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Research on Opportunity-Driven Redesign Process to Cooperate With Training Innovative Engineers in China

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Abstract

Many design engineers in cross-domain industries have attended training classes of TRIZ to improve their innovative abilities in China. Most of them are successful, but others are not. So the latest target of the trainers is to improve the training process used now in industry in China and to make the engineers to understand the basic principles of TRIZ better. Based on the mass-engineer-oriented training model (MEOTM) and mechanical engineers' design cases, a relationship between managing activities about the opportunities for innovation and the training process is set up. It is shown that the inventive problems come first from opportunity searching for engineers. A training and gate system for evaluation is developed to involve the managing activities of the companies in the training process. Then comparison between the general analogous process and the application of TRIZ is made, which shows the advantages and depth principles of TRIZ for the engineers to apply them confidently. Lastly a new process is formed in which opportunity searching, engineers training, inventive problems identifying and solving,and three redesign paths are connected seamlessly. The research proposes an opportunity-driven redesign path that cooperates the training and opportunity searching, which will be applied in future training classes to make more and more engineers to follow.

Keywords: TRIZ, Mass-engineer oriented training model, Redesign path, Opportunity-driven, Redesign process

1 Introduction

TRIZ [1], the theory of inventive problem solving, emerged from Russia,has spread to over 30 countries across the world [2]. A review [3] shows that TRIZ has been applied in the fields of quality improvement, reduction of product pollution, lunch of new product, productivity improvement, product/process innovation, energy reduction, safety improvement and cost reduction. There are also some new further developments in TRIZ extension and application. Zhang et al. [4] proposed a new model to integrate TRIZ and design-centric complexity and applied the model to electromechanical systems. Liu et al. [5] made an integration between TRIZ and analogy process to form a new model for analogy-based conceptual design. Liang et al. [6] applied TRIZ to set up an innovative design process model for existing products. The target of TRIZ and the further development are the application in industries. As a result the propagation of TRIZ is also an important topic for research and application. Now in the world the channels for the propagation of TRIZ are training [7, 8] which is applied by many companies of different countries in an attempt to improve the innovativeness of their employees [9].

In China, a mass-engineer-oriented training program led by government has been underway since 2008. As a part of that program, more than 70 training classes have been carried out to propagate systematic innovation methods to companies in the National Engineering Research Center for Technological Innovation Method and Tool [10] (hereinafter referred to as "center"). The core of the innovation methods transferred is TRIZ and its new development. Many engineers from different companies attended the training classes and were

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certificated to the title of innovative engineers. The program is now going on in China.

An interactive seven-step process model for training engineers [11] is developed by the center, which is a mass-engineer-oriented training model (MEOTM). The first feature of the model is that it is a mass-engineer-oriented in which 40–80 engineers from different companies and regions may attend a class at same time. The second is long time that a full process for a class lasts 6–15 months accordingly. Most of the engineers attending the training classes are successful, but less than 1/3 of the attendees fail or drop out of some classes in the middle of the training process. In order to make the situation better, the training process and the knowledge system transferred should be improved to make more and more engineers to follow.

There are some literatures which are related to the training of TRIZ. That Bertoncelli et al. [12] showed that strongly learning and creativity training for applying TRIZ are linked. It is an example, but only a few deal with the training process. Kalevi and Ellen [13] showed a model for the implementation of TRIZ in large companies in which a pilot training and application is the first step. Isak [14] put forward the course contents for training of TRIZ. In a word, there is little research to tough upon the mass-engineer-oriented training of TRIZ in the literatures. And there is a gap between the needs of mass-engineer-oriented training of TRIZ and the system innovation methods trained.

The engineers attending training classes started by the center are from different companies. Some of them are responsible for research and product design, who are design engineers. Others may be responsible for process, manufacturing or management who are process or management engineers. In order to improve training quality of following classes started by the center in the future, a new model to cooperate the training process into design processes of companies is setup.

2 Mass-engineer Oriented Training Model and Some Project Cases

An entire innovation process in a manufacturing company is typically divided into three stages: fuzzy front end (FFE), new product development (NPD) and commercialization [15]. An interactive training or mass-engineer-oriented training model (MEOTM) is developed based on this process. It is for innovative engineers in China [11] as shown in Figure 1.

According to this model, the training process has seven steps which are selecting companies, selecting engineers, training stage-1, finding problems, training stage-2, finding solutions and summing up. A full process for a class lasts 6–15 months accordingly. The training outputs are innovative engineers and inventions from their research projects.

Steps 4 and 6 are main steps in the training process. Step 4 is finding problems, in which every engineer attending the class must find an inventive problem using the knowledge of TRIZ from his or her workplaces. The inventive problems to be solved are the research projects for them to follow the later steps of the class. Step 6 is finding solutions in which the problem is solved and inventions are formed. The two steps, 4 and 6, are directly related to the design process of the companies for the design engineers.

