP。具體分為三個步驟：

1. 根據 DEMATEL 法建立的系統結構模型建立未加權超級矩陣；
2. 建立加權超級矩陣；
3. 將加權超級矩陣多次相乘得到超級化矩陣，即可得到各個指標權重。

然後利用 DANP 所運算出來的組織創新管理系統評估指標體系系統結構模型各準則被影響權重值，再透過 VIKOR 的方法，進行組織創新管理能力評估指標的績效評估來完成實證分析。

5.建構創新管理系統關鍵要素影響關係

本研究應用混合式多評準決策建立組織創新管理能力評估系統模型，以期幫助組織順利推動創創新管理。首先經由文獻探討獲得組織創新管理能力評估系統 ，共有六個構面二十七項準則。以此指標體系為基礎，透過專家問卷調查法和得運算數據，經運算分析後討論各構面與構面下準則之間之影響關係性， 之後再藉由的 DANP 方法之運用得到影響權重值，最後以 VIKOR 方法進行個案組織創新能力評估系統之績效評估。

5.1. 創新管理系統構面層級關鍵要素影響關係

本研究以中小企業為研究對象，首先從文獻探討中基於 CEN/TS 16555 建立了組織的創新管理能力評估指標體系，接著應用 DEMATEL 方法建構創新管理系統主要構面之間的相互影響關係。我們手心從 CEN/TS 16555 條文中整理出關鍵成功因素或關鍵評估指標 — D1「辨識組織環境能力」、D2「創新領導與創新策略能力」、D3「創新成功規劃能力」 、D4「創新推動/驅動因素」、D5「創新管理流程能力」、D6「創新管理技術能力」，然後透過專家問卷的回饋資料，應用 DEMATEL 方法建構創新管理系統主要構面之間的相互影響關係。如圖 11-11 所示。

構面 D3「創新成功規劃能力」為主要影響源，影響構面 D2「創新領導與創新策略能力」和 D1「辨識組織環境能力」，進而影響其它構面 D4「創新推動/驅動因素」、D5「創新管理流程能力」，最終影響構面 D6「創新管理技術能力」。構面 D6「創新管理技術能力」為最終備影響源，受到其它構面的影響。

組織具備好的「規劃創新成功能力」，就會有更好的創新領導與創新策略能力，進而提升了辨識組織環境能力及創新管理流程能力；組織的創新管理流程能力促進創新推動/驅動因素，這些創新驅動因

素直接影響組織的創新管理技術能力。換言之，組織建構創新管理系統的目標是要改善組織的創新管理技術能力，未達到這個目標，組織創新的要務就是先建立組織的成功創新規劃能力。

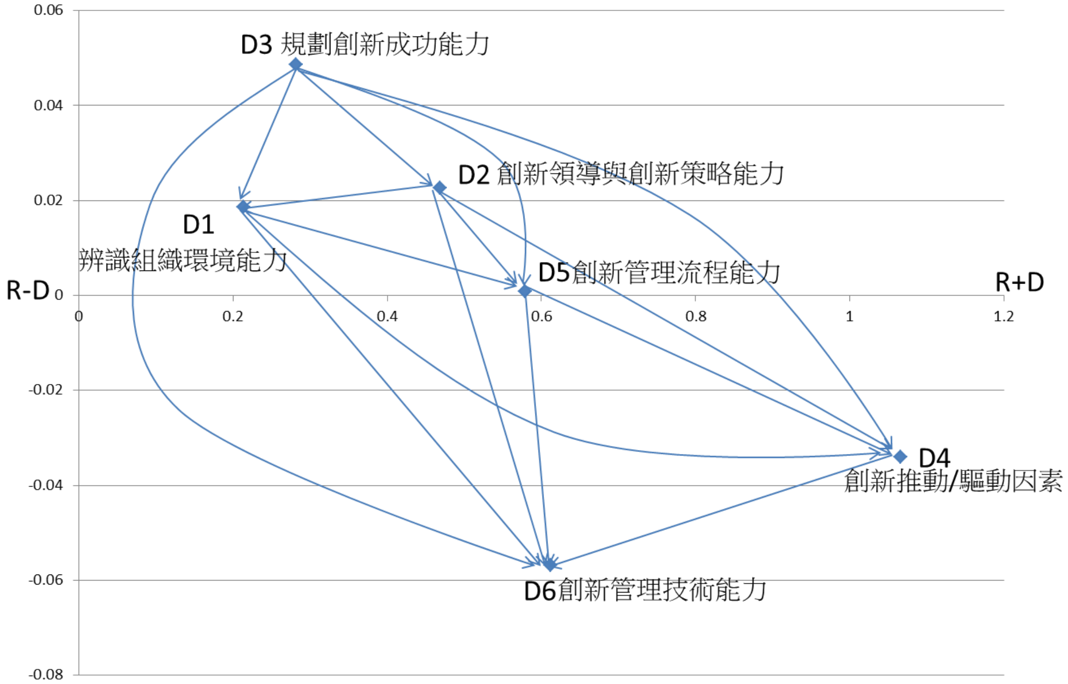


圖 11: 創新管理系統關鍵因素之構面層級影響網絡關聯圖

實務經驗告訴我們，很多時候，匆匆規劃的腦力激盪會帶來很多好的構想，而這些好的創新構想可能永遠不會被使用，反而那些想要擺脫的無聊構想似乎會被一次又一次地使用。其中一個主要原因是缺乏創新規劃能力。如果您想最大限度地發揮您創造的構想的創造力，並確保實現最好的構想，您需要一個創新計畫，一個好的創新計畫決定於好的規劃創新成功之能力。

我們的經驗使我們確信，創新領導與創新策略是產生創新型組織的基石，而創新成功規劃能力則決定創新領導與創新策略的實現。第一步是將創新正式納入到高層領導的策略管理議程中。透過這種方式，不僅可以鼓勵創新，而且可以將其作為公司發展願景的核心要素進行管理、跟蹤和衡量。 其次，高層管理人員可以更好地利用現有的（通常是未開發的）創新人才，而不必執行顛覆性的變革計劃，創造條件使動態創新網絡能夠蓬勃發展。最後，他們可以採取明確的步驟，在員工之間建立一種基於信任的創新文化。在這樣的文化中，人們明白自己的想法是有價值的，相信表達這些想法是安全的，並與經理一貣集體監督風險。在維持創新方面，這種環境可能比金錢激勵更為有效。

組織須確定在外部和內部與其宗旨有關而且影響其達成創新管理系統預期結果之能力的議題。組織須確定創新管理系統之界線與應用，以便建立創新管理系統的範圍。組織環境背景由影響績效、營運和資源的組織周圍的部隊或機構組成。它包含了組織邊界之內外的所有要素，並且有可能影響組織的一部分或全部。辨識組織環境的能力，特別是辨識出組織的創新環境，是組織創新的基礎資訊來源。對組織整體的創新環境是受到組織創新領導與創新策略的指導下，以及創新規劃的指導下，才能

正確地蒐集內外部資訊，正確瞭解組織的創新環境。此外，鼓勵創新氛圍通常與組織的長期成功高度相關。挑戰自己和高層管理團隊，發展有效創新成為您持續創新策略規劃一部分的技能和氛圍。

創新管理過程(或稱為創新通道)已經成為許多企業運營的重要組成部分，因為認識到創新措施的重要性已經變得越來越普遍。儘管如此，許多公司確實請圖對創新和創新採取堅實的態度，但實際上很少有公司把它作為一個單一的功能集中在一貣。相反地，他們似乎孤立地進行了許多獨立的創新活動，例如腦力激盪會議，請點專案和活動，與市場的模糊交流，只是不斷地交叉，最終會聚到一貣。雖然這在過去有些效果，但是完成這個重要任務還不是理想的方式。相反，要做到這一點，最好的辦法是有一套創新活動，將這些創新活動整合成一個過程並融入到企業的正常循環中。組織的創新成功規劃能力、創新領導與創新策略能力和辨識組織環境能力都會影響創新管理過程能力。

創新推動/驅動因素主要是從策略性人力資源的角度，來審視組織對創新人才的培養和提升其創新能力的措施。透過創新推動/驅動因素進能提升組織整體創新管理技術能力。創新管理技術能力雖然是最終被影響源，但它的相對權重卻是最高的。企業面臨著威脅生存的嚴峻市場環境，人們越來越意識到"一切照舊"已經不夠了，他們的未來取決於他們提供創新產品和服務的能力，創新和提高他們的價值主張和相關的商業模式。不斷變化的市場條件迫使企業必須透過新技術或獨特的價值主張來適應或重塑他們的業務。與此同時，企業高層管理的主要責任是提升基於創新管理技術和工具（IMTs）以開發結構化創新流程所需的資源、知識和技術能力。IMTs 可以被看作是一系列工具、技術和方法，幫助公司適應環境並以系統的方式應對市場挑戰。

5.2. 創新管理系統準則層級關鍵要素影響關係

圖 12 呈現出構面 D1「辨識組織環境能力」各準則之間的影響關係，準則 c2「辨識利害關係人需要和期望的能力」為總影響源，準則 c1「瞭解組織及其內外部環境的能力」為被總影響源。

CEN/TS 16555-1 條文 4.1 和 4.2 指出，組織須確定與創新管理系統相關之利害關係者，並且辨識其需求、期望、要求。組織須確定在外部和內部與其宗旨有關而且影響其達成創新管理系統預期結果之能力的議題。組織在瞭解所有利害關係人的需要和期望後，明確其正確的需要和期望，組織就可以更準確地蒐集相關內外部環境資訊，進而影響組織準確地瞭解其內外部環境的能力，以制定組織創新能力的改善措施。同時識別利害關係者之間的關係，有助於組織利用這些關係建立聯盟或潛在的合作夥伴，以提高開放式創新成功的機會。

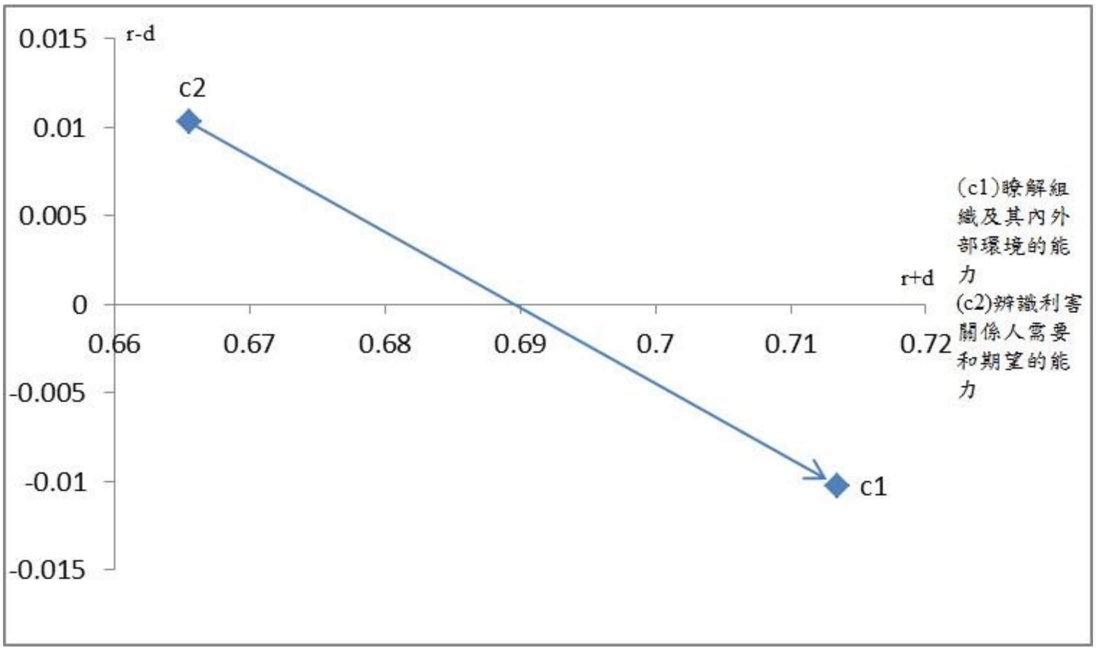


圖 12：辨識組織環境能力準則影響網絡關係圖

圖 13 為構面 D2「創新領導力與策略能力」各準則之間的影響關係，準則 c4「領導力和高層管理的承諾」為總影響源，準則 c6「組織的角色、職責和權利的設計能力」為被總影響源，且準則 c3「制定創新策略的能力」影響權重為其中最高。

