Innovative Product Design Based on General Theory of Powerful Thinking

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Abstract. Contradiction widely exists in product design. The key to product innovation is to find and solve design contradictions thoroughly. In view of the insufficient ability of existing design theories to solve multi-contradiction problems, this paper introduces a method for the innovative product design based on the general theory of powerful thinking. This method starts with the patent analysis and simplifies unnecessary steps in the design process. A concept scoring matrix is introduced to evaluate the design, which reduces subjectivity in the evaluation process. This research is conducted in cooperation with manufacturing enterprises. The design solution has been verified.

Keywords: Multi-contradiction problem, General theory of powerful thinking (OTSM) theory, Technology-effect matrix, Concept scoring matrix, Tire breaker
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1 INTRODUCTION

Innovation is a key for enterprises to be competitiveness in the market. The innovation lies mainly in the product design stage. Design is a process of transforming user needs into concrete structures. It is inefficient for designers to rely on experience in design on the basis of trial and error. It is an inevitable trend to systematize the theory of product innovation.

There have been many design methods proposed [25]. Engineering design [18] has been widely used, and its research searches for a methodology that is universally available and independent of specific disciplines. Axiomatic design [22] considers the complexity of a design process to solve the coupling problem in products. The goal of adaptable design [9] is to enable a product to meet different needs or working environments for the competitiveness of the product in the market. Reliability design [10] is based on reliability test and statistical analysis of failure data to ensure that the product can work steadily within the specified life period. Modular design [11] and product platform design [21] can shorten the design cycle and reduce costs while ensuring product performance. Green design [1] considers the impact of the product life cycle on the environment for the social development trend of nature protection.

Invention Problem Solving Theory or TRIZ in Russian is an innovative design theory [23]. Based on analyzing a large number of high-level patents around the world, it is firmly believed that contradictions in product design are fundamental reasons leading to failure of the product to meet users' needs. Therefore, in the process of product design and improvement, contradictions must be found and solved, rather than using compromise methods to ease contradictions.

Classical TRIZ methods can help design of new products, but they can no longer meet needs of solving multi-contradiction problems in complex systems. The multi-contradiction problem is not a simple superposition of the single contradiction. There are hierarchical and logical relations between contradictions. In a complex system, while improving a subsystem, it will affect other parts of the system. This influence cannot be ignored, it is related to stability of the whole system. In recent years, multi-contradictions have become one of the urgent problems in the field of product innovation. For this reason, some scholars proposed a general theory of powerful thinking, or OTSM in Russian [5]. This paper introduces a product innovation method based on the OTSM theory for solving multi-contradiction problems. This method deeply excavates internal relations of contradictions in a product to improve shortcomings of the classical TRIZ method in analyzing multi-contradiction problems, and thus enhances reliability of design solutions. A design process of the tire breaker is presented with a prototype verified by the manufacturer.

2 OTSM THEORY

OTSM theory was proposed by Altshuler, the founder of TRIZ. Later it was perfected and popularized by Professor Khomenko of Belarus. The OTSM theory was originally for business and education, and later transplanted into technical systems [13]. The goal is to provide tools for the efficiency of solving complex system problems [7].

At present, research of the OTSM theory is mainly in Europe. Literature [5] introduced the relationship between the OTSM theory and ARIZ algorithm in a time-axis way, and expressed a contradiction network in the form of a Taiji diagram. Literature [7] used a basic form of the element-name-value (ENV) model to link it with contradiction networks in the OTSM theory. Literature [14] classified solutions in different stages of the OTSM theory to define semi-effective, conceptual, prototyping and implementation solutions. Literature [4] summarized hierarchical relationships in networks of the problem flow, contradiction, specific and general parameters in the form of pictures, and compared these relationships for contradictions.

The OTSM theory has also been applied in practice. Literature [8] compared the difference between the classical TRIZ and OTSM theory in three aspects: the problem definition, contradiction definition and management solution, for the structural design of a rigid welded grid. Literature [20] combined the OTSM theory with the topology optimization to solve problems existing in dot matrix printers. Literature [17] introduced a case study of a Chilean forestry enterprise using a new set of five-step algorithms in the field of enterprise supply chain management. Literature [16] applied the OTSM theory to modern regional integrated energy planning for the modeling process using a software tool, which shows a clear direction for the popularization and application of OTSM. Literature [2, 6] carried out research activities to stimulate young people's creativity and evaluate the design level of engineering students using the problem flow network in the OTSM theory.