GD-1 was the first training class organized by Guangdong Science and Technology Department in Guangdong province from August of 2010 to March of 2011. The center carried out the training process. 75 engineers were selected from 19 companies in Guangdong province, including BYD, BROAD-OCEAN and GAC et al., which were all belonging to manufacturing industries. 52 engineers did pass the final examination. All the

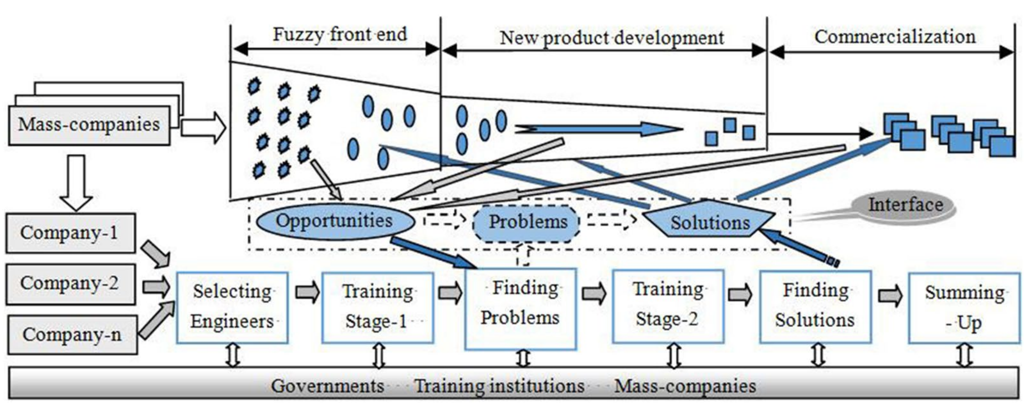

Figure 1 An interactive training model for innovative engineers in China [9]

52 engineers found out 52 inventive problems from the innovation process, solved them and formed 52 inventions at last. Figure 2 is the relationship between the number of the problems and innovation stages or subprocesses. The most problems, which are 18, are found from manufacturing. The least problems, which are 4, are in fuzzy front end. The problems from design process are total 30, in which the problems to the conceptual design, embodiment design and detailed design are 10, 15, and 5, respectively.

The solutions of the problems in fuzzy front end will be directly output into the following design stages. If the fuzzy front end is identified as a stage of design process, the number of the problems in this process is 34, which is 65.3% of the total problems for this class. The situations for most of classes are similar, if only the companies are in the domain of manufacturing industries.

Table 1 shows 10 engineers' successful design cases, including the location of company, main products, name of project, original situation, domain problem, TRIZ problem and the domain solutions.

In Table 1, location of company is the city where the engineer works. The main products are the outputs of the company that they work. The project's name is the topic that the engineer selects in the training process. The original situation is description about the problematic information that the company or the engineer faces at the beginning. The domain problem is abstraction from the original situation. The TRIZ problem is the inventive problem or problems based on the TRIZ concepts. Domain solutions are the results of solving domain and TRIZ problems.

All the 10 projects in Table 1 are the successful design cases of innovative engineers of classes started by the center before. Some of the cases have been transformed to products after following redesign and manufacturing process. Others are waiting for the transformation, but the domain or inventive problems from design processes have been solved. All the domain problems of the cases are directly related to essential or potential opportunities for innovation, which are from the changes of markets, technologies, new knowledge from training and some obstacles of product development in companies.

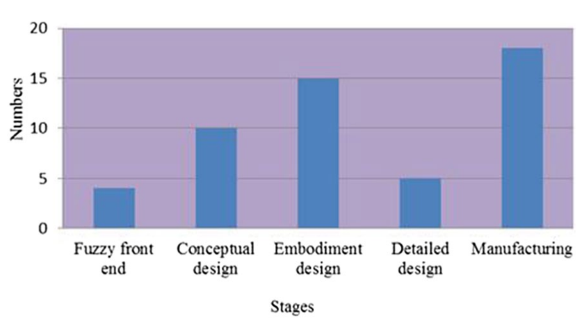

Figure 2 Project number and innovative stages from GD-1

Another feature of the cases is that some engineers' inventions have been transformed into products at the end of the training classes. Before the transformation some managers in a company must make evaluations and decisions that the engineers' inventions should be invested and put forward or not. This is the key step for the successful implementation of the inventions. If the some managers pay more attention to the training process and make decisions rapidly and correctly, some innovation opportunities for companies may be identified from the training process.

The seven-step training model in Figure 1 has been implemented for many classes and the cases in Table 1 also show successful projects of engineers in training classes. But less than 1/3 of the attendees fail or drop out of some classes in the middle of the training process. The target of improvement for training process is to make more and more engineers to follow it.