根據 CEN/TS 16555-1 條文 5.1 到 5.4 指出，高層管理者首先要遵守創新管理體系的領導力和承諾；然後，應該為創新管理系統而建立貣創新願景、戰略、政策和目標；進而在組織中培育支持創新的文化；最後，高階管理者應該確保在組織內指派與傳達相關職務的責任與職權，以建立符合組織創新文化的創新管理系統，從而支持組織創新策略的實現。

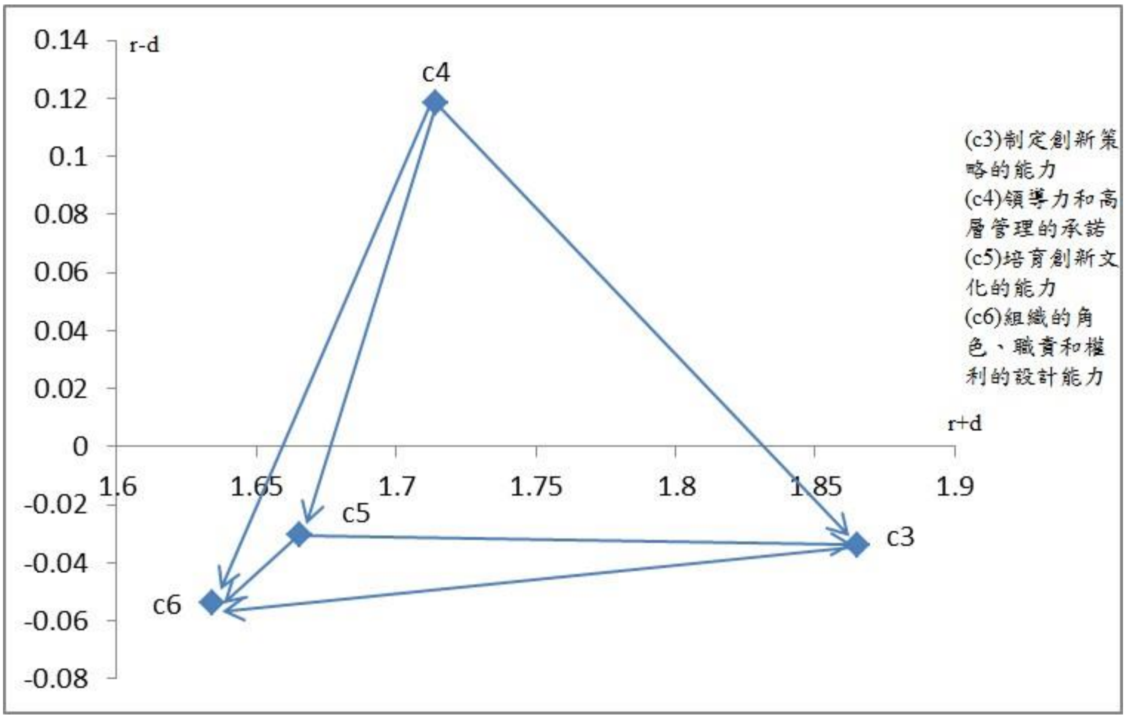


圖13：創新領導力與策略能力準則影響網絡關係圖

圖 14 為構面 D3「成功創新規劃」各準則之間的影響關係，其中準則 c8「執行規劃的能力」為總影響源，準則 c7「處理風險與機會的能力」為被總影響源，且準則 c8「執行規劃的能力」影響權重為其中最高。

Bossidy, L., and Charan, R.(2003)認為組織縱然有怎麼偉大的想法，若不能轉換為具體的行動步驟，就等於毫無意義可言。少了執行，突破性思考沒有用，學習不會帶來價值，員工無法達成延展性目標，革命也會半途而廢。這樣的改變反而使情況惡化，因為隨之而來的失敗會虛耗組織的能量。一而再、再而三的失敗，終將摧毀組織。

CEN/TS 16555-1 條文 6.1 到 6.2 指出，在規劃創新管理系統的過程中，組織應考量外部與內部的相關議題、利害關係者的需要及期望、組織高層的創新願景與策略、以及確定需要面對的風險與機會。而處理這些機會和風險的能力，明顯地受到組織規劃如何達成創新目標能力的影響，換言之，組織應在相關的部門及層級建立創新目標的同時，就應該考慮達成創新目標過程中的創新管理系統的風險與機會，這才是成功的創新規劃。

根據 CEN/TS 16555-1 的指引，敏捷創新專案團隊的規劃中，同時必須對新產品開發專案所面臨得機會和風險進行管理。成功地創新規劃，可以降低創新專案的風險，透過風險管理的程式 ─ 辨識風險、評估風險、回應風險和控制風險，或是使用相關工具和方法，例如設計失效模式與效應分析

(DFMEA)、過程失效模式與效應分析 PFMEA，可以有效預防風險事件或危害事件的產生。

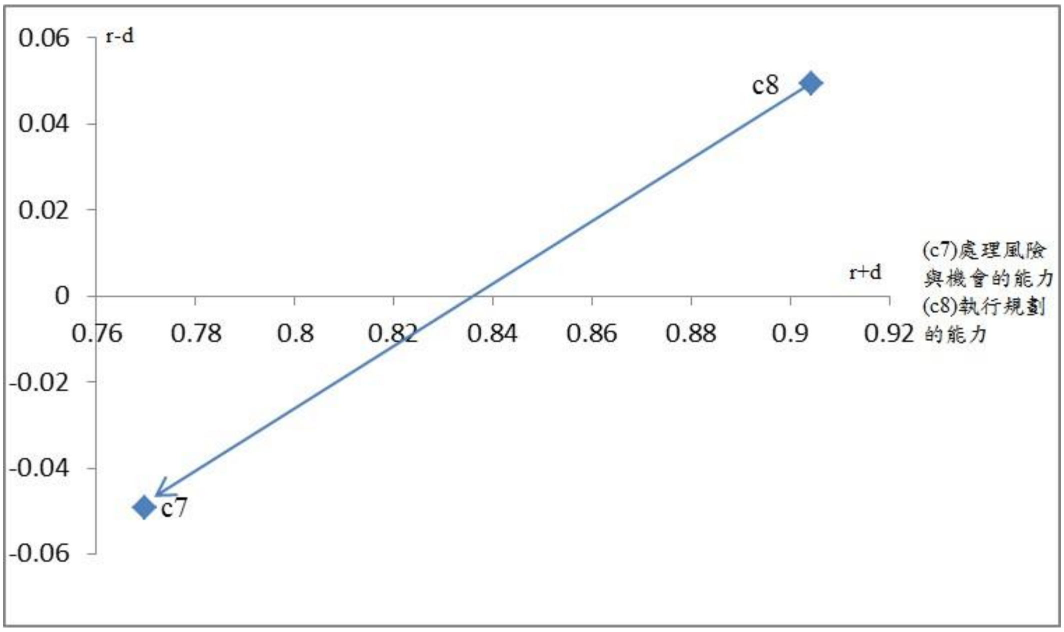


圖 14：成功創新規劃準則影響網絡關係圖

圖 15 為構面 D4「創新推動/驅動因素」各準則之間的影響關係，準則 c9「定義組織的創新角色與職責」為總影響源，影響了其他準則；準則 c16「知識產權和知識管理的能力」為總被影響源。

CEN/TS 16555-1 中的創新推動/驅動因素包括：組織的職務與責任、資源、能力、意識、溝通、文件化資訊、策略性人力資源、智慧財產與知識管理和協同等驅動因素。這些因素之間會相互影響。在影響組織發展與管理創新管理系統的所有因素中，「人」是最關鍵的一個因素，組織內的每個角色是否適合組織機構、團體或成員，以及組織機構、團體或成員的職責是否被明確的定義，將會影響組織執行的成效；確定共同工作的人員應該具有的必要的技能；保證這些人員通過適當的基本教育、培訓和實踐具有勝任工作的能力；採取行動獲得必要的技能，並且評估採取的行動的有效性；要求持續改進技能和能力從而提升組織創新績效。

準則 c16「知識產權和知識管理的能力」的相對權重最高，顯示專家們都認為「知識產權和知識管理的能力」對於個案公司的創新是很重要的，而它又是最終被影響源，因此，個案公司必須先改善影響準則 c16 的其他準則，才能有效提升組織的「知識產權和知識管理的能力」。

在當今瞬息萬變的商業世界中，創新已經成為組織的中流砥柱。 全球經濟增長的本質已經被創新的速度所改變，創新的速度可以通過快速發展的技術，更短的產品生命週期以及更高的新產品開發速

度來實現。隨著組織可用知識的增長，創新的複雜性也在不斷增加。組織必須有效管理不斷增長的知識，確保持續創新。

另一方面，人們普遍認為，在知識驅動、競爭激烈的商業環境中，創新是成功企業績效的主要決定因素。 因此，需要對企業實際使用知識產權制度的工具進行系統和定期的研究和審查，以便經濟學家能夠為決策者提供經驗的，循序的指導，以調整知識產權制度，使其繼續服務衝突的私人和公共利益刺激進一步創新，並在最短的時間內廣泛傳播。