Due to the OTSM theory was not originally established for technical systems with different design steps introduced in literature [3, 4, 17], its applications can encounter many difficulties in the design process. On the one hand, there is a lack of information sources in the process of collecting problems, it is questionable for the integrity of the problem network established only based on the personal experience. On the other hand, the OTSM theory is often used to get more than one preliminary design scheme, the selected scheme is too subjective without the help of mathematical tools.

In order to improve the above shortcomings, this paper proposes a new design process according to the actual needs in solving engineering problems. The process is inspired by the general solution process in design [18], including several operational steps and decision steps. Beginning with qualitative analysis, it gradually becomes concrete and advances to quantitative work. Figure 1 shows a dynamic problem network based on the work of literature [4], it is an improved process. The ENV model network is added as the transition between the problem network and contradiction network. Through the dynamic problem network, we can express several related contradictions at the same time, which improves deficiency of the classical TRIZ in solving multi-contradiction problems.

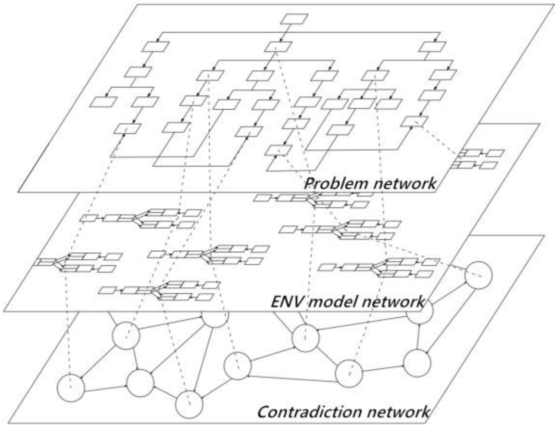


Figure 1: Dynamic problem network.

A product is designed to serve users, and the users' needs can guide a design process after being transformed into technical features. Quality Function Deployment (QFD) is a structured analysis tool that enables the conversion between user requirements and technical features [12]. However, it is difficult for designers to have enough information by collecting only user needs, because the need of individuals may not be the need of an entire group [22]. This research builds a problem network based on patent documents. The advantage is that the patent documents not only contain the innovative idea of predecessors, but also can be easily accessed. Facing problems of the optimal selection in multiple design solutions, the evidence theory can process multiple sources of information [24] at the same time. Results of the combination of expert opinions can be satisfied. However, this method is complicated to operate and is not convenient in applications. The Analytic Hierarchy Process (AHP) decomposes complex multi-objective decision problems into multiple specific criteria, which can help designers in decision-making [3]. The disadvantage is that weights of criteria are not credible by the subjective judgment. This paper introduces a conceptual scoring matrix. Comparing the criteria in pairs is simple and intuitive, and the score based on the performance range of existing products is more objective. Therefore, the proposed process has improved the existing method in decision-making of complex multi-objective problems.

3 PROPOSED DESIGN PROCESS

3.1 Constructing Problem Network

As understanding a product is the basis of design innovation, many methods have been developed to analyze information related to the target product such as patent information. However, it is hard for non-specialists to collect and analyze this information as its enormous and rich in the technical and legal terminology [15]. In view of this situation, a technology-effect matrix is used in the patent analysis. The statistical results are presented in the form of a bubble chart after indexing the technical types and effect of related patent documents, which can grasp the distribution of patents at a glance to play an important role in understanding the status of technology and analyzing competitors to help formulating technology of development strategies.

Through a series of design method analyses, several major problems (Pb) in the product design can be exposed. By refining these problems, we can form sub-problems and Partial Solution (PS) [14]. A partial solution is the subjective response of designers when facing problems, which does not consider design constraints and can only be used to find some further sub-problems. The sub-problems and partial solutions are then aggregated into a table for a complete problem network based on internal relationships of the problem.