In order to meet the needs of this target, the following questions are put forward and are needed to be answered from the point of the product redesign:

Question 1: How to attract the attention of some managers of the companies to the training classes which the engineers of the classes come from?

Question 2: Why are the inventive problems solved effectively using TRIZ in the product design process?

Question 3: How to cooperate the training process into the redesign and management processes in companies effectively?

3 Improvement of the Training Process

3.1 Re-position of the Training

Most innovations, especially the successful ones, result from a conscious, purposeful search for innovation opportunities from some situations, such as unexpected occurrences, incongruities, process needs [16]. According to the situations, the technologists or engineers discover the technological insights which are possible or potential opportunities for following innovations. However, the insights are waiting for being stumbled across by a research manager in an established company. Because the technologists have not enough experiences to evaluate the business opportunities [17]. One method to improve the training process is that the cooperation between the training process and the management activities of companies should be strengthened.

Most of the engineers of the training classes are from established companies. They are familiar with the routine design work and know everything about the design

Table 1 Ten design cases from innovative engineers

No.	Location of company	Main products	Project name	Original situation	Domain problem	TRIZ problem	Domain solutions
1	Qinhuangdao	Construction machineries	A new bridge girder erection machine for small curves	The development of high-speed railway in china needs a bridge girder erection machine for small curve roads. But structures for the machines used now are weighty and costs more for constructing the bridges over this king of roads	How to decrease the weight of the structures and costs of the machines and keep the functions and performances?	A technical contradiction	Two patents
2	Shijiazhuang	Valves with big diameters	A new glasses valve for energy saving	In some iron and steel plants stiffen plates are added to increase the strength of a glasses valve for its application in higher pressure situation. Sometimes a butterfly valve is needed. This results in some harmful effects, such as high cost, complex process, and increased weight	How to design a glasses valve which has ability to bear high pressures in double directions? At the same time the butterfly valve should not be needed for the new design	A technical contradiction	Two new products for the specific application
3	Xinhe	Drilling machines	Improvement of the structure for a spiral drilling rod	A structure attached to the spiral drilling rod for a kind of drilling machine could not fulfill the function of cleaning soil well. This results in low efficiency for drilling and safety problems	How to make redesign for the structure that cleans the soil well?	A technical contra-diction	A patent
4	Shijiazhuang	New product development	Improvement of assorting machine for specific bottles	A sorting machine for bottles is being developed. One function of the machine is to measure the inside and outside diameters of the bottles during transmitting them. The current design shows low measuring efficiency	How to overcome the contradiction between measuring efficiency and complexity?	Two technical contradictions	A new product, which has been developed and sold

Table 1 (continued)

No.	Location of company	Main products	Project name	Original situation	Domain problem	TRIZ problem	Domain solutions
5	Tianjin	Hydraulic machines	The heat radiation for electric element in a control system	The company is developing a big actuator and its control system. The electric element in the system will produce heat during the work. The working temperature for the element should not be higher than a certain numerical value	How to make a redesign for the specific electric element to reduce its working temperature?	Eight technical contradictions	New concept been developed for the heat radiation system
6	Baoding	Storage battery	Reduction of deformation in plastic slot of storage battery	The company has produced storage batteries for many years. The deformations of plastic slots in batteries result in leakage. The problem has not been solved for a long time	How to make a redesign of the slot?	One technical contradiction	New design of the die for new slot
7	Shijiazhuang	Chemical machine	Improvement of heating efficiency	The heating efficiency of the current heating machine is low because the interactions of several factors	How to make a redesign of the embodiment for the heating machines?	Two technical contradictions and two physical contradictions	One patent
8	Langfang	Instruments	Improvement of a length measurement instrument	The degree of accuracy for existed length instrument is not satisfied by new users	How to change the principle of the instrument?	One standard problem	New design
9	Tangshan	Train	Reduction of the wear for bogie element	One element of bogie in a train produced in the company is easy to be worn. The situation should be improved	How to change the embodiment of the bogie?	One standard problem, one contradiction, one trimming problem, one evolution problem	New design (a patent)
10	Hengshui	Products made from engineering rubber	New product development for tunnel of railway	There is a new need for development of a new product for tunnels in order to reduce or stop the leakage of rail water	How to make the design?	Function solving	7 patents

details of the products being sold. However, the decisions about the new product development are made by management activities of the company. Therefore, the first thing is to set up a relationship between the training process and the managing activities of the companies in which some engineers are sent to attend the training classes. In order to achieve this goal, the training process in Figure 1 must be modified to connect the engineers' problems of projects to the company or business opportunities directly.