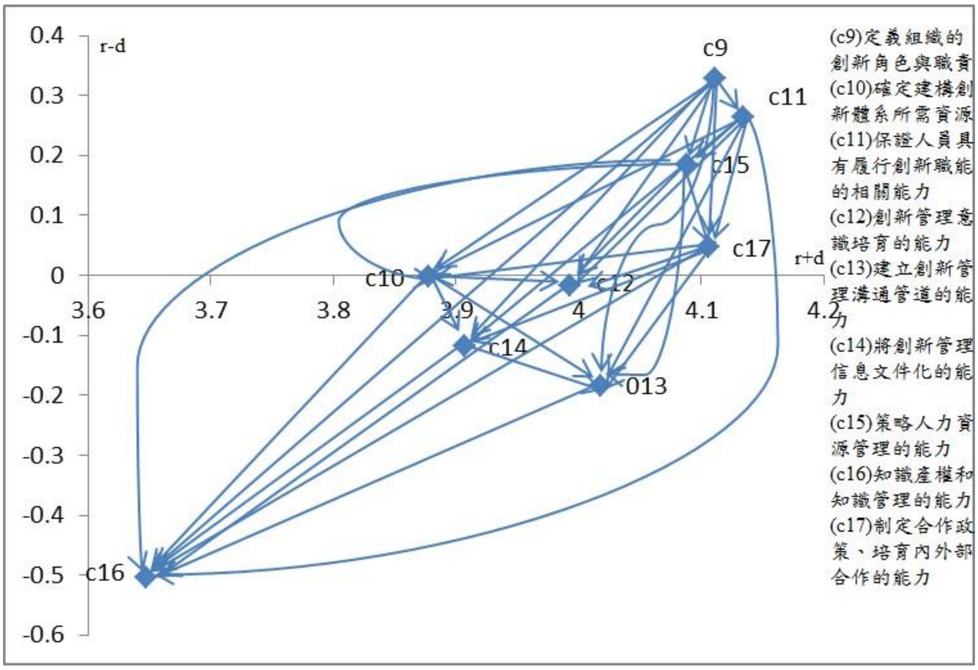


圖 15：創新推動/驅動因素準則影響網絡關係圖

圖 16 為構面 D5「創新管理流程」各準則之間的影響關係，其中準則 c19「創意管理的能力」為總影響源，準則 c21「結果的保護和利用的能力」為被總影響源，且準則 c20「創新專案開發的能力」影響權重為其中最高。

CEN/TS 16555-1 中的創新管理過程是指創新程式(或創新通道)及創新過程的成果評估。創意管理包括對新創意的生成、捕捉、評估和選擇。具體活動包括:確定創意產生的範圍；收集、評估和選擇創意的頻率；應該收集的創意的源頭；在知識資本價值較高的情況下，組織應在新的創意組織內部被分享之前進行系統化的保護；制定評估與選擇創意的方法和標準。

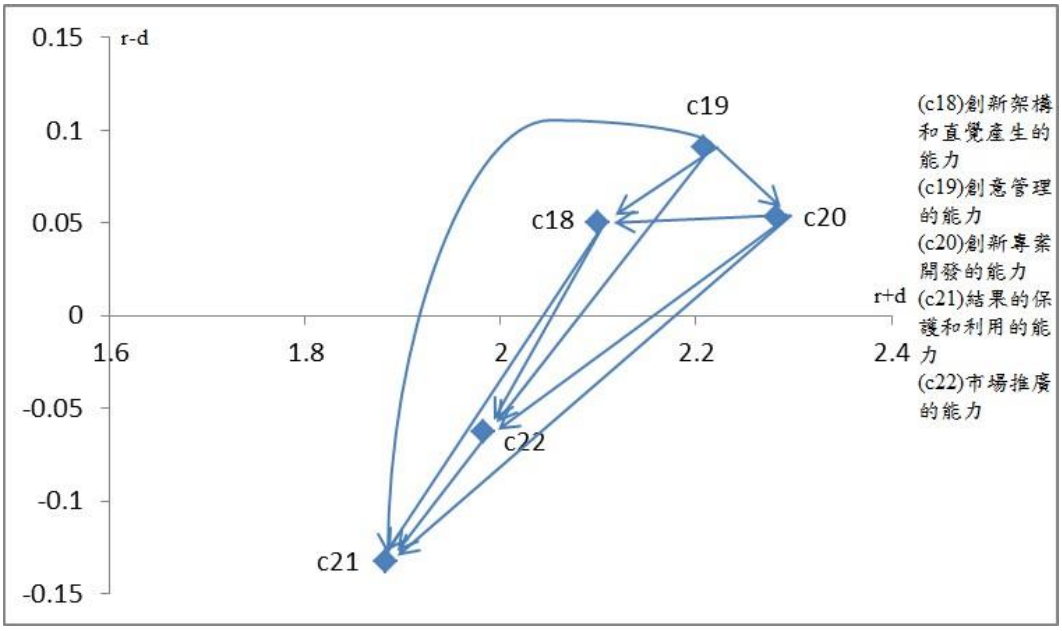


圖 11-16：創新管理流程準則影響網絡關係圖

圖 17 為構面 D6「創新管理技術」各準則之間的影響關係，其中準則 c27「創造力管理的能力」為總影響源，準則 c25「智慧財產管理的能力」為被總影響源，且準則 c24 創新思想的能力」影響權重為其中最高。

CEN/TS 16555-1 指出，這些創新管理技術涉及各種正確發展創新管理和提昇企業創新活動的影響所需的不同層面。這些技術應用在創新管理系統層級，以瞭解背景和策略發展等，也應用在每個創新專案層級，以生產、評估和選擇新構想、發展創新專案、確保成果的保護與利用等。組織的創造力管理的能力直接影響其它創新管理技術的有效實施。良好的創新管理能力會激發組織成員的創新思維能力，進而意識到協同創新管理的需要，通同開發出策略智慧決策系統或工具，組織有效應用這些創新管理技術或工具，才能產出有價值的智慧財產及其管理能力。

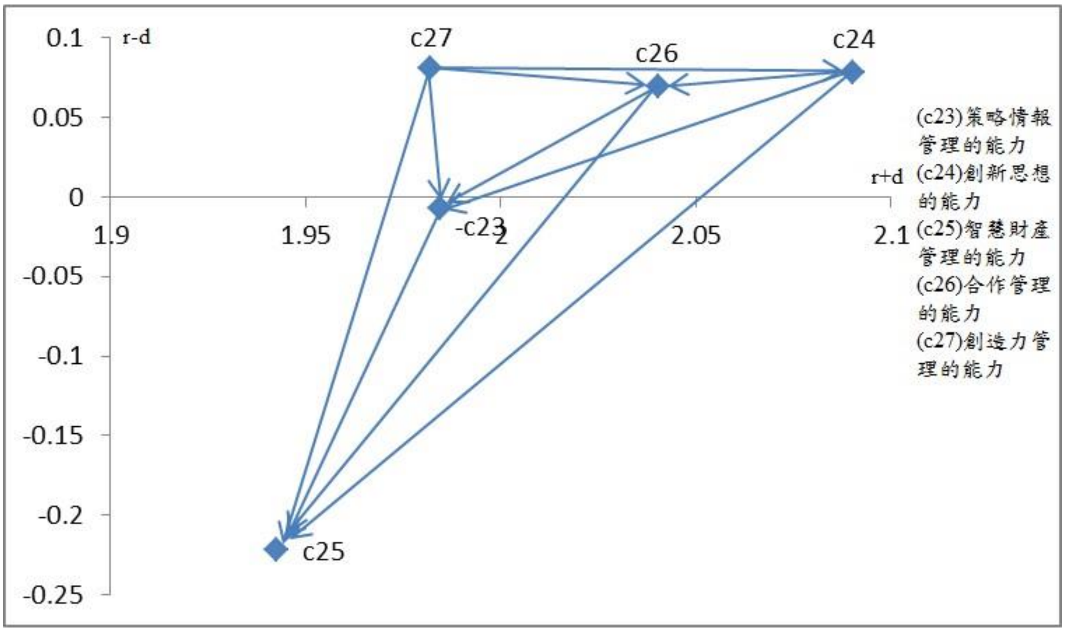


圖 17：創新管理技術準則影響網絡關係圖

5.3. 創新管理系統關鍵要素影響關係的管理意涵

本節主要目的在於藉由 VIKOR 方法結合由 DEMATEL 方法所獲得之系統結構模型來針對個案企業之組織創新管理能力進行績效評估與後續組織管理人員應有作為。在將績效評估問卷回收並進行分析，則可獲得本研究之績效雷達圖。

由圖 18 可以發現個案企業在組織創新管理能力績效評估雷達圖當中，準則 c17「制定合作政策、培育內外部合作的能力」的績效值最低，而配合本研究所建立之系統結構模型進行分析，在構面 D4「創新推動/驅動因素」中，準則 c9「定義組織的創新角色與職責」為總影響源，而準則 c11「保證人員具有履行創新職能的相關能力」影響權重值為該構面中最高者。因此本研究認為要改善個案企業 c17 「制定合作政策、培育內外部合作的能力」的績效值，應先補強該企業之「定義組織的創新角色與職責」。

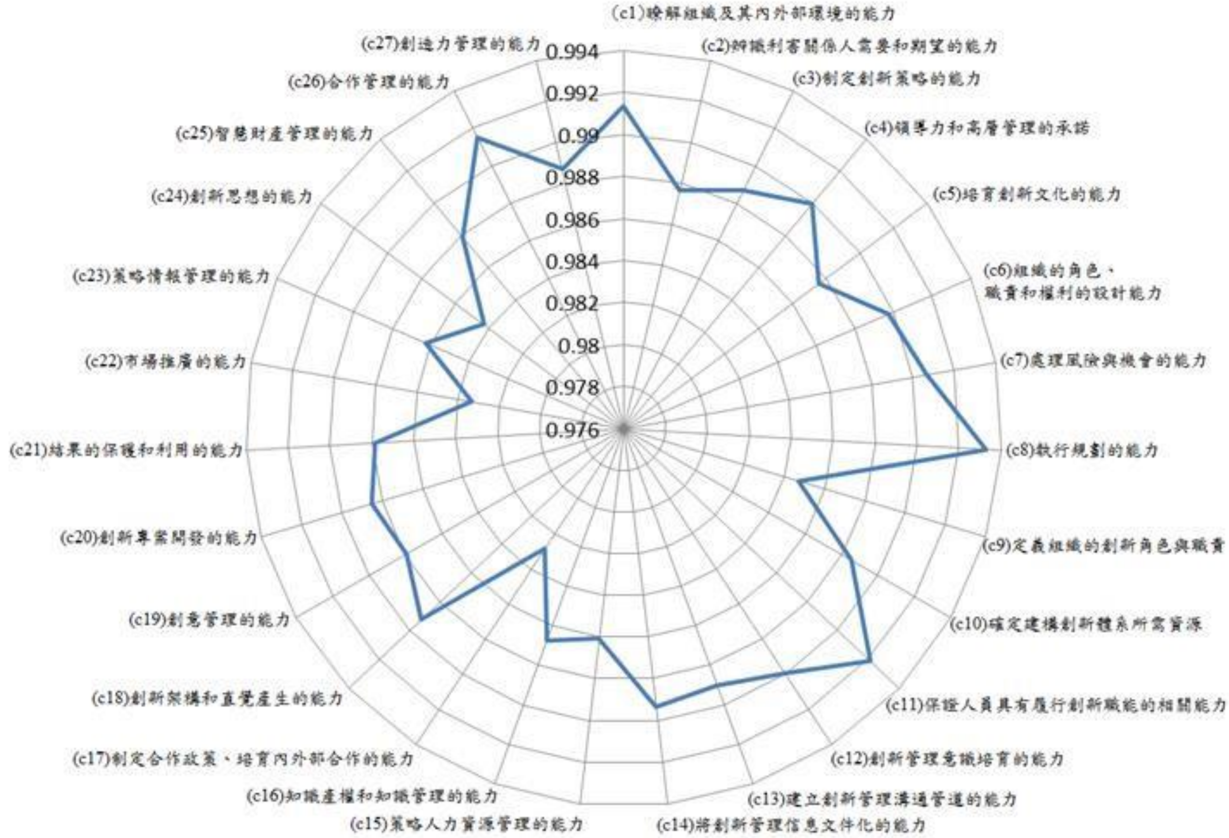


圖 18：個案企業組織創新管理能力績效評估雷達圖

圖 19 為準則層級影響關係圖，此圖橫軸為 DEMATEL 所得各準則之中心度，縱軸為各準則之關係度。透過此圖能夠將準則分為兩大指標，分別為「原因類指標」及「結果類指標」。如圖所示，原因類指標有「辨識利害關係人需要和期望的能力」、「領導力和高層管理的承諾」、「執行規劃的能力」、「定義組織的創新角色與職責」、「保證人員具有履行創新職能的相關能力」、「策略人力資源管理的能力」、「制定合作政策、培育內外部合作的能力」、「創新架構和直覺產生的能力」、「創意管理的能力」、「創新專案開發的能力」「創新思想的能力」、「合作管理的能力」與「創造力管理的能力」等十三項。結果類指標有「瞭解組織及其內外部環境的能力」、「制定創新策略的能力」、「培育創新文化的能力」、「組織的角色、職責和權利的設計能力」、「處理風險與機會的能力」、「確定建構創新體系所需資源」、「創新管理意識培育的能力」、「建立創新管理溝通管道的能力」、「將創新管理資訊檔化的能力」、「知識產權和知識管理的能力」、「結果的保護和利用的能力」、「市場推廣的能力」、「策略情報管理的能力」與「智慧財產管理的能力」等十四項。此分類方式將幫助組織進行創新管理的策略制度及改善方案的優先順序。

