

ANALYSIS OF CONSTRUCTION INVENTIVE PATENTS BASED ON TRIZ

<p>Shao-tsai Cheng Assistant Professor Inst. of Const. Management Chung Hua University Hsinchu, Taiwan shaotsai@chu.edu.tw</p>	<p>Wen-der Yu Professor Inst. of Const. Management Chung Hua University Hsinchu, Taiwan wenderyu@chu.edu.tw</p>	<p>Chih-ming Wu Master Student Inst. of Const. Management Chung Hua University Hsinchu, Taiwan m09416037@chu.edu.tw</p>	<p>Ruey-sen Chiu Ph.D. Student Inst. of Tech. Management Chung Hua University Hsinchu, Taiwan rdesignchiu@hotmail.com</p>
--	---	---	---

Abstract: In this research, a specific category of construction technologies, e.g., formwork, is selected for case study. 40 invention principles and 39 engineering parameters were applied with contradiction matrix to find out the “improving” and “deteriorating” parameters for a design case. By consulting the contradiction matrix, innovative principles can be found. It is concluded that TRIZ provides an effective approach for improvement of construction problem solving in terms of time and cost. Moreover, the principles identified by TRIZ also assist the construction technology researchers in searching direction for technology advancement. Forty innovative principles of TRIZ are used in this article to analyze the patents of formwork engineering in the construction industry in Taiwan and to investigate current innovative trend, besides, contradiction matrix is used to investigate the innovative concept of operability and automation demand of formwork.

Keywords: TRIZ, 40 Principles, Construction innovation, Formwork

1. MOTIVATION

Construction industry is a labor-, technology-, variance-, and complication-intensive industry. There are patents of new material and construction method generated continuously to improve the cost and quality. Generally, the newly created concepts or ideas are sudden ideas. Usually a new invention is neither practical nor systematic enough to consider all aspects of a thing. As a result, the original thought of a new invention is difficult to be realized. It is desirable to develop systematic approach for patent analysis to expedite the invention of new material and construction method for the construction industry.

Therefore, this article presents the result of a research applying the forty inventive principles of TRIZ (Theory of Inventive of Problem Solving) to analyze the patented formwork technologies in Taiwan. By analyzing the evolution trends of formwork patents with TRIZ principles, one can easily generate new ideas for invention. Finally, the contradiction matrix of TRIZ is used to provide innovative concept for future advancement of formwork in construction industry based on innovative development of operability and automation.

The rest of this paper will be presented in the following manner: Section 2 reviews previous works related to the issues in this papers; Section 3 describes the patent searching for formwork technologies; in Section 4, TRIZ is applied for formwork patent analysis to suggest innovation directions; conclusions are drawn in Section 5.

2. RESEARCH BACKGROUND

2.1 The innovation of construction industry

Construction innovation in particular may increase social benefits by reducing the costs of constructed facilities and making them affordable for a greater proportion of the population. Innovations also improve the technical feasibility of construction projects that would otherwise appear beyond the technological barrier. They may also

provide intangible benefits for companies in terms of better competitiveness and improved reputation [1].

According to Slaughter, an innovation does not necessarily mean an invention. By contrast, it does not require a detailed design, a physical manifestation, nor to be novel with respect to the existing arts, but just a creative institution [1, 2].

The direction of innovative development in construction industry usually focuses on the innovation of the building or the location of production, production means, materials and systems design, etc. Major factors of consideration in construction innovation are usually cost, time and performance [3].

Toole proposed a model for technological trajectories influence new product diffusion as shown in Fig. 1, where the technology innovation starts with new location of work, new means of production, new materials, and new system design; following that, advantages in cost, time and performance are achieved; finally, diffusion of innovation happens.

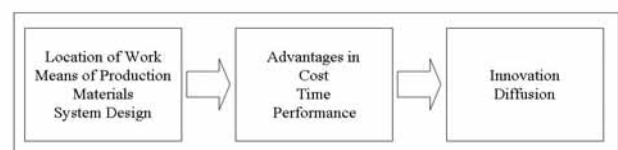


Fig. 1. Technological Trajectories Influence New Product Diffusion [3]

2.2 Formwork technology

Formwork, by definition of ACI 116R, is “the total system of support for freshly placed concrete including the mold or sheathing that contacts the concrete as well as all supporting members, hardware, and necessary bracing” [14]. Formwork is one of the most cost-intensive items of concrete work. It may cost as much as 60% of the total cost of the concrete in place [14]. The cost of formwork

sometimes exceeds the cost of the concrete and reinforcement for the structure. Labor cost is the most important item of formwork costs, which may cost more than 30% of the overall concrete cost. Many innovative formwork technologies have been developed to reduce labor and material costs. All of the developed methods involve construction equipment such as cranes, jacks, and in-house manufacturing equipment or additional prefabrication processes. Involvement of additional equipment and fabrication processes in the new formwork methods results in the additional cost (compared with the conventional formwork method). Constructability analysis should be performed to select the most appropriate formwork technology for a given project scenario in order to achieve better project performance.