From view of innovation management, a typical innovation process includes opportunity search, opportunity recognition, opportunity evaluation and implementation [17–19]. In step 4 engineers attending training classes must identify an inventive problem or a project which is identical to target of opportunity search of the typical innovation process. During the opportunity search process, the engineers do identify domain problems which are some inventive problems and transformed to TRIZ problems. After that the engineers must solve the TRIZ problem by applying the TRIZ tools and related case bases, which are the activities in step 6. The outputs are inventions, new designs or processes, which may be the opportunities for the engineers' companies. At this time point, the managers of the companies should make evaluations about the possible opportunities for innovations. If some opportunities do exist, the implementation for innovations should be organized systematically in the companies. At last some innovations come into being. Figure 3 shows activities between managing and the operating levels. The operating level includes all the technical activities of training and the following implementation for innovation.

The start point for essential opportunity of innovation is the search from information changes, such as changes in markets, technologies, government policies and regulations, other events or changes. The engineers should know some information changes which the managers maybe familiar with. The new knowledge studied in training courses is also a kind potential opportunities for changes. The changes will stimulate engineers to find inventive problems in step 4. In order to make the inventive problems better or meaningful, some managers should make an evaluation about the selected problems to be solved by engineers. After step 6 domain solutions have been existed. Some managers also need to make an evaluation for making decisions about the potential solutions for the following innovation, which are the business or company innovation opportunities. If an evaluation or examination is a gate, there should be 6 gates in the training process with a management involvement, as shown in Figure 4.

The functions of all gates in Figure 4 are as follows:

Gate-1: The function is Evalu-1, in which some managers make an evaluation about the appropriateness of every engineer selected to attend the training classes.

Gate-2: The function is Exam-1, in which the trainers make an examination to evaluate the knowledge level studied for all the engineers in classes.

Gate-3: The function is Evalu-2, in which the engineers attending the classes find inventive problems, which are domain problems, and the solutions of the problems are inventions

Gate-4: The function is Exam-2, in which the trainers make an examination to evaluate the knowledge level studied for all the engineers.

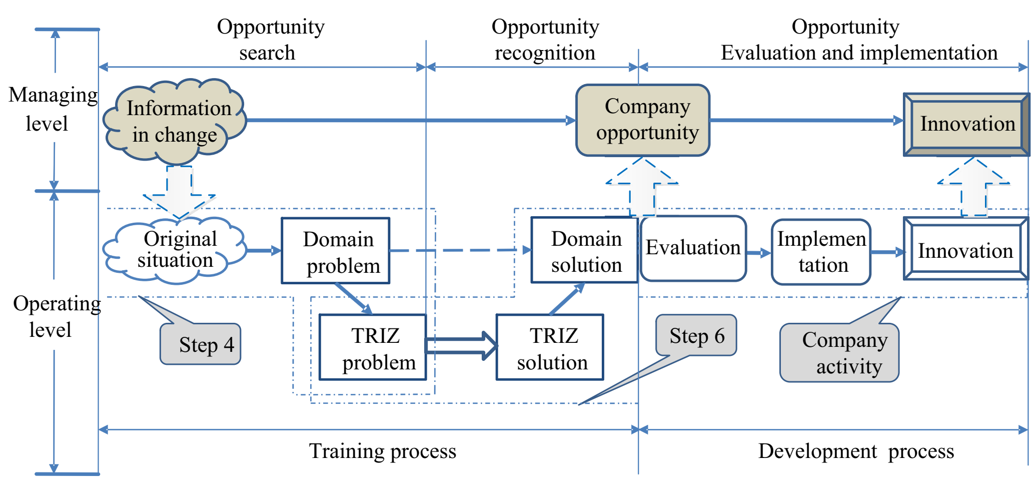

Figure 3 Transformation of opportunities by training process

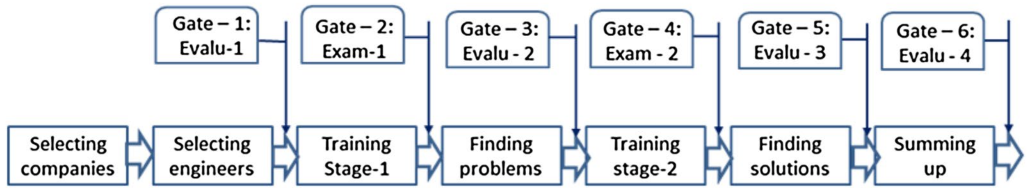

Figure 4 Training—gate system

Gate-5: The function is Evalu-3, in which some managers and trainers make evaluations whether the problems are really solved or not and recognition that there are some opportunities for innovation or not.

Gate-6: The function is Evalu-4, in which every engineer in a class must make an open reply for his or her projects. The trainers make decisions about their level. Some managers make decisions whether the inventions are opportunities of possible investment for following innovations of the company.