在圖 16 中，準則 c9「定義組織的創新角色與職責」為 (r-d) 值最大者，表示該準則直接影響其他準則的影響程度較大，而且其 (r+d) 值為第二大，代表其關聯強度也較大，因此建議組織在實施改善時可以考慮先改善該準則；準則 c16「知識產權和知識管理的能力」為 (r-d) 值最小者，代表該準則受其他準則影響程度最高；準則 c11「保證人員具有履行創新職能的相關能力」為 (r+d) 值最大者，代表該準則核心程度最高，因此準則 c11「保證人員具有履行創新職能的相關能力」最需要被改善。

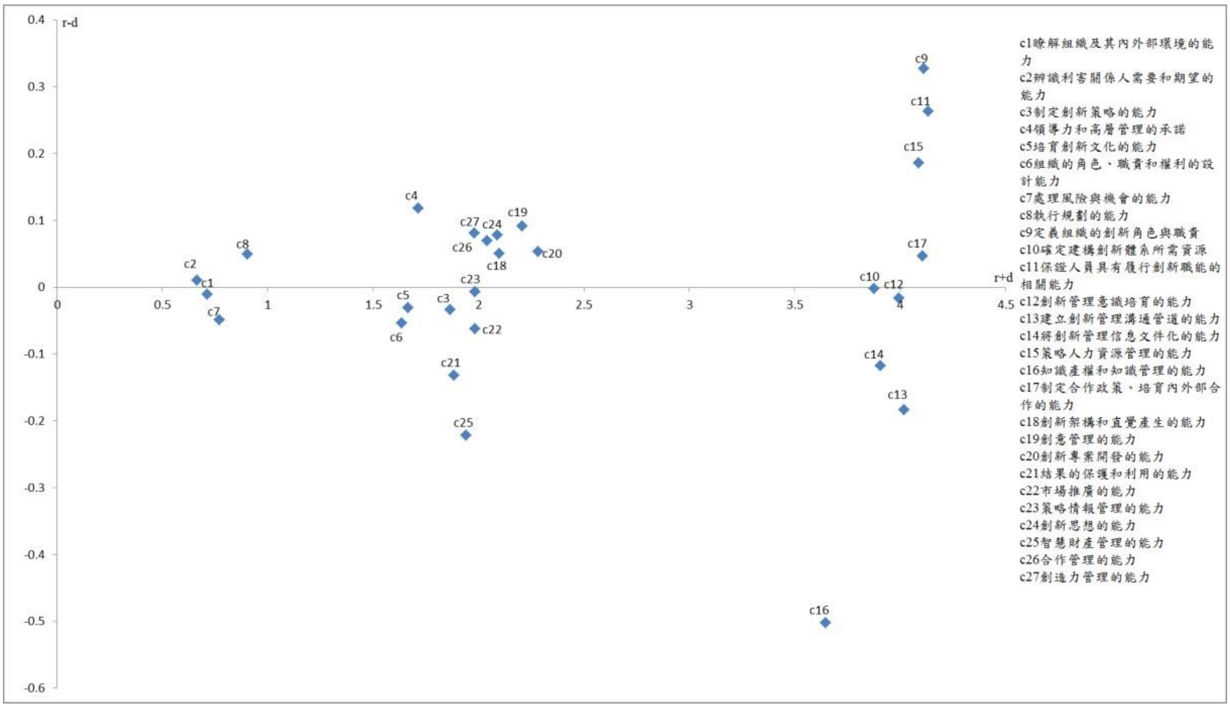


圖 19：準則層級影響關係圖

圖 20 為影響權重與績效值二維圖，橫軸是由 DANP 方法所獲得之準則影響權重，縱軸為個案組織的創新管理能力績效值。圖中兩條虛線將準則分為四個象限，經由象限圖的方式可以清楚的看出組織創新管理能力評估系統中各準則績效值與影響權重的整體表現，準則績效值越大，代表影響程度越高;準則影響權重值越大，則代表影響越大。

位於第一象限的準則有(c3)「制定創新策略的能力」、(c7)「處理風險與機會的能力」、(c8)「執行規劃的能力」、(c11)「保證人員具有履行創新職能的相關能力」、(c12)「創新管理意識培育的能力」、(c13)「建立創新管理溝通管道的能力」、(c14)「將創新管理資訊文件化的能力」、(c20)「創新專案開發的能力」、(c26)「合作管理的能力」、(c27)「創造力管理的能力」等十項，代表這些準則績效值較好，影響權重也較大。位於第二象限的準則為(c1)「瞭解組織及其內外部環境的能力」、(c4)「領導力和高層管理的承諾」、(c6)「組織的角色、職責和權利的設計能力」、(c10)「確定建構創新體系所需資源」、(c18)「創新架構和直覺產生的能力」等五項，說明該準則績效較好，但是影響組織創新管理能力程度

較小。位於第三象限內的準則為(c2)「辨識利害關係人需要和期望的能力」、(c5)「培育創新文化的能力」、(c9)「定義組織的創新角色與職責」、(c15)「策略人力資源管理的能力」、(c16)「知識產權和知識管理的能力」、(c17)「制定合作政策、培育內外部合作的能力」、(c19)「創意管理的能力」、(c21)「結果的保護和利用的能力」、(c22)「市場推廣的能力」、(c24)「創新思想的能力」等十項，這些準則績效值較差，但是影響組織創新管理能力程度不高。位於第四象限內的準則有(c23)「策略情報管理的能力」、(c25)「智慧財產管理的能力」等兩項，表示該準則績效值較差，對於個案組織影響權重較高，因此這些準則必須優先改善。配合網絡影響關係圖的結果，要改善「策略情報管理的能力」和「智慧財產管理的能力」，個案組織應先從改善「創造力管理的能力」及「創新思想的能力」著手。

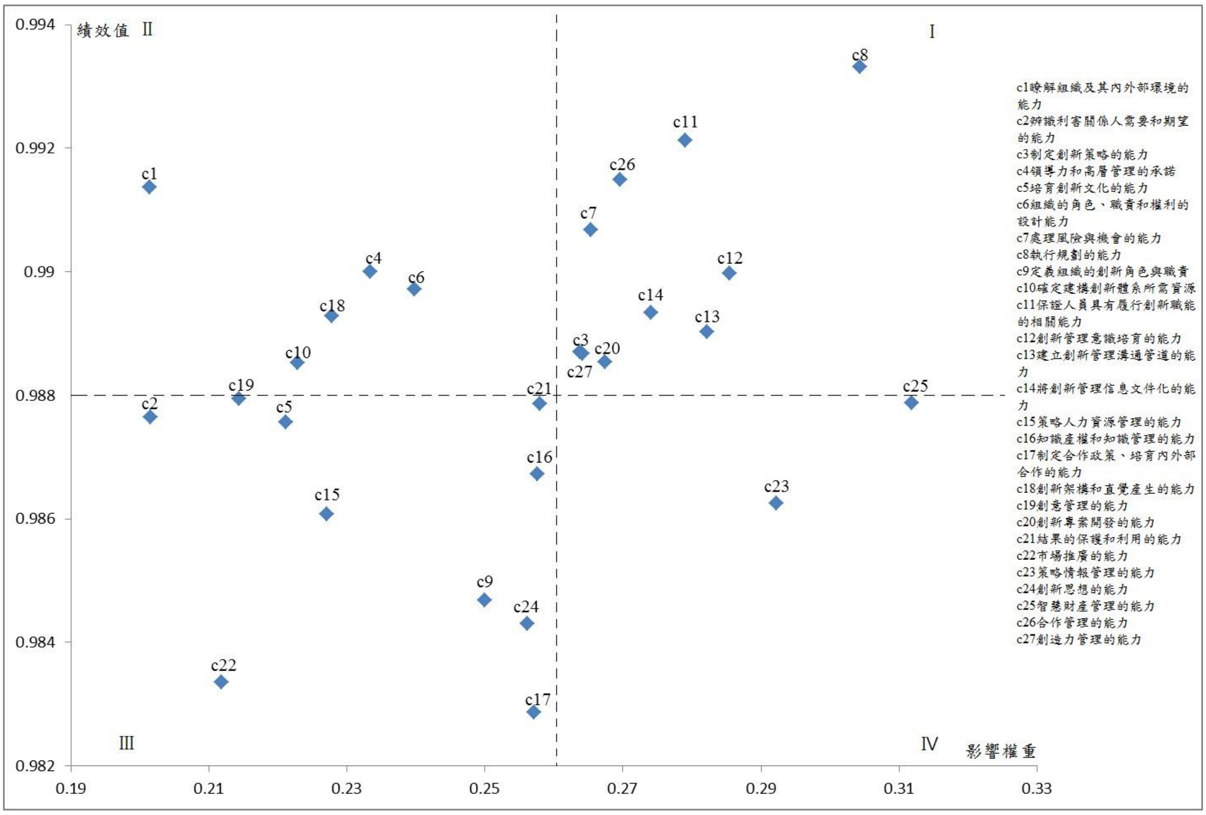


圖 20：創新管理系統關鍵因素相對影響權重與績效值二維圖

6.創新管理系統是持續競爭優勢的基礎

6.1.持續競爭優勢與創新

您可能想知道為什麼這節的標題是“持續競爭優勢”？ 我們是不是應該談論創新管理系統？ “持續競爭優勢”和“創新管理系統”有什麼共同之處？ 這些話描述了兩個不同的概念，但它們確實相關。組織要如何在商業上獲得競爭優勢？

競爭優勢意味著建立一個與競爭對手相比具有獨特優勢的系統。 為了提供和維持這種競爭優勢，企業應該考慮創新的競爭戰略。 創新一直是競爭力的核心，是創造競爭優勢和卓越客戶價值的關鍵手

段。 一個認真對待快速變化的市場與快速變化的技術競爭的企業必須讓事情發生 ─ 必須創新其產品、服務、流程或管理實踐。這個想法是以有效和可持續的方式創造客戶價值。這就需要有效地應用這些競爭優勢策略，這些創新策略必須與創新、創新管理系統和競爭的可持續性發展相關聯。