2.3 Theory of Inventive Problem Solving (TRIZ)

TIPS is the acronym for “Theory of Inventive Problem Solving,” and TRIZ is the acronym for the same phrase in Russian. TRIZ was developed by Genrich Altshuller and his colleagues in the former USSR starting in 1946, and is now being developed and practiced throughout the world [4]. Altshuller believed that traditional process for increasing creativity suffers a major flaw that their usefulness decreases as the complexity of the problem increases. Altshuller determined to improve the inventive process, which led to the creation of TRIZ [5]. He studied more than 400,000 patents while deriving this theory.

Table 1. 40 Principles [5,6]

01.Segmentation	21.Rushing through
02.Extraction	22.Convert harm into benefit
03.Local quality	23.Feedback
04.Asymmetry	24.Mediator
05.Combining	25.Self-service
06.Universality	26.Copying
07.Nesting	27.Dispose
08.Counterweight	28.Replacement of mechanical system
09.Prior counter-action	29.Pneumatic or hydraulic construction
10.Prior action	30.Flexible membranes or thin films
11.Cushion in advance	31.Use of porous material
12.Equipotentiality	32.Changing the color
13.Inversion	33.Homogeneity
14.Spheroidality	34.Rejecting and regenerating part
15.Dynamicity	35.Transformation of properties
16.Partial or overdone action	36.Phase transition
17.Moving to a new dimension	37.Thermal expansion
18.Mechanical vibration	38.Use strong oxidizers
19.Periodic action	39.Inert environment
20.Continuity of useful action	40.Composite materials

To date, TRIZ specialists have analyzed approximately 2 million patents. The analysis of these patents in different engineering areas resulted in several important discoveries,

which form the theoretical basis of TRIZ and can be summarized as follows: Technological systems evolve not “accidentally” but in accordance with certain patterns. This pattern can be used to solve difficult problems, forecast the evolution of the evolution of technological systems, and create and enhance the tools used for inventive problem solving. Examples of these tools are trend of evolution, contradiction matrix, physical contradiction resolution principles, substance and field analysis, and ideal final result.

The 40 Principles have a remarkably broad range of application; they even work in business environments. These principles are so powerful that simply looking at the list often stimulates several new ideas. To appreciate the power of the principles, select one at random and think of all the related applications you have actually experienced. Next, take any product and see which principle(s) would cause an improvement. The forty innovative principles of TRIZ are as shown in Table 1 [5,6] and the 39 engineering parameters are as shown in Table 2.

Table 2. 39 Parameters [5,6]

01.Weight of moving object	21.Power
02.Weight of nonmoving object	22.Waste of energy
03.Length of moving object	23.Waste of substance
04.Length of nonmoving object	24.Loss of information
05.Area of moving object	25.Waste of time
06.Area of nonmoving object	26.Amount of substance
07.Volume of moving object	27.Reliability
08.Volume of nonmoving object	28.Accuracy of measurement
09.Speed	29.Accuracy of manufacturing
10.Force	30.Harmful factors acting on object
11.Tension, pressure	31.Harmful side effects
12.Shape	32.Manufacturability
13.Stability of object	33.Convenience of use
14.Strength	34.Repair ability
15.Durability of moving object	35.Adaptability
16.Durability of nonmoving object	36.Complexity of device
17.Temperature	37.Complexity of control
18.Brightness	38.Level of automation
19.Energy spent by moving object	39.Productivity
20.Energy spent by nonmoving object	

Contradiction Matrix is a table of 39 design parameters, which answers the question of how we can face an unfamiliar conflict by offering 1201 generic problems that were solved using at least one of 40 generic principles. The table offers several principles frequently used to solve analogous problems. The problem solver can then concentrate on adapting these principles to the innovation problem considered [5]. The 40 Principles in TRIZ are used in this article to analyze the formwork patents in the

construction industry, the inventive principle used in each patent is investigated. Finally, the inventive principle used in each category of patent is summarized and the inventive principles used in the formwork patents are displayed. The future formwork innovation idea is suggested. The contradiction matrix table is used to summarize the inventive principles of the parameters to be improved so that the future development trend in the formwork innovation is recommended.