3.2 Problem Transformation

Following questions are used in a design process to identify a bottleneck problem: (1) Does it affect the main function of the product? (2) Is it an unsolved difficult technology problem in this field? (3) Does it affect other sub-problems in particular? and (4) Is it a direct demand from consumers? As long as it meets one of them, it can be identified as a bottleneck problem.

The element-name-value (ENV) model is proposed to represent bottleneck problems of a design process in the form of contradictions. The control parameter (CP) in the model is controlled by designers, and its changes will affect the product in some way, while the evaluation parameter (EP) represents the measure of a variable in the product [17]. Using these two parameters, design requirements and physical attributes can be correlated. Contradictions can be described intuitively and systematically, which builds a link between the concrete structure of a product and description of abstract design problems. For example, if element A is a battery in Figure 2, the control parameter is volume. At the current level of technology, the volume is proportional to electricity. Evaluation parameter 1 is standby time and evaluation parameter 2 is portability. Then the corresponding element B is a cell phone, and element C is the user. The bigger the volume, the longer the standby time, but the worse the portability. The relationship between the control parameter and evaluation parameter affects the direction of arrows shown in Figure 2.

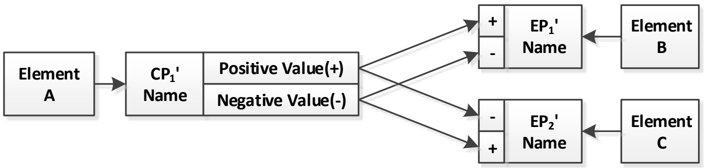


Figure 2: Relations of control and evaluation parameters.

It is observed that different contradictions often share one evaluation parameter, or one contradiction evaluation parameter is another contradiction control parameter. According to the relation between two kinds of parameters, all contradictions can be integrated into a contradiction network [4]. Taking Figure 3 as an example, nodes in the figure represent contradictions, and direct lines represent the relation between contradictions. Where C1, C2, and C3 form a ring contradiction, and three contradictions must be solved at the same time. C2 is a multi-output contradiction, and its change will affect five contradictions, while the multi-input contradiction C4 will be affected by the change of the other three contradiction parameters. C7, C8 and C9 form a contradiction chain with a causal relation. To solve this problem, we must start at C7. There may be independent contradiction C10, which cannot be included in the contradiction network. Contradictions with three or more input-output relationships can be identified as core contradictions, which has a greater impact on the product innovation design process. After the core contradiction is solved, the less-importance contradictions associated it can be solved easily.

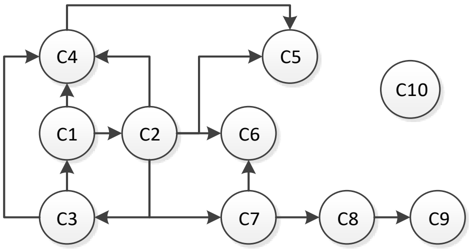


Figure 3: A general form of contradiction network.

3.3 Contradiction Resolution

After using the above process to find the core contradiction, the difficulty for designers to solve problems is reduced. That is because the classical TRIZ has provided different tools to solve contradictions [23], including the TRIZ algorithm, contradiction matrix, 4 separation principles, 76 standard solutions and effect libraries. At least one contradiction in the product should be solved by using the TRIZ tool, and its beneficial effect should be greater than its harmful effect. Such a design is called Concept Solution (CS) in the OTSM theory [14].

3.4 Concept Solution Evaluation

There are usually more than one CS for a product. All concept solutions need to be evaluated. A concept scoring matrix [26] is introduced into the design process as follows. Firstly, the evaluation criteria are determined based on the problem network. Comparing these criteria in pairs, the weight of each criterion is obtained. Secondly, conceptual solutions are analyzed for the performance related to criteria. Since it has not yet entered the detail design stage, the conceptual performance here is compared to the existing products. Finally, the total score of each CS is calculated for concept ranking.

For example, an enterprise needs to choose a best design from four concepts of Ⅰ, Ⅱ, Ⅲ and IV. Criteria extracted from the problem network are A, B, C, D, E, F and G. Results of criteria comparison and each criterion weight are shown in Tables 1. Based on the existing products, the comparison of the four conceptual solutions is shown in the right half of Table 3. The relative performance score is multiplied by the criterion weights, and then scores of the seven criteria are summed. As shown in Table 3, CS 1 is scored the highest.