當一家公司的利潤超過其行業if均水準時，該公司就被認為具有競爭優勢。很多商業策略的目標是實現可持續的競爭優勢(sustainable competitive advantage)。(哈佛商學院 – 策略與競爭力研究所 - www.isc.hbs.edu)

您可以看到"可持續發展(sustainable)"這個詞，當然您可能會問："當您的商業環境中的環境每天都在變化的時候，您怎麼能夠在全球市場上保持可持續性呢？答案是： "透過不斷地接受這些變化─或創新(innovation)。創新型組織的特徵之一就是持續創新，透過持續創新維持組織的可持續發展。

由於世界貿易自由化而日益激烈的競爭導致了根據全球市場出現的新需求而生產的產品和服務。在全球競爭環境中取得優勢地位取決於確定正確的策略和創造不同的價值觀。每天，我們都面臨著更為激烈的競爭，環境威脅和新的消費行為等挑戰。為了能夠預見未來趨勢，規劃未來並確定未來商機，我們需要強大的創新方法和工具。創新必須與組織開發和商業化產品和服務的能力，從概念到實現。本研究開發和提供創新管理系統成熟度模型和績效評估的方法，並支援分析和加強組織的創新能力，

從而提升組織的持續創新競爭優勢。

6.2.持續競爭優勢與創新管理系統

在當今高度活躍的商業環境中，企業需要發展新的競爭優勢，以跟上技術變革的速度，客戶需求和全球競爭。透過創新活動，組織才能達到提高生產力和盈利能力、獲得新市場、提高現有市場份額等目標。因此，企業要發展創新能力，獲得可持續發展能力，提升創新績效，企業持續創新競爭優勢。而創新型組織提高創新能力需要引導和組織創新專案活動的新方法 ─ 我們稱之為敏捷創新創新管理 ─ 並且有系統地與創新管理系統*(IMS)*國際技標準整合。

我們回顧第三章中的企業競爭優勢結構化方程式，可以明顯看出本研究以 CEN/TS 16555-1 創新管理系統標準為參考所建立的六個關鍵指標構面 ─ D1「辨識組織環境能力」、D2「創新領導與創新策略能力」、D3「創新成功規劃能力」、D4「創新推動/驅動因素」、D5「創新管理流程能力」、D6「創新管理技術能力」，都會影響組織的競爭優勢。

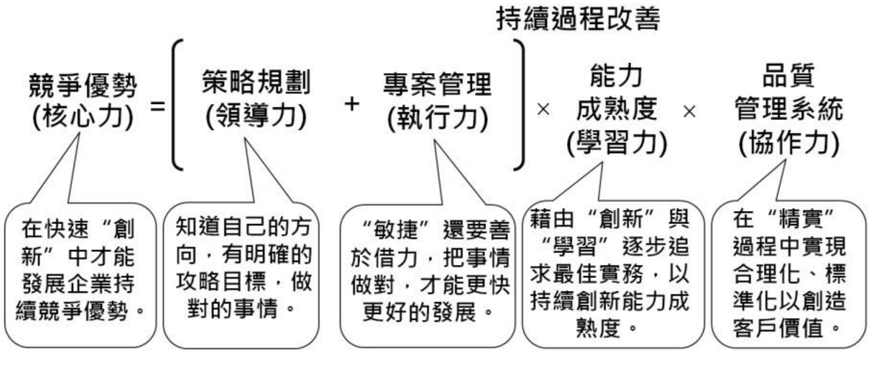


圖 21：創新型企業應用敏捷、創新及精實方法實現競爭優勢

目前最被熟悉的 IMS 就是 CEN/TS 16555-1 創新管理系統 (CEN/TS IMS)。透過創新管理系統，關於業務（服務邏輯）的服務觀點允許您創建能夠為客戶帶來利益和價值的新產品。而透過瞭解收益和價值，就可以發現新的商業機會。例如，Volvo CE´s(沃爾沃建築設備公司)在其研究中分析了公司目前的創新管理策略，並與歐洲標準化委員會的 CENT/TS IMS 標準化創新管理系統進行比較；這項研究有助於組織理解現行管理系統與 CEN / TS 創新管理體系中建議的差距；總的來說，研究認為 VOLVO 建築設備公司有一個很好的潛力，可以根據 CEN / TS 16555-1 的要求，將他們現有的創新管理模式作為基礎，並遵循研究提供的參考資料和建議，公司在這一使命中獲得成功的機會很大[7]。

組織不僅要生產新的商品和服務，將一系列創新活動作為一個過程或系統進行管理也很重要。為了確定創新績效，綜合考慮所有影響創新管理系統或創新管理過程的關鍵因素是非常重要的。本研究基於 CEN/TS 16555-1 創新管理系統標準之關鍵條文所建構的評估指標體系，不僅符合國際標準，同時應用混合式多評準決策方法所建立的關鍵指標影響關係，具有可操作性。遵循最新的歐洲創新管理標準，本研究幫助和支持我們的客戶開發和創新維護一個系統的創新管理實踐的系統結構模型。建立這樣一個管理系統，可以使企業變得更具創新性，並透過創新產品和服務獲得更大的成功。

Reference：

English Reference:

Amanda E.M., Palmovist and Patrik E. U. (2015), Exploring the Design and Use of Innovation Management Systems in Swedish Organisations, Department of Technology Management and Economics, Chalmers University of Technology.MoisesMira,

MartíCasadesúsa and LucHonorePetnjib (2016), The impact of standardized innovation management systems on innovation capability and business performance: An empirical study, Journal of Engineering and Technology Management, Volume 41, July–September 2016, Pages 26-44.

Bansemir, Bastian and Neyer, Anne-Katrin (2009), "FROM IDEA MANAGEMENT SYSTEMS TO INTERACTIVE INNOVATION MANAGEMENT SYSTEMS: DESIGNING FOR INTERACTION AND KNOWLEDGE EXCHANGE", Wirtschaftsinformatik Proceedings 2009. 69. https://aisel.aisnet.org/wi2009/69.

Benjamin Knoke, A Short Paper on Innovation Capability Maturity within Collaborations, http://ceur-ws.org/Vol-1006/paper2.pdf.

Burns, T. E., Stalker, G.M.: The Management of Innovation, University of Illinois (1961)

Mâsse, L.C. Moser, R.P. Stokols, D., Taylor, B.K., Marcus, S.E., Morgan, G.D., Hall, K.L., Croyle, R.T., Trochim, E.M.: Measuring Collaboration and Transdisciplinary Integration in Team Science, American Journal of Preventive Medicine, 35, 151-160 (2008).

Chesbrough, H., & Schwartz, K. (2007). Innovating business model with co-development partnerships. Research Technology Management, 50(1), 55-59.

CMMI Product Team, Capability Maturity Model® Integration (CMMI®), Version 1.1.

[7] Mälardalens University(2016), The new standard for innovation management systems, Master Thesis in Innovation Management, Department of Innovation, Design and Engineering (IDT), Jan 2016.

CMMI® for Systems Engineering, Software Engineering, Integrated Product and Process Development, and Supplier Sourcing (CMMI-SE/SW/IPPD/SS, v1.1), Carnegie-Mellon Software Engineering Institute, Pittsburgh (2002).

Essmann, H., Preez, N. du. (2010), An Innovation Capability Manturity Model-Development and application [J], International Journal of Human and Social Seiences, 2010, 5(1) : pp. 44-55.

Mann, D. (2012), Innovation Capability Maturity Model (ICMM)- An Introduction [M], IFR Press, 2012.

Tse, K. M. (2012), Innovation Capability and the Maturity Model- with a case studies of Apple Computer, Inc. and I Pod, Google Scholar, 2012.

Essmann, H. (2009), Towards Innovation Capability Maturity [D], University of Stellenbosch, 2009.

Filippov, Sergey and Mooi, Herman, "Innovation Project Management: a research agenda" 6th International Conference for Innovation and Management(ICIM2009), Sao Paolo, 2009/12/08-10.

Keegan, A. Turner, J.R. (20002), "The management of innovation in project-based firms, Long Range Planning," 2002, 35(4):367-388

M. Lerch (2012), Innovation Project Portfolio Management: A Qualitative Analysis, IEEE Transactions on Engineering Management (Volume: 60, Issue: 1, Feb. 2013)

Mälardalens University(2016), The new standard for innovation management systems, Master Thesis in Innovation Management, Department of Innovation, Design and Engineering (IDT), Jan 2016.

Meng-Jong Kuan, Chia-Chun Hsiang and Gwo-Hshiung Tzeng, (2012) “Probing the Innovative Quality System Structure Model for NPD Process Based on Combining DANP with MCDM Model,” International Journal of Innovative Computing, Information and Control, Vol. 8, No. 8, August 2012, pp.5745~5762.

Chinese Reference:

管孟忠(2018)，創新型組織的敏捷創新專案管理，翰蘆圖書出版公司，ISBN：9789869611541。

管孟忠、陳以明、邵秀文（2013），應用混合式多評準決策方法建構創新專案管理能力評價模式，管理資訊計算，2013 年第 2 卷第 1 期。

陳以明、向佳君、楊皓博(2010)，結合 DANP 之 MCDM 模型探討新產品開發過程品質關連性之研究，運籌與管理學刊，9(1)，第 39-54 頁。

安景文、李園春、劉海東、甄海虹、梁瑞文(2006)，企業技術創新能力成熟度評價指標體系研究，中國科技論壇，2006 年 06 期。

趙林捷、湯書昆(2007)，一種新的技術創新管理工具—創新管理成熟度模型研究(IMMM)，《科學學與科學技術管理》，2007，(10)，pp.81-87。

陳玉和、俞其慧(2010)，企業技術創新能力成熟度探析，西南交通大學學報(社會科學版)，2010，(5)，pp. 70-74。

張潔(2010)，高新技術企業自主創新管理能力成熟度模型與提升方法研究，《經濟與管理科學》，http://wap.cnki.net/lunwen-1011044964.html 秦德智和胡宏(2011)，企業技術創新能力成熟度模型研究，《技術經濟與管理研究》，2011 年 07 期。 http://www.cnki.com.cn/Article/CJFDTotal-JXJG201107013.htm 姚麗(2015)，組織創新能力成熟度模型研究，《產業經濟研究》，2015 年 01 期。

汪忠國和姚麗 (2017)，基於能力成熟度模型的高新技術企業創新能力成熟度分析，《集寧師範學院學報》

2017 年 06 期。 http://www.cnki.com.cn/Article/CJFDTOTAL-JNSI201706016.htm

Apply TRIZ Theory to Chinese Medicine Aluminum Foil Clip Chain Bag

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Abstract

In recent years, the development speed of Chinese Herbal Pieces has been astonishing, but the long-term usage is not uniform and the packaging is not standardized, and the manual packaging has caused poor efficiency. To break this bottleneck, to intensify the innovation of packaging methods, and to improve the packaging level of Chinese Herbal Medicine Pieces is a pressing issue. This study uses the Jiugong lattice method to help break through the psychological inertia to think about various issues. The RCA+ root conflict analysis tool developed by the TRIZ International Association (2004) was used to identify and analyze the causes of the problems and identify key issues. Then the TRIZ conflict matrix and inventive principles were used to identify Standard answer, and through the patent analysis search and the related patents of this research expect to find a possible solution, and then compare the before and after improvement of the simulation map or the actual product designed by the concept idea, and then use the statistical analysis method of the correlation t test before and after the questionnaire survey and improvement to evaluate. This study uses the statistical method t-test and the production-side expert-rating method evaluation case, both showing that the improved data is better than the pre-improvement data, as for the total profit, the improved scheme B will be higher than the previous improvement of about NT$35,989 thousand, showing improved results is effective, and can increase productivity and reduce occupational injuries. It is suggested that if similar research can be done in the future to make creative ideas for automated machinery and equipment, and 18 mechanical vibration principles that are not realized in this study can be considered as priority discussions.