2.4 Patent information collection

Table 3. Number of public domain patent documents to IPC Section [7]

Section of IPC	Title of section of the IPC
A	Human Necessities
B	Performing Operations; Transporting
C	Chemistry; Metallurgy
D	Textiles; Paper
E	Fixed Construction
F	Mechanical Engineering; Lighting; Heating; Weapons; Blasting
G	Physics
H	Electricity

IPC (International Patent Classification, Section 7) [7] is used for patent classification in this paper. The IPC classifies patent into 8 Sections, the descriptions are as in Table 3. The formwork investigated in the study belongs to

IPC Section E, its Class number is E04G009, and includes about 176 patents ended in year 2005 here at Taiwan and includes about seven categories of the formwork patent classification, and this is as shown in Table 4.

Table 4. Number and category of formwork patents applied in Taiwan

Subclass	Name	Quantity
E04G009/00	Forming or shuttering elements for general use	6
E04G009/02	Forming boards or similar elements (9/08, 9/10 take precedence)	47
E04G009/04	The form surface being of wood	11
E04G009/05	The form surface being of plastics	25
E04G009/06	The form surface being of metal	11
E04G009/08	Forming boards or similar elements, which are collapsible, foldable, or able to be rolled up	53
E04G009/10	With additional peculiarities such as surface shaping, insulating or heating, permeability to water or air	23
Total		176

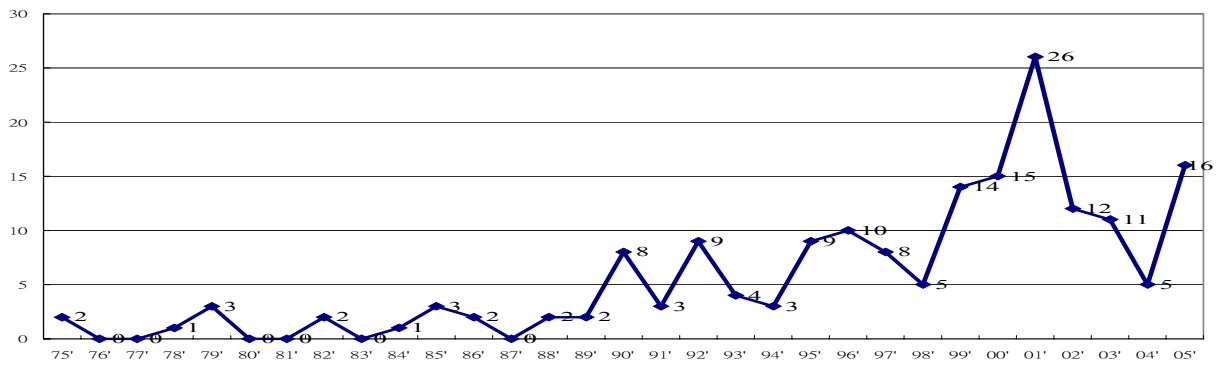


Fig. 2. Number of formwork patents applied in Taiwan during 1975~2005

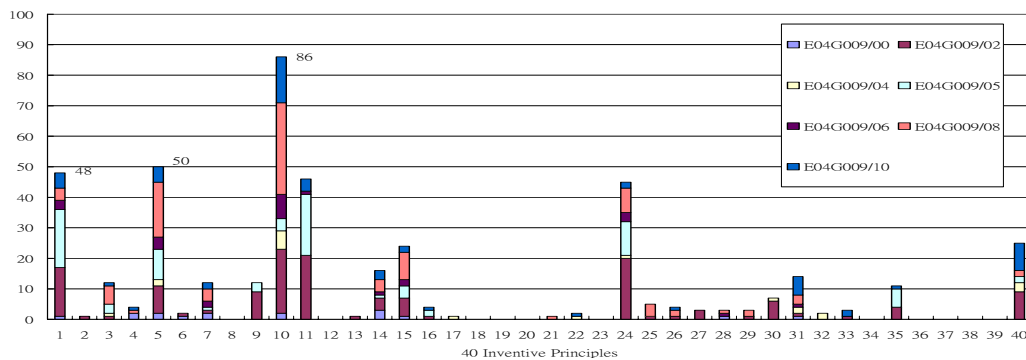


Fig. 3. Statistical diagram of inventive principle of formwork in construction industry

3. PATENT INFORMATIONS ANALYSIS

3.1 Collection of patent information

The total number of formwork patents collected in this study is about 176. These patents consist of technologies for location of production, production means, materials and systems design. The inventive principles of TRIZ are used to analyze formwork patents so as to calculate the frequency of adoptions of the 40 invention principles. There are seven categories for construction industry. Fig. 2 shows the issue number of patents in Taiwan in 1975~2005. It's found from the figure that the peak happened in 2001 with 26 patents.