Criteria	*A*	*B*	*C*	*D*	*E*	*F*	*G*
A		B	C	D	E	F	A
B			B	D	B	F	G
C				D	C	F	C
D					D	F	D
E						E	E
F							G
G							
Total hits	1	3	2	5	3	4	2
Weights	0.05	0.15	0.10	0.25	0.15	0.20	0.10

Table 1: Criteria comparison results and weights.

Level	*Meaning*
1	50% to 75% performance of existing products
3	75% to 100% performance of existing products
5	same performance as the existing products
7	100% to 125% performance of existing products
9	125% to 150% performance of existing products

Table 2: Relative performance level.

Criteria	*Weights*	*Design I*	*Design II*	*Design III*	*Design IV*
A	0.05	5	7	5	9
B	0.15	7	5	3	5
C	0.10	7	7	5	5
D	0.25	5	9	5	5
E	0.15	3	7	7	5
F	0.20	5	7	9	7
G	0.10	3	5	7	7
Total score		5	7	6	5.8
Rank		4	1	2	3

Table 3: Concept scoring matrix.

A process of the innovative product design is shown in Figure 4. Various analytical methods including the patent analysis are used to understand the existing products comprehensively. The main problems collected are decomposed to construct a problem network using internal relationships of sub-problems and partial solutions. If the problem network is incomplete, we need to repeat the above steps to complete it. Criteria are used to identify bottleneck problems in the problem network. The bottleneck problems are represented as contradictions using the ENV model. Core contradictions are determined from the contradiction network. TRIZ tools are used to resolve the contradictions. The concept scoring matrix is used to evaluate concept solutions. The CS with the highest score enters the stage of detail design. The prototype that passes the test will be produced as an innovative product.

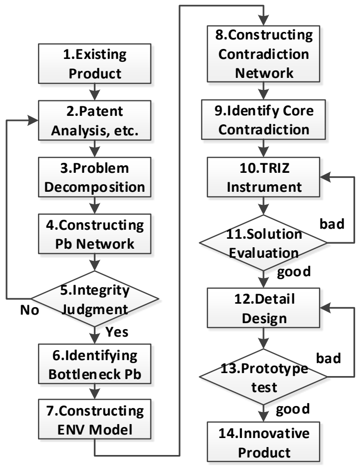


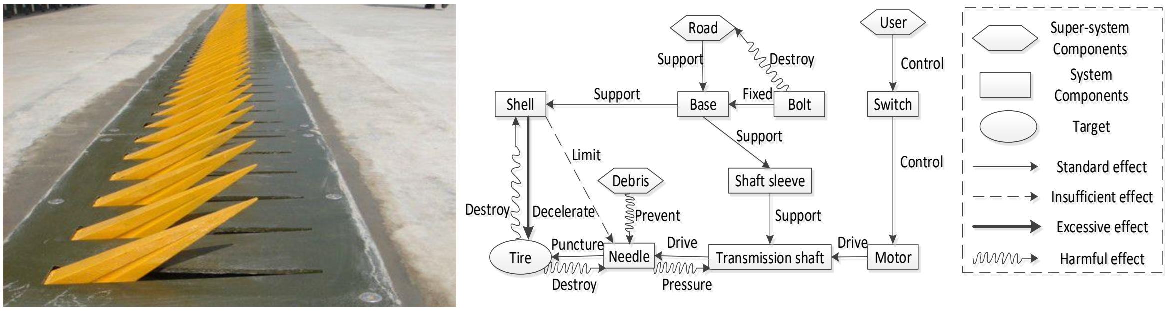
Figure 4: Innovative product design process.

4 CASE STUDY

4.1 Problem Network of Tire Breaker

Tire breaker is a kind of the security device to prevent illegal activities. Problems exist in the application of existing products, sometimes it may affect the normal travel of residents, and even cause the long-term traffic paralysis. Therefore, the improvement of the tire breaker has become an urgent demand. A new tire breaker is designed using the proposed method as follows.