Keywords: jiugong method, RCA+(root cause analysis), contradiction matrix, 40 innovation principles

應用 TRIZ 理論於中藥鋁箔夾鏈袋

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摘要

近年來中藥飲片發展速度驚人，但長期用量不統一與包裝無規範，且人工包裝造成效率差，為打破此瓶頸，加強包裝方式創新，提升中藥飲片包裝水準已是形勢所迫。本研究運用(1)九宮格法幫助突破心理慣性思考各種問題；(2)TRIZ 國際協會 2004 年所開發，RCA+根源衝突分析工具確定與分析問題原因，找出關鍵問題；(3)TRIZ 矛盾矩陣與發明原則找出標準解答，並透過專利分析搜尋與本研究相關專利,期望找到可能方法解；(4)問卷調查與改善前後的相依性 t 檢定統計方法進行評估。本研究結果顯示改善後優於改善前，此外改善後總利潤部分，改善後利潤高出改善前約 35,99 萬元，且能提高生產效率，降低職業傷害。本研究於 TRIZ 之四十發明原則中「＃18 機械震動」，於本研究尚未實現於創新治具，建議未來若有類似研究優先設計導引。

Keywords: 九宮格法、.RCA+根源衝突、矛盾矩陣、40 發明原則

1. 緒論

近年來，中藥飲片發展速度驚人。但長期以來存在著用量不統一，包裝無規範，且人工包裝造成效率差，因此要打破這個瓶頸，除制定品質可控制的中藥飲片標準規範，加強包裝方式創新，支持產業發展、促進產業升級及提升中藥飲片的包裝水平已是形勢所迫。

1.1 研究動機

中藥包括「中藥材」、「中藥飲片」及「中成藥」，為中藥行業的三大支柱。中藥中最傳統的一種劑型為「中藥飲片」，俗稱「湯藥」或「大藥」即到中藥房或中藥店抓回家熬成湯藥的原料藥物。中藥飲片若儲存期過長或保管不善，易受潮、蟲蛀或霉變等狀況產生，目前市面上的中藥飲片皆以鋁箔夾鏈袋來對中藥飲片進行保護，避免蟲蛀、霉辨惑受潮情形產生，因為內層鋁箔材質氣體阻隔性佳，具良好的遮光性，延長內容物的保存時效，其夾鍊設計方便重複拿取並保持內容物新鮮度，具環保效果。

1.2 研究目的

本研究期望設計一治具來取代人工按壓夾鏈袋壓條，使其提高生產效率，保障人機安全並使人能夠有效舒適的工作。

2. 文獻探討

中藥飲片包裝規格未統一，使飲片汙染甚鉅，且容易變質，影響療效，不能滿足食用安全的需求，以下針對本研究所牽涉的方法進行文獻探討：

2.1 單層/複合塑料袋比較

將川芎分別裝入單層麻袋和雙層複合夾鏈袋，密封後，分成高溫低濕組和常溫常濕組，觀察 70 天的實驗研究結果：結果複合夾鏈袋 (牛皮紙或鋁箔袋)包裝的防潮、隔熱、密封等性能比單層包裝好，其揮發油、水分和外觀質量均好於其它包裝材料(曾俊超等 1997)，如圖 1。

圖 1. 層/複合塑料袋

2.2 TRIZ 理論

TRIZ 理論是由前蘇聯發明家 Altshuller (1946) 創建的，Altshuller 也被尊稱為 TRIZ 之父。 Altshuller 和他的 TRIZ 研究機構 50 年來提出了 TRIZ 系列的多種工具，如衝突矩陣、76 標準解、 ARIZ、物質-場分析、ISQ、DE、8 種演化類型、科學效應等，常用的有基於巨集觀的矛盾矩陣法和基於微觀的物場變換法。事實上，TRIZ 針對輸入輸出的關係、衝突和技術進化都有比較完善的理論。

2.3 TRIZ 歷史

由下表可看出 TRIZ 發展從 1946 年開始至今已有將近 70 年的時間，然而 TRIZ 的分水嶺於 1998 年以前稱為傳統 TRIZ，1998 年以後則為現代 TRIZ，本研究所探討的 xTRIZ 則為 1999-2003 發展出的，是由一些 TRIZ 專家所開發出的版本，另外研究中所探討的 RCA+根源衝突分析則於 2004-2008 年所開發出來的，如表 1。

表 1. TRIZ 歷史

年代	代表人物	事件
1946-1950	G. Altshuller	1. 開始開發並首次舉辦 TRIZ 培訓課程。 2. 意識到解決一個技術矛盾的關鍵作用。
1956	G. Altshuller R. Shapiro	在雜誌上發表關於技術創造力文章，這是 TRIZ 第一次正式出版物。
1970	G. Altshuller	於解決創造性問題的理論與實踐中介紹到 TRIZ 一詞。
1971	G. Altshuller	1. 包括 35 個步驟，40 個發明原則(88 個附屬發明原則)，39*39 參數解決技術問題矩陣。 2. 小矮人法的第一個版本。
1985	G. Altshuller ;B. Zlotin S. Litvin; V. Gerasimov	1. ARIZ 的出現，包括 32 個步驟，並說明利用時間、空間和物質場資源，已獲得最理想的解決方案。 2. 完成 76 個標準解。 3. 另外開發 Trmming 分析，還有 TRIZ 工具應用到專利規避領域。
1995-1996	G. Altshuller	俄羅斯 TRIZ 協會成為 TRIZ 國際協會。
1997	G. Altshuller	國際 TRIZ 協會註冊。
1999-2003	國際 TRIZ 協會	1. 1999 年 TRIZ 協會將所有權利轉讓給國際 TRIZ 協會（MATRIZ） 2. 具有 TRIZ 專業知識的不同組織開發了他們自己的 TRIZ 版本（I-TRIZ，TRIZ +，xTRIZ，CreaTRIZ，OTSM-TRIZ)。 3. 歐洲 TRIZ 協會於 2000 年成立。 4. 介紹 40 個發明原則在不同領域的應用。 5. 解決技術矛盾的新版本為 2003 版。 6. TRIZ 法國協會、義大利 TRIZ 協會、韓國 TRIZ 協會及台灣系統性創新協會成立。
2004-2008	國際 TRIZ 協會	1. 發展新工具根源衝突分析(RCA+)。 2. 提出 150 個創新標準體系。 3. TRIZ 與 QFD 及六標準差結合。 4. 日本 TRIZ 協會成立。 5. TRIZ 年度會議於 2005 年啟動。

資料來源：本研究整理

2.4 RCA+ 根源衝突法

Souchkov (2007) 提到一種名為 xTRIZ 的流程法，其中 "x”代表延伸或擴展的 TRIZ，主要在分析商業或管理面的問題，識別根源衝突，選擇要解決的問題，產生新的想法和策略，並評估最終結果，此方法使用經典 TRIZ 與現代 TRIZ 作為結合，除經典的矛盾矩陣與 40 個發明原則外，還使用到 RCA+根源衝突分析與多標準決策以加強問題解決和決策過程。

3. 研究方法

3.1 中藥飲片包裝製程

中藥飲片包裝製程，如圖 2，開始由外袋貼標→人工選別→產品秤重→人工封口壓條→包裝入庫即完成包裝作業，其中目前最大的瓶頸作業流程於人工封口壓條站，此為人工落後製程，有待進一步改善。

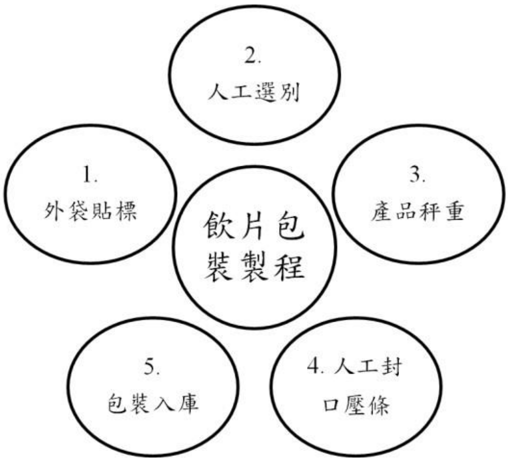


圖 2. 包裝製程　　　　　　資料來源：本研究自繪

3.2 問題分析與解決

3.2.1 定義問題

九宮格分析，是以時間 (過去、現在、未來) 對應到系統 (超系統、系統、子系統) 的方式描述，九宮格的目的是幫助突破心理慣性來思考各種可能問題的解答，並以邏輯系統推演的方式來思考周遭環境可利用的事物 (資源)，或尚未利用用到的資源來解決問題，如表 2。

表 2. 九宮格分析說明

	過去	現在	未來
超系統	中、草藥店	中藥房、大型中藥醫院	網路購物、大型賣場
系統	傳統飲片包裝型態 (人工綑綁/大包裝/費力)	現代飲片包裝型態 (人工封口/小包裝/費力)	未來飲片包裝型態 (自動化封口/小包裝/省力)
子系統	聚丙烯塑料編織袋(PP) 麻袋、布袋、紙箱	聚乙烯塑膠袋(PE) 牛皮紙夾鏈袋 (單層或複合)	牛皮夾鏈袋

資料來源：本研究整理

- 過去：傳統的中藥飲片包裝型態較為雜亂，多為人工綑綁大包裝，較費力，且大大降低生產效率，皆於中草藥店購買以麻袋、布袋、紙箱、PP 編織袋造成中藥材變質的風險較高，原因可能為蟲蛀、發霉、變色。
- 現在：現代的中藥飲片包裝型態多為人工封口小包裝，較費力，當封口處壓條未封緊密，產品容易發霉變質，生產效率差，於中藥房或大型中藥醫院購買以 PE 聚乙烯塑膠袋。
- 未來：未來的中藥飲片包裝型態期望能達到省力，提高生產效率，使用治具或自動化設備代替人工包裝且密封性良好的鋁箔夾鏈袋進入綠色包裝產業。

3.2.2 問題探討

RCA+為近代國際 TRIZ 協會 (2004) 所發展出的根源衝突分析工具，是一種結構化的問題處理法，用以逐步找出問題的根本原因並加以解決根本原因分析是一個系統化的問題處理過程，包括確定和分析問題原因，找出問題解決辦法，並制定問題預防措施，如圖 3。