3.2 Analysis with TRIZ inventive principle

The patent analysts are trained with TRIZ analysis training course [12, 13] before conducting the analyses. Totally 447 TRIZ were found in the collected 176 patents. Averagely, each patent employs 2.54 invention principles. From Figure 3, it shows the top five inventive principles most frequently used in the formwork patents are shown in table 5, they are: (1) Prior action—with 86 counts; (2) Combining—with 50 counts; (3) Segmentation—with 48 counts; (4) Cushion in advance—with 46 counts; and (5) Mediator—with 45 counts.

Table 5. Top five inventive principles employed in formwork technologies in Taiwan

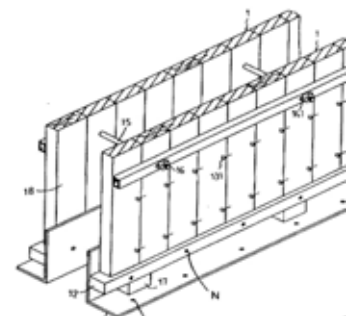
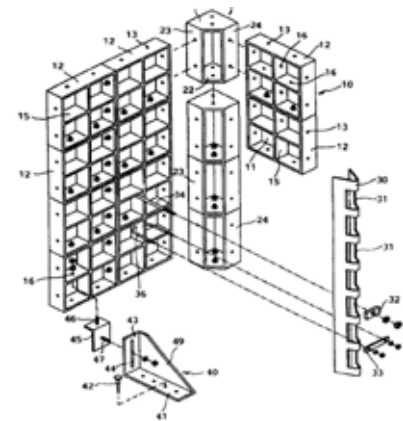
Inventive principle	Freq.	Descriptions
10.Prior action	86	(A)Perform, before it is need, the required change of an object. (B)Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery
05.Combining	50	(A)Bring closer together identical or similar objects, assemble identical or similar parts to perform parallel operations. (B)Make operations contiguous or parallel; bring them together in time
01.Segmentation	48	(A)Divide an object into independent parts. (B) Make an object easy to disassemble. (C) Increase the degree of fragmentation.
11.Cushion in advance	46	(A) Prepare emergency means beforehand to compensate for the relatively low reliability of an object.
24. Mediator	45	(A) Use an intermediary carrier article or intermediary process. (B) Merge one object temporarily with another.

It is found from the patents applied in formwork field that 'prior action' is the top one inventive principle; that is, some actions need to be taken before formwork activity in order to reduce the use of human power and time. The items in the second and third places are that 'different objects are

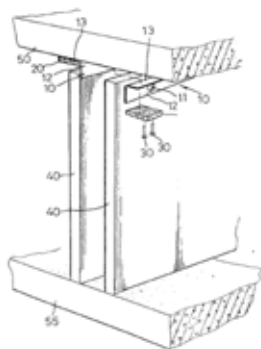
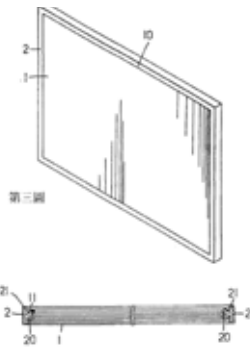
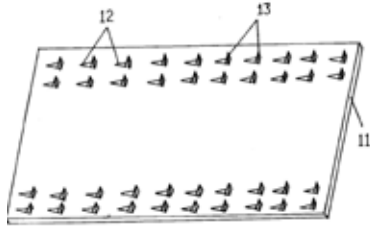
assembled' or 'split into small parts', so that time and space effectiveness are enhanced in the mean time to increase the convenience of use. The items in the fourth and fifth places are that 'some object strengths or stabilities are increased' in the formwork in advance before the use of it; through such methods, the disassembly of the formwork after use can thus be more convenient or the performance of it during the use can be greatly enhanced. The descriptions with some examples of the above principles are shown as in Table 6.