Function modeling is a mature analysis tool in TRIZ, which clearly shows the relationship of parts. As shown in Figure 5(b), it can be found that the non-standard effect relationship is mostly related to the needle. Therefore, in the patent analysis of tire breakers, we need to pay a special attention to the needle improvement.



(a) (b)

Figure 5: Tire breaker: (a) Installation scenario, (b) Function model.

The key word of "tire breaker" was used in searching the product information on the patent website [19]. Searched results of patent documents in Table 4 show that the number of patent applications is on the rise from 2008 to 2017.

Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
Num	3	3	7	7	5	2	14	39	40	44

Table 4: Patent applications of tire breaker.

After screening, 58 valuable patents were obtained. The technical structure and design improvements described in these patents are extracted one by one to form a technology-effect matrix shown in Figure 6. Although these patents have their own structural characteristics, the portability and reliability cannot be satisfied at the same time. The technical system of the existing tire breakers has not yet reached to the mature stage. The development space for the industry is still vast. From the patent analysis, it is found that users' dissatisfaction in the existing tire breakers mainly lies in following areas: the short product life (Pb1), poor use effect (Pb2), affecting driving (Pb3), ugly appearance (Pb4), and hidden danger (Pb5). In a further analysis of causes for the above problems using the decomposition of the problems, sub-problems and partial solutions are summarized in Table 5. Its problem network is formed as shown in Figure 7 based on the problems' internal relations.

4.2 Contradiction Network of Tire Breaker

All sub-problems in the problem network are evaluated according to the criteria specified in Section 3.2. If a gap of the tire breaker is blocked by debris, the needle will not rise normally. Pb1.3 affects the main function of the product as the bottleneck problem shown in Table 6.

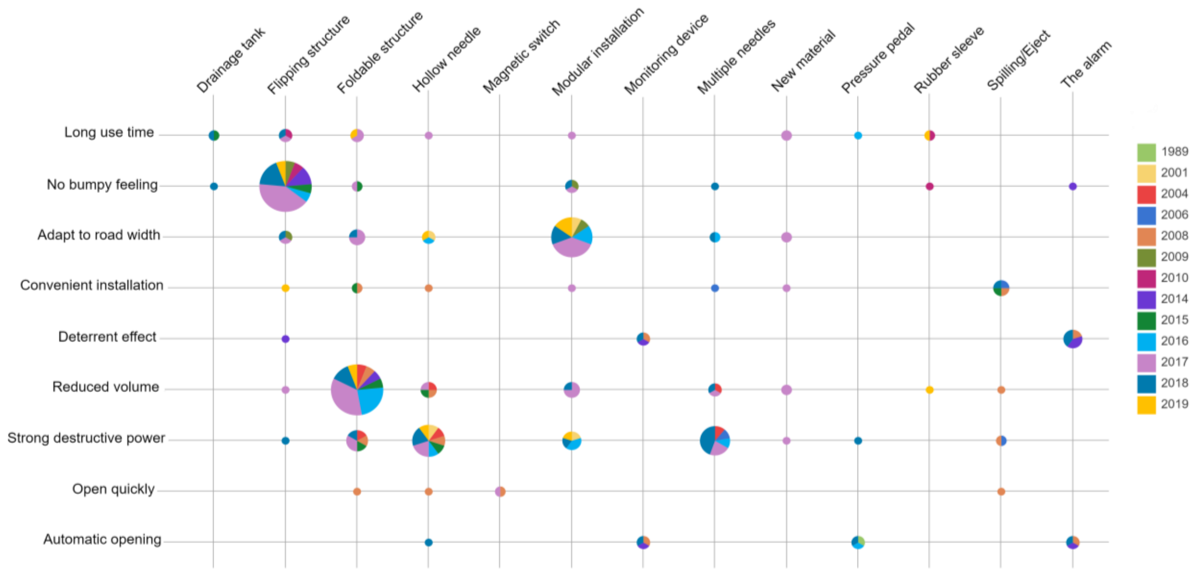


Figure 6: Technology-effect matrix.