Figures 3 and 4 also show that the training process for innovative engineers is not independent activities from the management activities of the companies. The managers in the companies in which some engineers attend the training classes should pay more attention to the steps of the process and make evaluations at proper gates. The engineers attending the training classes should always make a contact with their managers to exchange information of training, find and solve right inventive problems effectively. The 6 training-gate system in Figure 4 is formed which is a training-managing model. The training process is activities for companies to identify innovation opportunities, which is new reposition of the training.

3.2 Analogy for Similar Problem Solving

Right solutions for a tough problem need right method to solve it. Once the methods in TRIZ are the right, the engineers could apply them to solve inventive problems.

The problem solving using method in TRIZ is an analogous process in which TRIZ problems, the mapping process for TRIZ solutions and TRIZ solutions themselves are sources for analogies. If the problems are located in a design process, the application of TRIZ is a kind of analogy-based design (AbD) [20] including two stage analogy processes [21]. There are a few models for AbD in the literatures, such as model-based analogy (MBA) [22], functional vector space model (VSM) [23], etc. The application of TRIZ in both academic [24] and industries [2] are all successful. Therefore, advantages of TRIZ as a method of analogy should be deeply understood better by the engineers in the classes started by the center.

A general and accepted model for analogical problem solving is shown in Figure 5a [25, 26]. In this model L is a library for solved exemplars which are problems, problem solving methods and solutions. X is a problem instance or an exemplar for a problem retrieval which includes a problem XP, a problem solving method XM and a solution XS. P is a problem to be solved. M is the

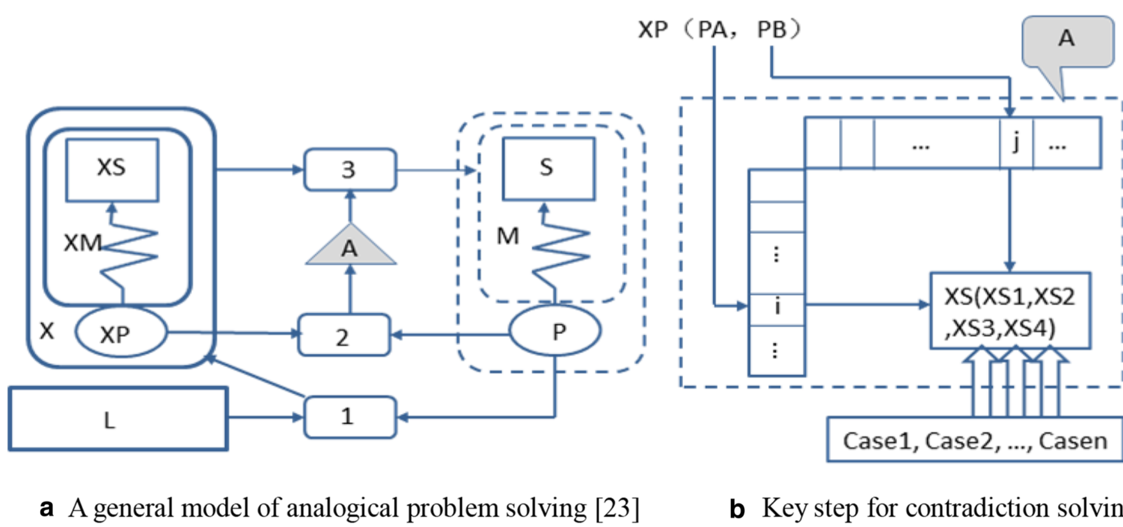

Figure 5 General method or TRIZ in analogy process.

method to solve problem P and S is the solution of the problem P using method M. A is an analogy from X to solve new problem P. At first a new P is screened against the library L of solved exemplars to find the exemplar X whose problem-instance XP is most analogically similar to P. Once an appropriate analogy A between P and XP is derived this analogy is used to construct either a solution-method M or a solution S for P from the solution-method XM or solution XS for X. But it is possible that inadequate results may be obtained at any phase above [25], i.e., an irrelevant retrieved solved-exemplar, an insufficiently rich analogy. The problem solving in TRIZ provides a better systematic process for retrieving solved-exemplar and rich analogies as a case shown in Figure 5b.

Figure 5b is a process case using TRIZ which shows the basic principle to apply the contradiction matrix to solve inventive problems. Technical contradictions are a general type of inventive problems in TRIZ which arises when an attempt to improve certain attributes or functions of a system leads to the deterioration of other attributes of that system. One contradiction XP is represented by pairs of conflicting parameters PA and PB. The two parameters are used to determine a specific element XS in the matrix. The numbers XS1–XS4 in XS are the recommend consequential numbers of inventive principles for solving the contradiction. There are several cases in books or knowledge bases for every inventive principle, which show the applications in cross domains of the principles. XP, XS1–XS4 and all cases relevant are analogies which are transferred to solve similar contradiction problems. When an engineer or inventor faces a contradiction P in design process he or she defines it using two conflicting parameters from the 39 standard parameter list of TRIZ. The instance of XP, matrix, XS and relevant cases as whole is the analogy A of solving a technical contradiction. The engineer applies the analogy to generate domain solutions.