Table 6. Illustrations of the top five applications of inventive principles of formwork

Issue No. and title of the patent	Figure and Descriptions
375143 The structure of assembly type construction formwork	In that patent, several holes are pre-installed on the formwork and several bolts are used to assemble several square formworks into a large formwork wall structure which is ready for grouting. Besides, cross reinforced rib boards are installed among the boards. (Principle 9, 10, 24, 35)
43926 Formwork structure which can be assembled rapidly.	A formwork which can be assembled rapidly, the formwork is installed with multiple blocks which extend toward both sides of the formwork so that the formworks can be rapidly assembled, besides, the blocks can be stops to prevent the collapse of the formwork, they provide the functions of easy assembly and disassembly of the formworks. (Principle 1, 5, 10)
472813 An attached	A long strip of board made up of stainless steel is first pressed with multiple cones by a



Issue No. and title of the patent	Figure and Descriptions
board for the formwork	press machine, the sharp nature of an attached board for the formwork is thus formed and the attached board is nailed on the formwork directly. (Principle 1,10,11)
439825 Improvement on the formwork	The patent shown in the left diagram has been drilled with slot and embedded with protruded protection rod so that a protection frame is formed. The main purpose of this patent is to enhance the structural strength of formwork during the use and to prevent the impact of external force and the further damage of the formwork. (Principle 11)
432143 An improved construction method for inner wall formwork.	Several head reception boards are provided during the use to fix the wall board and to facilitate the construction of formwork for the inner wall. (Principle 24)



4. DISCUSSION ON THE APPLICATION OF TRIZ

In searching of future formwork innovative directions, the study focuses on formwork automation. The conceptual evolution trend and direction are provided through the use of 'contradiction matrix' table of TRIZ. It is identified that the part to be improved is item 33 "Convenience of use" in

the 39 engineering parameters, and item 35 "Adaptability" of TRIZ. First, the other 38 deterioration parameters corresponded to each parameter to be improved is statistically analyzed based on inventive principles. The priority of that parameter in the forty inventive principles is summarized [8]. The summarized inventive principles for those two parameters are thus combined to suggest the improvement direction. The result is shown in Fig. 4. From Fig. 4, it is found that top five inventive principles are suggested first for future improvement of formworks, among them, "13. Inversion" appears 21 times, "01. Segmentation" and "35. Transformation of properties" appears 18 times, "28. Replacement of mechanical system" appears 16 times, and "02. Extraction" appears 14 times. The descriptions of principles are as shown in Table 7. The inventive principles of TRIZ in Table 7 are used to suggest future innovation of formwork engineering:

- (1) The application of the sub-principle of Principle 13-(B) in the formwork patent of construction industry informs that precast method will be the future innovative direction of formwork operation; concrete component is formed in advance in the pre-cast plant before it is delivered to the construction site, the basic principle is that the equipment and tools in the precast plant can be viewed as immobile and the precast concrete components are mobile. Through such method, construction convenience and automation can be achieved. The stay-in-place formwork is just another application example.
- (2) The application of sub-principle of Principle 1-(C), for example, the use of plastic formwork has the characteristic of light weight and convenient operation. Should reinforced ribs be added on the back side of the plastic formwork, the original drawbacks of weak strength of plastic formwork during the use can be improved. Deck formwork is the similar application example.
- (3) Principle 35 is the phase change of material. its applicability still needs to be studied.
- (4) For the application of sub-principle of Principle 28-(B), a magnetic monitoring system can be added to formwork so that the status information of formwork and concrete can be obtained, for example, the stress or temperature.
- (5) For the application of sub-principle of Principle 2-(B), it is to separate or isolate the key components of object, semi-precast method can be used to cast part of the component. Therefore, the strength of this component can be used in the construction site for supporting purpose, and the casting operation of the entire component is completed. This construction method has the following advantages: the reduction of supporting systems, shorten the construction time, increase safety and satisfy the level of automation.