No	*Problem description*	*No*	*Problem description*
Pb1.1	Rolling of Vehicles under Driving	Pb2.12	Large power consumption
Pb1.2	Malicious destruction	Pb3.1	Low Chassis Vehicle Bottom
Pb1.3	Debris blocking crevices	Pb3.2	Cause passenger discomfort
Pb1.4	Keep outdoors for a long time	Pb3.3	Over thickness
PS1.5	Corrosion Resistant Shell Material	Pb3.4	Require parts installation space
PS1.6	Temporary placement	PS3.5	Buried below the ground
Pb1.7	Cost increase	PS3.6	Increase body area
Pb1.8	Long installation time	Pb3.7	Destroy the road
Pb2.1	Shaft is easy to bend	Pb3.8	Inconvenient transportation
Pb2.2	Short needles, few needles	Pb4.1	Limited use scenarios affect sales
PS2.3	Enlarged diameter	PS4.2	Products with color and shape
PS2.4	Increase the number of needles	Pb4.3	Manufacturing difficulties
Pb2.5	Need greater momentum	Pb5.1	Dispersion inconvenience recovery
Pb2.6	Weight gain	Pb5.2	Hand-held or manual opening
PS2.7	Hydraulic drive	Pb5.3	Injury to pedestrians and vehicles
Pb2.8	Complex structure	PS5.4	Cable Control Open and Close
Pb2.9	Hydraulic oil leakage pollution	Pb5.5	Limited cable length
PS2.10	Maintenance difficulties	PS5.6	Remote control
PS2.11	Electric lifting	Pb5.7	Signals are easily disturbed

Table 5: Sub-problems and partial solutions.

There are total 8 bottleneck problems obtained as Pb1.3, Pb1.4, Pb2.1, Pb2.2, Pb2.7, Pb3.3, Pb4.3 and Pb5.6. Contradictions contained in bottleneck problems are represented by the ENV model to obtain contradictions C1 to C8. Taking Pb5.6 as an example, the control mode of a tire breaker includes the wired and remote control. The wired mode has a high reliability, but users need to close the tire breaker for operation. By contrast, the remote control is safer for the operator but lower reliable, which results in contradiction C8 as shown in Figure 8.

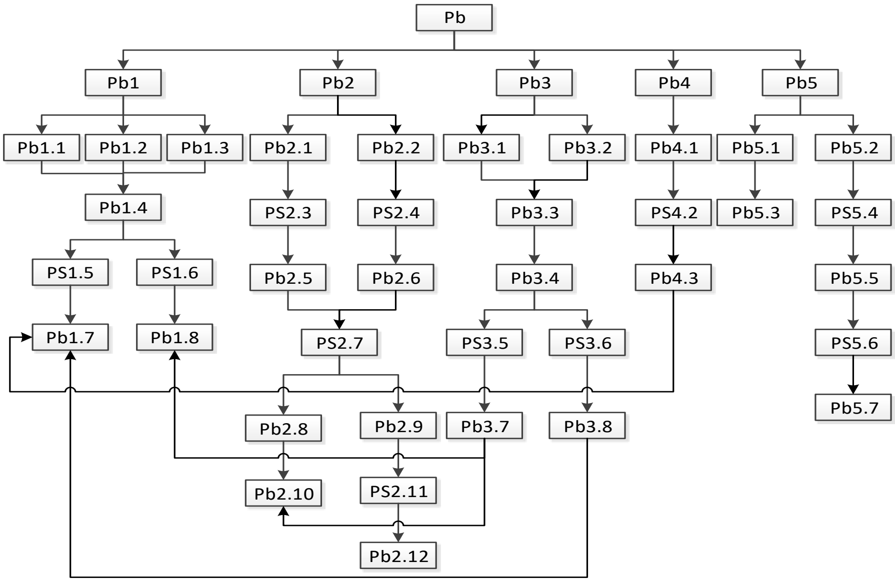


Figure 7: Problem network of the tire breaker.

Criteria / *No*	*1*	*2*	*3*	*4*	*Bottleneck problem*
Pb1.1	x	x	x	x	no
Pb1.2	x	x	x	x	no
Pb1.3	√	x	x	x	yes
Pb1.4	x	x	√	x	yes
...	...	...	...	...	...
Pb5.5	x	x	x	x	no
PS5.6	x	x	x	√	yes
Pb5.7	x	x	x	x	no

Table 6: Identification of bottleneck problems.