From comparing the process Figure 5a, b, the following three advantages in analogous process using TRIZ are found.

(1) The application of TRIZ to solve an inventive problem in design stages is an analogous process which is the same as a general process of AbD.
(2) The analogy is implicitly included in the systematic process of solving inventive problems when TRIZ is used.
(3) The knowledge of cross domains to solve similar problems in TRIZ is applied by reusable paths, general solutions and relevant cases, which as a whole is an analogy of problem solving.

All these advantages will assist engineers of training classes to understand the basic principles of TRIZ better and to apply the methods in TRIZ to solve inventive problems confidently. So the analogy process in Figure 5 will be added to the "training stage-2" in Figure 1.

3.3 Seamless Connection between Design and Training Process

One trend to develop TRIZ further is to link up TRIZ process to the main process of the product development in the companies to make full use of methods and tools in TRIZ. In order to implement the trend, it is a key step to set up a connection between product design and training process seamlessly.

The most influential design theory and methodology is the Pahl and Beitz's research [27]. That Feng et al. [28] hold that the writing is the modern design science and Qiu et al. [29] had a view that the "verb + noun" is a general model for description of functions. So the design process model is selected as the main reference in this study.

According to the Pahl and Beitz's research [27], there are four phases in the design process which are clarification of the task (TA), conceptual design (CD), embodiment design (ED) and detail design (DD). The input of the model is the task and the output is the design document (DO). Many innovative engineers' projects are to find and solve inventive problems of existing product designs to form new designs. But how to stimulate redesign process remains as a topic to be studied, which is essential to improve the instructional quality for the training innovative engineers.

The problems identified by the engineers in the training process are stimulated by some factors, such as that included in essential opportunities from any changes of society, competitive companies, economic situation or new knowledge learned from training courses of the path A. The solutions of solved problems are returned to the main design process. After the following design process new innovative designs are generated. The relationship between the main design process and the training process is shown in Figure 6.

Figure 6 shows the path for engineers to find and solve an inventive problem. Because of stimulating by some factors, the engineers first re-examine an existing product again, its conceptual designs (CD), embodiment designs (ED) and detailed designs (DD), which they are familiar with. They may find some clues of problem or superficial problem. Then they analyze the root causes of the superficial problem using methods learnt from training courses in the class [11]. Lastly they find the inventive problems of TRIZ which are the root causes of superficial problems, such as contradictions [10].

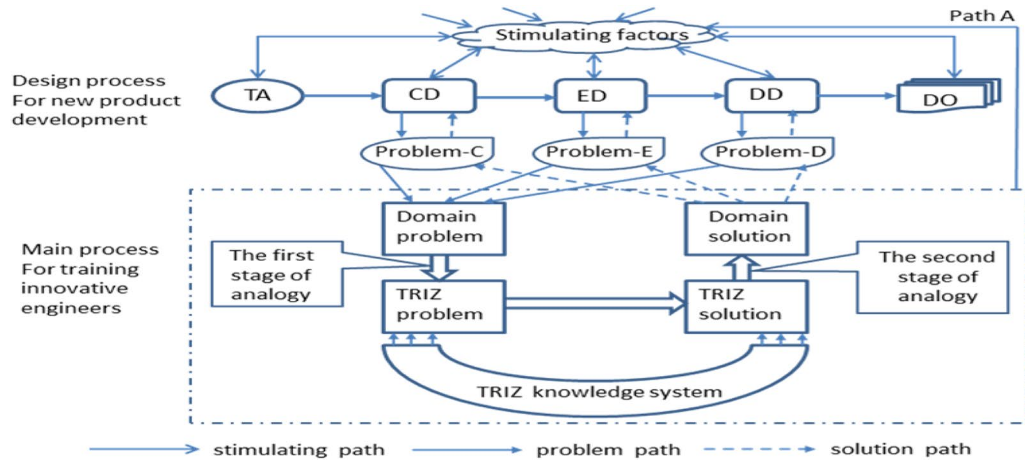

Figure 6 Relationship between the design and training process

The inventive problems may be located in different stage of design process. For example, the problem is identified in the stage of conceptual design. The engineers must solve the problem using some methods or tools in TRIZ and generate solutions. The solutions are then returned to the conceptual design stage and original concept of the product must be changed or redesigned. The following stages, embodiment and detailed design must also be changed. After the chain reaction to the solutions of the inventive problem the new design or new document is formed. If the inventive problem is in the stage of embodiment design, the original embodiment and the detailed design must be changed. If the problem is in the stage of detailed design, the only original detailed design must be changed. As a result the main design process and the training process are connected seamlessly which is a new type of redesign process.