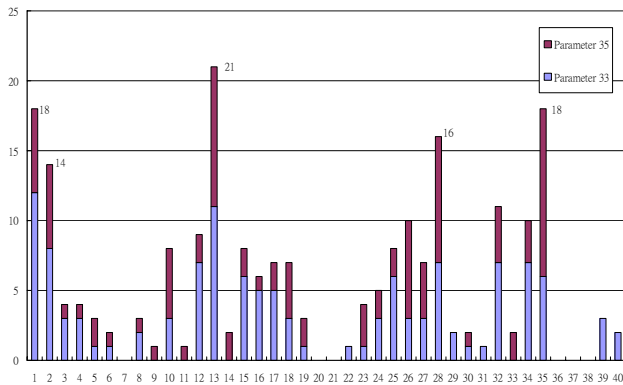


Fig. 4. Statistical diagram of inventive principle of operability and automation level to be improved in the contradiction matrix table

Table 7. Inventive principle and sub-principle of TRIZ

Principle	No.	Descriptions of the sub-principle
13.Inversion	21	(A)Invert the action(s) used to solve the problem. (B)Make movable parts fixed, and fixed parts moveable. (C)Turn the object or process upside down.
01.Segmentation	18	(A) Divide an object into independent parts. (B) Make an object easy to disassemble. (C) Increase the degree of fragmentation.
35.Transformation of properties	18	(A)Change an object's physical state. (B)Change the concentration or consistency (C)Change the degree of flexibility. (D)Change the temperature.
28.Replacemnt of mechanical system	16	(A)Replace a mechanical means with a sensory means. (B)Use electric, magnetic and electromagnetic fields to interact with the object. (C)Change from static to movable fields, from unstructured fields to those having structure.
02.Extraction	14	(A)Separate an interfering part or property form an object, or single out the only necessary part (or property)of an object. (B)Extract only the necessary part or property from an object.

5. CONCLUSION

TRIZ is used in this article to analyze the patents of formwork technologies in Taiwan. The engineering parameters and contradiction matrix provided by TRIZ theory are used to obtain the underlying inventive principles and to suggest future innovation directions. 447 inventive principles are identified from 176 formwork patents issued from 1975 to 2005 in Taiwan. Top five inventive principles are concluded for future innovation of formwork

technologies. It is concluded that TRIZ provides a systematic approach for technology research.

This research has shown the potentials of TRIZ in formwork innovations, other construction technologies can also be analyzed with TRIZ to improve the performance of construction works.

ACKNOWLEDGEMENT

The patent analysis of this research is conducted using Patent Guider[®] 2.0 which is provided by Learning Tech Inc. The authors appreciate the contribution of Learning Tech Inc. in supporting this research.

REFERENCES

- [1] Slaughter S. "Models of construction innovation." *Journal of Construction Engineering and Management* (ASCE), 124(3), 226–231,1998.
- [2] Freeman, C. "The economics of industrial innovation," MIT Press, Cambridge, Mass,1989.
- [3] Toole, T. M., "Technological trajectories of construction innovation." *Journal of Architectural Engineering* (ASCE), 7(4), 107–114,2001.
- [4] The TRIZ Journal, <http://www.triz-journal.com>
- [5] John Terninko, Alla Zusman, Boris Zlotion. "Systematic Innovation- An Introduction to TRIZ.", CRC Press,1998.
- [6] Altshuller, G. "40 principles: TRIZ keys to technical innovation.", L. Shulyak and S. Rodman, trans., Technical Innovation Center, Worcester, Mass,1998.
- [7] World Intellectual Property Organization (WIPO),<http://www.wipo.int/index.html.en>, 2006
- [8] Liu Chih-Chen , "A study of TRIZ method improvements and Eco-Innovative design methods", P.H.D, Department of Mechanical Engineering National Cheng Kung University,2003.
- [9] Altshuller, G., Ziotin, B., Zusman A., and Philatov V. *Tools of classical TRIZ*, Ideation Intl. Inc., Southfield, Mich,1999.
- [10] Darrell Mann."Hands on systematic innovation" CREAX Press, 2002.
- [11]Y. Mohamed and S. AbouRizk, "Application of the Theory of Invention Problem Solving in Tunnel Construction." *Journal of Construction Engineering and Management*.(ASCE) P1099~P1108,2005.
- [12]Zhang J.H., Yang. B., Tan R.H., "The analysis of 2002 Chinese Inventive Patent Based on TRIZ " *TRIZ Journal*, <http://www.triz-journal.com>,Aug 2004.
- [13]Darrell Mann, "Assessing The Accuracy of The Contradiction Matrix For Recent Mechanical Inventions" *TRIZ Journal*, <http://www.triz-journal.com>,Feb 2002.
- [14] Bordner, R. H., "Guide to formwork for concrete." *ACI Structure Journal*, ACI, Reported by ACI Committee 347, 85(5), 530-562, 1988.