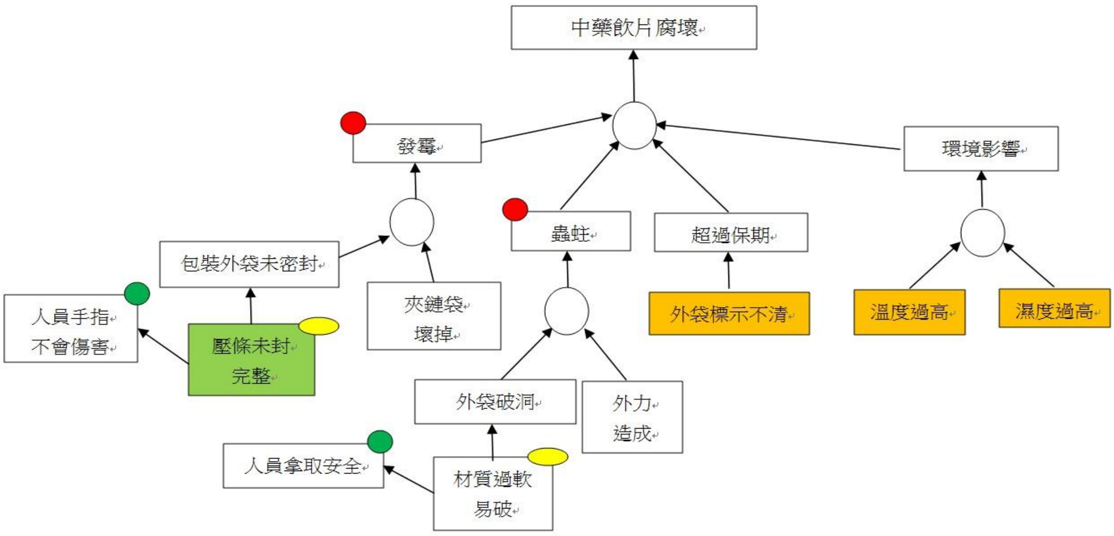


圖 3. RCA+根源衝突分析資料來源：本研究自繪

由圖 3 最上方找出問題為中藥飲片腐壞，再以結構狀發展出造成中藥飲片腐壞的原因有「發霉」、「蟲蛀」、「超過保期」、「環境影響」，再針對發霉的問題探討原因，可能有「包裝外袋未密封」或「夾鏈袋壞掉」，蟲蛀的部分可能是「外袋破洞」或「外力造成」，再針對「包裝外袋未密封」與「外袋破洞」的問題分別找出可能為「壓條未封完全」與「材質過軟易破」造成，分別由最終找到的「壓條未封完全」與「材質過軟易破」問題，產生其中的衝突矛盾，如壓條未封完整其正面影響為「人員手指不會傷害」其負面影響為可能造成「產品發霉」，又如材質過軟易破其正面影響為「人員拿取安全」，負面影響為可能有「蟲蛀」的疑慮。

3.2.3 TRIZ 找尋標準解答

本研究矛盾矩陣法藉由問題改善與惡化得到觸發解(40 個發明原則)。因為目前中藥飲片人工包裝生產效率差，為改善生產效率問題，各中藥廠已著手引進先進包裝設備來改善此生產效率差的問題，如表 3、4。

(1) IF 設計一個治具代替人工，Then 改善 39 生產力，But 惡化 16 固定件耐久性

(2) IF 設計一個治具代替人工，Then 改善 39 生產力，But 惡化 31 物體產生有害因素

表 3. 矛盾矩陣

惡化 / 改善	31 物體產生有害因素
39 生產力	35 22 18 39

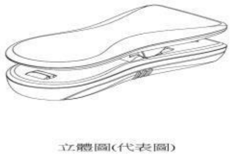
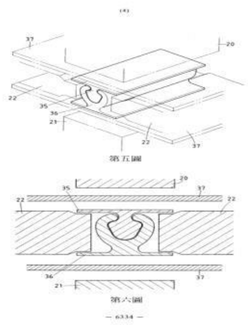
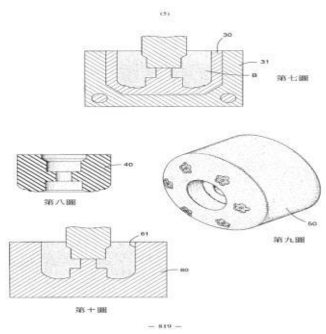
表 4. 發明原則

NO.	40 發明原則	說明	設計概念發想
35	參數改變	改變彈性 (伸縮性、彎曲性)的程度	找尋有彈性或可彎曲的物件來取代手壓夾鍊條的落後製程
22	轉有害為有利	轉變有害的物體或作用以獲得正面的效果	取廢鋁材加工後當滾輪底座
18	機械震動	使物體震動或震盪	本研究目前期望找尋可替代手工壓合小型治具，針對此發明原則相關機械震動較無法實現於治具構想中，故不特別探討。
39	惰性環境	加入中性物質或鈍性添加物體或系統中	使用中性物質聚氨酯橡膠製作的滾輪治具，其機械性能好、高硬度、高彈性、耐磨耗性佳

3.1.5 專利分析

經由中華民國專利資訊檢索系統找到與本研究相關專利分析並做成分析表，研究中發現雙頭型封口機與夾鏈袋封口其共同點皆為上、下模具或封合概念，期望藉由專利分析能找到可能的方法解，如表 5。

表 5. 專利分析表

專利簡圖	專利說明
 專利號碼：D190167 專利名稱：雙頭型封口機	本設計之特點為雙頭型封口機整體造型包括一底座以及一可供按壓之蓋體。此外，本設計之另一特徵在於其新式的雙頭型彈壓設計，於使用時，一端可進行袋口熱壓封合作業，另一端則可進行袋體裁切作業。 優點：使用時，一端可以進行袋口熱壓封合作業， 另一端可袋體裁切，可謂一機兩用。 缺點：因體積較小，加熱時間較慢。
 專利號碼：459748 專利名稱：夾鏈袋封口成行隔板結構改良	本創作之主要目的，係在提供一種夾鏈袋封口成 型隔板之結構改良，又其中，可使該二成型隔板，利用連動結構固組於熱熔上、下模具之間，使其於實際執行夾鏈袋封口成型加工時，以各種方式諸如：彈簧、氣、液壓元件等，使該二成型隔板可隨上、下模之加工而略為產生上、下浮動之現象，避免拉動送料時與熱熔 上、下模摩擦造成刮痕之實用效益者。 優點：執行封口加工時，隔板可隨上、下浮動，避 免拉動後的刮傷。 缺點：加工成本較高。
 專利號碼：200711829 專利名稱：橡膠輪體的製作方法	本設計是一種能以較低成本來大量製造具有凹凸標誌的橡膠輪體的製造方法，做法為先製作表面具有凹凸標誌且形狀與輪體模具的模穴相同的金屬模型,再將金屬模型以底部平放於對合模具的模穴內而以玻纖塑膠灌注於金屬模型周圍，藉此翻製成輪體模仁，將輪體模仁嵌設於輪體模具內再配合上模進行灌注 PU 橡膠的步驟，最後將橡膠輪體取出經修整加工後即可得到具有凹凸標誌的輪體。 優點：高硬度、高彈性、耐磨性佳。 缺點：不耐臭氧、不耐高溫。

依照發明原則的概念發想與專利分析，找出可能的設計圖，如圖 4。

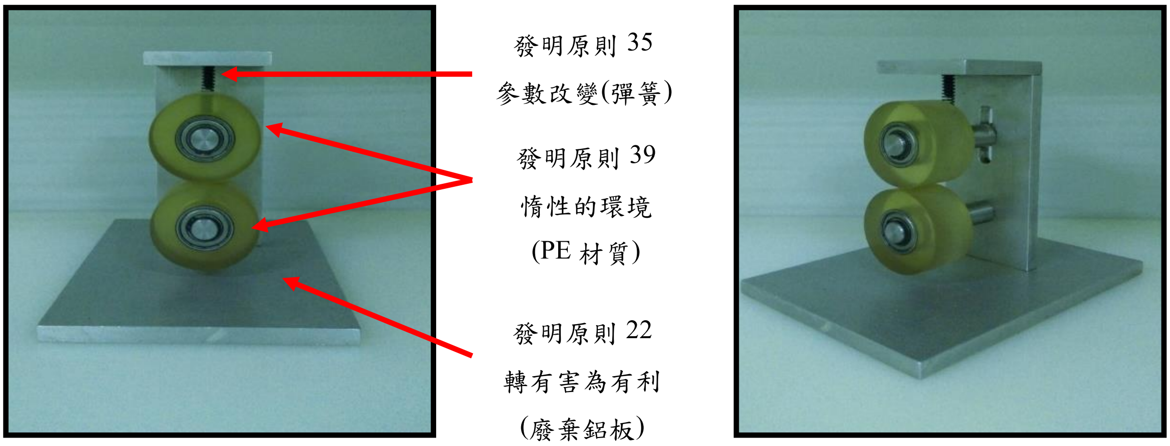


圖 4. 夾鏈袋滾輪設計圖；左圖為正視圖 右圖為側視圖

3.3 產品評估

本研究以問卷的方式進行產品評估調查，受測者須經由 5 道評估程序，才可進行問卷的填寫。

3.3.1 評估程序

由製造課包裝作業人員擔任受試者，包裝組長擔任主試者，每次測試以一位受試者為主，並由同一位受試者分別進行改善前的手壓封口及改善後的滾輪封口測試，完成後，再由主試者將封口總數量、良率、不良率進行統計作業，此時受試者同步進行改善前後主觀問卷調查五點量表的填寫作業，直到完成改善前後問卷後，再請進行下一位受試者進行測試，如圖 5。

Step 1：

- 進行測試作業前，由主試者下達口令：「開始練習」，同步按下碼錶，計時 3 分鐘。
- 結束時，再由主試者下達口令：「停止練習」，人員需立即停止練習。
- 由主試者下達口令：「休息 1 分鐘」，受試者就地休息 1 分鐘，活動筋骨。

Step 2：

- 休息過後，再由主試者下達口令：「開始測試」，同步按下碼錶，計時 10 分鐘。
- 結束時，再由主試者下達口令：「停止測試」，人員需立即停止測試。

Step 3：

- 此時，由主試者下達口令：「開始填寫問卷」，人員立即開始填寫問卷直到完成改善前後問卷填寫作業。

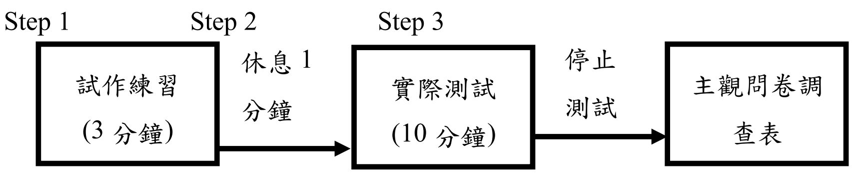


圖 5. 測試流程圖

資料來源：本研究自繪

3.3.2 受試者

受試者共計 30 人，男生 10 人及女生 20 人，平均年齡為 29.9 歲(標準差 6.2 歲)。

3.3.3 問卷設計

本研究問卷填寫對象為製造課包裝作業人員，共發出 30 份，回收 30 份，回收率 100%，扣除填答不全與亂填答之無效問卷 0 份，共得有效問卷 30 份，有效比率為 100%，主要以李克特五點量表作為主要衡量依據，非常滿意為 5、滿意為 4、普通為 3、不滿意為 2、非常不滿意為 1，並進行信、效度分析作業，若信度 Alpha 值>0.7，則表示具有良好的穩定性及一致性；若效度 KMO 值>0.5，則具有良好的可靠性。

3.3.4 參數

本研究參數設定分別為獨立變數與相依變數，如表 6。

表 6. 變數分析表

	獨立變數	
	改善前	改善後
相依變數	完成總件數良率(%) 不良率(%)	