3.4 Opportunity-Driven Redesign Process

The changes of technologies, the need for reducing cost, new knowledge, etc. are the stimulating factors for innovation. These factors are potential or essential opportunities for the engineers. It is an important step to connect the factors to the design process which are being implemented in the companies.

The engineers attending the training classes identify inventive problems through stimulating factors which are impliedly included in the essential opportunities. Such as IFR, contradictions, resources, etc. [11] which are new knowledge in TRIZ are stimulating factors. If the problems are located in design stages, design problems are identified. The engineers solve the problems using TRIZ obtain domain solutions which are inventions. After evaluation from managing level of the company some redesign processes for innovations are starting up, as shown in Figure 7. This process is driven by opportunities.

There are three situations after the evaluation of domain solutions for redesigns. The first is that the original conceptual design CD0 should be changed. For example, the original effect for a sub-function in original conceptual design must be substituted by a new one. After the substitution of the original effect the CD0 is changed to new conceptual design CD1. The second and third conditions are ED0 and DD0 should be changed. Any change of CD0, ED0 or DD0 will result in the redesign process following that stage. So there are three redesign paths which are starting from CD0, ED0 or DD0 respectively.

3.4.1 Path 1: CD0→CD1–ED1–DD1–DO1

The path 1 is starting up from generating conceptual design CD1 which is new vision of original conceptual design CD0. Because of emerging of the new version CD1 the following embodiment and detailed design must be redesigned and new document for design DO1 comes into being. CD1–ED1–DD1–DO1 forms the first redesign path or path 1 for redesign of products for innovation.

The design cases No. 1, No. 2, No. 8, and No. 10 in Table 1 are the cases to follow Path 1. No. 1 is taken here as an example to make analysis of the redesign process. In No. 1 a new bridge girder erection machine for small curve roads is market need because of the rail network development in China. The opportunity for the company in which an engineer attending the classes started by the center is to develop a machine to decease the weight of structure and costs at the same time to adapt new

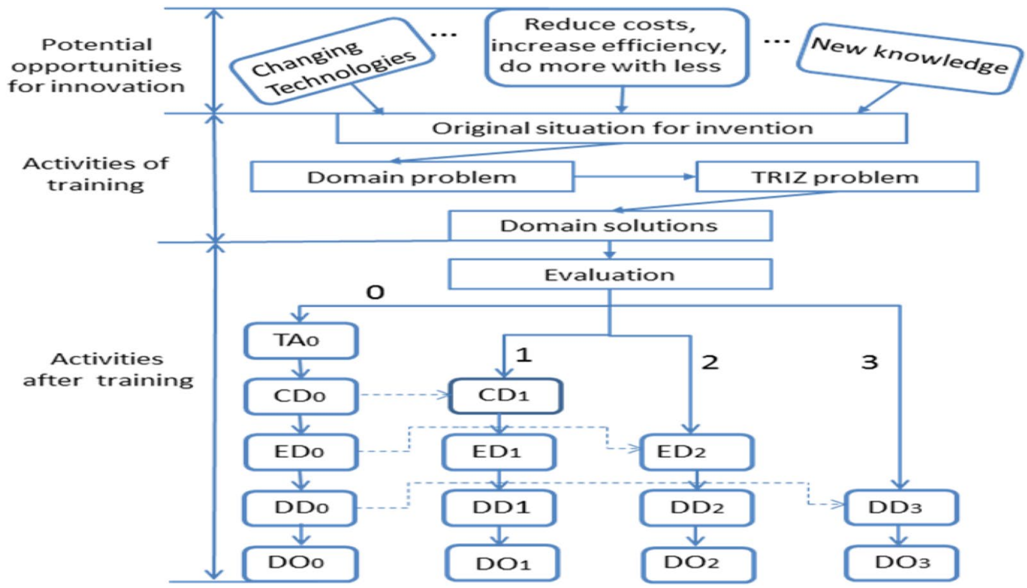

Figure 7 Three paths of opportunity-driven redesign

functions and performances of the existing machines in his company. The engineer finds a technical contradiction or an inventive problem that form a technical obstacle in original conceptual design CD0 for the new machine. In the training process the engineer solves the problem and forms the domain solutions which are two patents. After an evaluation in the company, the engineer returns knowledge of the two patents to the original conceptual design and makes a modification or redesign to form a new vision of the original conceptual design CD1. After that a redesign process for the following design stages ED1 and DD1 is stimulated which are the modifications of original embodiment and detailed design ED0 and DD0 of the bridge girder erection machine. At last a new design for the machine is formed and its document is DO1.

3.4.2 Path 2: ED0→ED2–DD2–DO2

The path 2 is starting up from ED2, a new version of original embodiment design ED0. A new chain from ED2 to DD2 and DO2 form the second redesign path.

The No. 3, No. 4, No. 5, No. 7, No. 9 of the ten design cases in Table 1 are the cases to follow Path 2. In case No. 3, the engineer of the classes finds that the products of his company could not fulfill the function of cleaning soil stuck to the drilling rod. The problem has been existed in this industry for many years, but there is no one to pay more attention to solve it. In the training process the engineer tries to solve the problem. The root problem of the superficial problem or invention situation is a technical contradiction of TRIZ. That is from the original embodiment design ED0. The domain solution of the contradiction is applied for a patent and results in a new version ED2. The following redesign stage is DD2 and the final output is DO2.

3.4.3 Path 3: DD0→DD3–DO3

The path 3 is from DD3 to DO3 where DD3 is the new version of original detailed design DD0.

The case No. 6 in Table 1 is a redesign of original detailed design. The engineer from a company to produce storage batteries finds that leakage of their batteries is an unsolved difficult problem for a long time. The problem is an opportunity for innovation of the products. After detailed analysis using TRIZ, a technical contradiction is identified as the root cause of leakage. Solution of the inventive problem is to change design of an element called "slot". A new die is developed for produce the new slot. The old slot is DD0 and new design of slot is DD2. Representation of DD2 is DO3. But the new die is the manufacturing tool for DD2.

The essential or potential opportunities are the original sources of innovations. The innovations are direct results of implementation of redesigns from these three paths. The engineers identify some opportunities and transform them to inventive problems and domain solutions. The domain solutions stimulate one of the three redesign paths. Redesigns DO1, DO2 and DO3 are new or innovative designs for following implementation of innovations. The whole process is opportunity driven or the redesign process is opportunity-driven.

4 Discussion

The key step for a successful innovation in a company is opportunity recognition [17–19]. There are many studies in literatures in management domain but few in engineering. Many new ideas for product development in established companies are generated by engineers working in design workplaces. However, there is a gap between the engineers and the managers who make opportunity recognition [17]. Figures 3 and 4 clearly show a relationship between training process and the opportunity recognition during the training process started by the center. If only some managers could follow the key time points of the training process according to the Figure 4, he or she will recognize some opportunities of innovation for his or her company. At the same time paying more attention to the classes from some managers of the company will stimulate the enthusiasm of the engineers to study and research. The effective interactions between the engineers and their companies will make more engineers to follow the training classes started by the center. That is the answer for the first question.

The confidence of TRIZ application is from the impressive understanding to the theory. The analogy based design is a widely recognized method in product design domain in the world. Figure 5a is a general model for analogous problem solving. The same analogous process in TRIZ is implicitly applied as shown in Figure 5b for contradiction solving in TRIZ. The advantage in Figure 5b is that the analogy A can be directly identified by designers. Comparison between Figure 5a, b for two kind of analogous processes is firstly made here to assist engineers to understand TRIZ better. That also answers the question 2.

Figure 6 represents the path for finding inventive problems which may be located in conceptual, embodiment or detailed design stages. All the problems are stimulated by essential or potential opportunities of innovation. The engineers in the classes solve these problems using methods in TRIZ and form some domain solutions. If the solutions are recognized and evaluated by some managers of the companies, the engineers come from three kind redesigns are starting up. Figure 7 shows the three paths for redesigns which are driven by opportunities. The whole process in Figure 7 is cooperation among managing activities, training process and redesign stages in a company. The training process is seamlessly connected with the innovative activities carried out in the companies in which some engineers are sent to the classes started by the center. That is the answer for question 3.

5 Conclusions

(1) A new model of transformation opportunity into inventions and a new training-gate system are developed. They connect the managing and training activities together. And the two models show that the managing level and training engineers should not be independent.
(2) The comparison between the general analogy model and the contradiction solving process in TRIZ shows the advantage and depth principle of TRIZ. This will make the engineers attending the training classes to apply TRIZ confidently.
(3) An opportunity-driven redesign model is established in which three paths for redesigns of the existing products are included. The training process and the redesign process are seamlessly connected by the model, in which the training process is a subprocess of the redesign process.

Through a seamlessly connected model from search of essential opportunities, training process for TRIZ, training and gate system for evaluations is formed, there are some difficulties to implement the processes because of the involvement of some management activities in the companies. Coordination among managing team for some companies, the engineers attending the training classes and the team of trainers should be studied in the future training practices to ensure the implementation.

Authors' Contributions
R-HT, Y-FD, B-JY and PZ was in charge of the whole trial; R-HT and Y-FD wrote the manuscript; B-JY and PZ assisted with sampling and laboratory analyses. All authors read and approved the final manuscript.

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Competing Interests

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