3.3.5 統計分析

- 將問卷調查表以 SPSS12 統計軟體進行信、效度分析。
- 使用統計手法進行相依 t 檢定分析。

3.4 結果分析**-**

- 3.4.1 改善前後各項目分析結果製作，如表 7。

表 7. 改善前後各項目分析結果

改善前後	改善前(手壓)	改善後(滾輪)

項目					
10 分鐘完成總件數		118		298	
良率		93.31%		99.85%	
不良率		6.69%		0.15%	
改善前後 / 項目		改善前(手壓)		改善後(滾輪)	
		Mean	STD	Mean	STD
問卷數值	公平使用	3.83	1.02	4.43	0.63
	彈性使用	2.43	0.68	4.57	0.50
	簡易直覺使用	4.53	0.51	4.47	0.57
	明顯的資訊	2.47	0.63	4.47	0.51
	容許錯誤	3.90	0.96	1.50	0.51
	省力	1.63	0.56	4.53	0.51
	適當尺寸與空間	4.13	0.97	4.57	0.50
	長久使用具經濟性	1.57	0.50	4.53	0.51
	品質優良美觀	4.13	0.73	4.47	0.51
	人體與環境無害	3.53	0.51	4.50	0.51
信度 Alpha 值		0.708		0.662	
效度 KMO 檢定		0.576		0.576	

表 7 為改善前後結果比較表，改善前的數據於 10 分鐘完成總件數、不良率彈性使用、明顯的資訊、省力及長久使用具經濟性的表現皆較差，大部分都是不滿意與非常不滿意居多，表示大部分的人員都認為以手壓夾鍊條來作業相對是費力且對人員是一種傷害，有改善的必要。改善後的數據在容許錯誤作答不滿意的居多，原因應該為大部分的人都認為如果是手指按壓夾鍊條，即使錯誤動作也不會發生不方便情形，所以皆選擇非常滿意選項，但如果是滾輪夾鍊條，假設錯誤動作操作，可能導致滾輪斷裂損毀，就無法使用，這樣就可能會有不方便情形發生，所以此選項大部分人員選擇非常不滿意選項。另外於信度與效度檢定中，改善前與改善後的問卷調查數據皆具有穩定性、一致性與可靠性。

3.4.2 改善前後相依性 t 檢定表 8. 改善

前後相依性 t 檢定

	項目		t 值	P value	有/無 顯著差異
	10 分鐘完成總件數		-155.02	P<0.05	有
	良率		-23.46	P<0.05	有
	不良率		23.49	P<0.05	有
問卷數值	1	公平使用*	-2.69	P<0.05	有
	2	彈性使用*	-13.581	P<0.05	有
	3	簡易直覺使用	0.582	P>0.05	無
	4	明顯的資訊*	-13.90	P<0.05	有
	5	容許錯誤*	11.61	P<0.05	有
	6	省力*	-22.31	P<0.05	有
	7	適當尺寸與空間*	-2.77	P<0.05	有
	8	長久使用具經濟性*	-22.62	P<0.05	有
	9	品質優良美觀	-1.90	P>0.05	無
	10	人體與環境無害*	-8.61	P<0.05	有

備註：＊表示統計上有顯著性差異。

由表 8 得知除問卷數值＃3 與＃9 無顯著差異，其餘皆有顯著差異，探究其原因如下：

- 無顯著差異

#3 簡易直覺使用：可以簡單操控。

此項問卷內容無論是針對男性或女性於手壓式或滾輪式治具皆屬於容易操控狀態，故針對問卷結果較無明顯差異。

#9 品質優良與美觀：材質使用上感受滿意。

此項問卷內容問針對材質感受度提問，無論男性或女性於手壓式或滾輪式主要目的是封合壓條，與材質關係較小，故問卷結果並無明顯差異。

- 顯著差異

***1** 公平使用：可以放心安全操控。　　此項問卷內容若發生在手壓式壓條生產，因為手指需長時間進行封合作業，較容易造成受傷，若為滾輪式治具因屬於治具取代手指，較不會有受傷疑慮，故針對問卷結果有明顯差異。

***2** 彈性使用：可以準確精確操控。

此項問卷內容若發生在手壓式壓條生產，較容易出現手指疲乏狀態，且有壓條不精確的狀況產生，若為滾輪式則較無此疑慮，故針對問卷結果有明顯差異。

***4** 明顯的資訊：可以完全清楚夾鏈袋有密封。

此項問卷內容若發生在手壓式壓條生產，因封合施力點並非完全平均，可能造成無法完全密封狀況產生，若為滾輪式治具其施力點較為平均，故能完全清楚夾鏈袋有密封，故針對問卷結果有明顯差異。

***5** 容許錯誤：錯誤動作下，也不會發生使用不方便情形。

此項問卷內容若發生在手壓式壓條生產，即使錯誤動作，手指仍然可以進行封合動作，若為滾輪式治具，當發生治具錯誤動作造成治具故障或損壞時，則無法進行封合動作，即可能發生不方便情形，故針對問卷結果有明顯差異。

***6** 省力：可以有效、舒適及不費力使用。

此項問卷內容若發生在手壓式壓條生產，因長期靠手指進行作業，容易產生疲乏，費力狀況，所以容易造成無效、不舒適及費力狀況，若為滾輪式治具則可以有效、舒適及不費力生產，故針對問卷結果有明顯差異。

***7** 適當尺寸及空間：使用者不同姿勢皆容易使用及足夠空間。

此項問卷內容若發生在手壓式壓條生產，使用者以不同姿勢會有疲勞狀況產生，若為滾輪式治具於不同姿勢封合作業，較無太大差異，故針對問卷結果有明顯差異。

***8** 可長久使用具經濟性：可以耐久且長期使用。

此項問卷內容若發生在手壓式壓條生產，容易造成手指疲乏受傷較無法長期使用，若為滾輪式治具取代手指則無疲勞或受傷疑慮，較可以耐久長期　使用。故針對問卷結果有明顯差異。

***10** 對人體與環境無害：有助於對周遭環境改善。

此項問卷內容若發生在手壓式壓條生產，因手指有疲勞受傷疑慮，封合速度會落後，工作桌上與周邊容易導致凌亂，若為滾輪式治具取代手指可加快生產速度，工作桌及周邊則較為乾淨整潔，有助改善周遭環境，故針對問卷結果有明顯差異。

3.5 方案評估與選擇

本研究依據林裕家(2018)系統性創新研討會使用，利用專家評分法評估，找尋廠內包裝、製程與工務專家針對生產面進行方案討論與評估，並以甲、乙方案分別依據有提升生產效率給予 9 分，若無則給予 1 分；有降低成本給予 9 分，若無則給予 1 分；有降低職業傷害給予 9 分，若無則給予 1 分、有提升方便性給予 9 分，若無則給予 1 分及已有專利給予 9 分，若無則給予 1 分，依據此評估方法進行評分，如表 9。

(1) 提升生產效率部分，於甲方案共計得到 1 分，乙方案共得 9 分。

(2) 降低成本部分，於甲方案共計得到 1 分，乙方案共得到 9 分。

(3) 降低職業傷害部分，於甲方案共計得到 1 分，乙方案共得到 9 分。

(4) 提升方便性部分，於甲方案共計得到 1 分，乙方案共得到 9 分。

(5) 專利部分，於甲方案共計得到 1 分，乙方案共記得到 9 分。

表 9. 方案評估

評估方案	評分準則 (分)	
	甲方案手壓式	乙方案滾輪式
提升生產效率	1	9
降低成本	1	9
降低職業傷害	1	9
提升方便性	1	9
有無專利	1	1
總分	5	37

資料來源：本研究整理

由表 9 方案評估中，以乙方案得到總共 37 分為 5 項評估案中最高分，則選擇滾輪治具作為改善牛皮夾鏈袋人工封條最佳解。

4. 結論

中藥飲片長期存在包裝無規範及效率差的問題，本研究針對包裝效率差的問題找尋方法並提出改善方案與評估，期望透過問題解決能改善人工落後製程，並降低職業傷害的風險，與降低成本。本研究經由 TRIZ 矛盾矩陣與發明原則的概念設計後，產生改善前後的方案評估比較，改善後的總件數及良率相較於改善前的數據有往上的趨勢，而不良率則是改善後相較改善前降低，皆顯示改善後明顯優於改善前，再由統計分析手法相依變數 t 檢定的分析後，發現改善後的總件數/良率/不良率及問卷數值大多與改善前有顯著差異，且都是變好的趨勢，僅#3 簡易直覺使用與#9 品質優良美觀無明顯差異，此僅是因為改善前後針對治具是否容易操控與外觀美觀與否，皆非對改善前後有直接關聯，故結果較無顯著差異。

本研究於生產面運用專家評分法針對提升生產效率、降低成本、降低職業傷害、提升方便性及有無專利等方案，邀請廠內包裝、製程與工務等專家進行評分，最終以改善後的乙方案總得分 111 分優於改善前的甲方案總得分 15 分，皆顯示改善後有明顯提升。

4.1 研究貢獻

本研究針對統計分析 t檢定及於生產面運用的專家評分法皆顯示改善後的數據優於改善前，再經由改善前後利潤比較，如表 10。

表 10. 改善前後總利潤比較

方案 / 時間	改善前甲方案	改善後乙方案
10 分鐘總件數 (件)	118	298
每小時總件數 (件)	708	1788
每日總件數 (件)	11328	28608
每周總件數 (件)	56640	143040
每月總件數 (件)	1132800	2860800
每包單價 (元)	20	
良率	93.31%	99.85%
總利潤 (元/月)	21,140,313	57,130,176

資料來源：本研究整理

由表 10 得知改善前甲方案每月總利潤約為 21,140,313 元，改善後乙方案約為 57,130,176 元，改善後總利潤約比改善前多 35,989,863 元，顯示改善後的方案是有效的。本研究改善後方案最終能提升生產效率、降低成本及降低職業傷害，且每月總利潤也能提升，也期望本研究能提供一些方法給尚在找尋改善方案的研究人員一些啟發與貢獻。

4.2 研究限制

本研究主要探討手壓式夾鍊條與滾輪式夾鍊條不同點，並以 TRIZ 矛盾矩陣方法進行分析，主要研究限制有以下三點：

- 本研究所蒐集之參考資料，以國內可取得之中、英文為限。
- 本研究因為部門人數有限，針對問卷調查部分僅能提供 30 份進行分析，為本研究數據量不足之處，也為本研究最大的限制。
- 本研究因為沒有多的個案可驗證，所以只針對鋁箔袋壓條封合治具來做了解與改善，進而加以分析研究。

4.3 未來研究

本研究於 TRIZ 階段針對矛盾矩陣與發明原則的關聯性中共找出 35.參數改變。22.轉有害為有利。18.機械震動。39.頓性環境。其中以 18.機械震動於本研究中尚未實現於創新創意治具中，未來研究將朝自動化機械設備做創意發想，且將本次尚未實現的 18.機械震動發明原則列為優先構想探討。

Reference

English Reference

1. Altshuller (1946) ,「TRIZ 理論」, MBA 智库百科。
2. Valeri Souchkov, Rudy Hoeboer And Mathijs van Zutphen（2007）, “RCA+ to solve business problems,” The Triz Journal, Feb. 05, 2007

Chinese Reference

曾俊超、趙玉森、盧先明（1997),「不同包裝材料對川芎的質量影響」, 四川中醫，第 15 卷，第 2 期，頁 17。

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