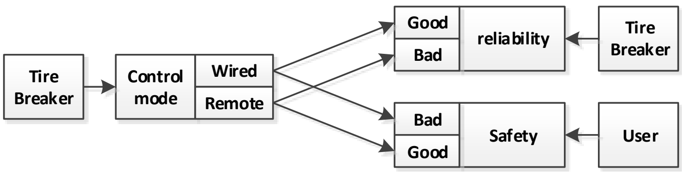


Figure 8: Contradiction C8 extracted from Pb5.6.

Relations of control and evaluation parameters of these 8 ENV models are illustrated using C3 as an example. Because needles are mounted on the transmission shaft, the number of needles changes the weight of the pressure on the transmission shaft, leading to the change of reliability of evaluation parameter C3, therefore C4 affects C3. Similarly, the internal space of the tire breaker is to place parts such as the transmission shaft. The diameter of the transmission shaft changes the required space, which leads to the change of the thickness of control parameter C6, C3 also affects C6. Based on understanding of relations among the eight contradictions, a complete contradiction network can be formed as shown in Figure 9, where the core contradictions are C3, C4, C5 and C7.

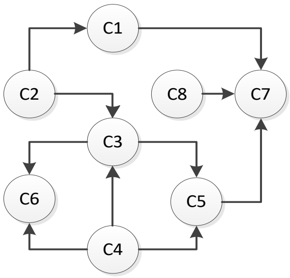
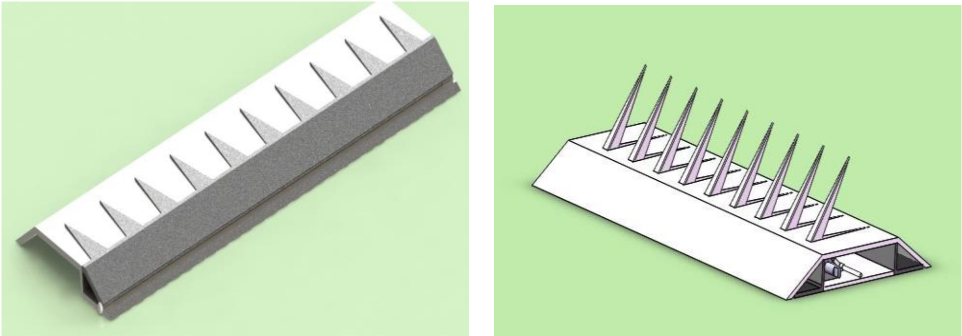


Figure 9: Contradiction network of tire breaker.

4.3 Concept Solution of Tire Breaker

After identifying four core contradictions, TRIZ tools are used to solve them according to the specific situation. Taking core contradiction C4 as an example, the existing products have a complex internal structure, large volume and heavy weight. Inspired by invention principle No.6: multi-purpose, we combine the shell with the needle as shown in Figure 10(a). The flat needle can be used as the shell when it is not opened to protect the internal structure. This reduces the number of components of the tire breaker and increases its reliability.



(a) (b)

Figure 10: Sketch map: (a) Concept solution Ⅰ, (b) Concept solution IV.

For the core contradiction C7, we choose the separation principle based on space. Concept solution IV is to design the tire breaker into separate modules, each module is one meter long with nine needles. The appropriate number of modules can be selected according to the width of the road, which increases the portability and maintainability of the tire breaker. In addition, different modules can have the different appearance and meet different installation environments.

4.4 Evaluation of Tire Breaker

Four concept solutions are evaluated based on the existing product shown in Figure 5(a). Five evaluation criteria are extracted from the five main issues in Section 3.2, including maintainability, reliability, portability, beauty and safety. Another criterion considers the cost of production. The evaluation process is shown in Tables 7 and 8.

Criteria	*M*	*R*	*P*	*B*	*S*	*C*
M		R	P	M	S	C
R			R	R	R	R
P				B	S	C
B					S	C
S						S
E						
Total hits	1	5	1	1	4	3
Weightings	0.07	0.35	0.07	0.07	0.28	0.21

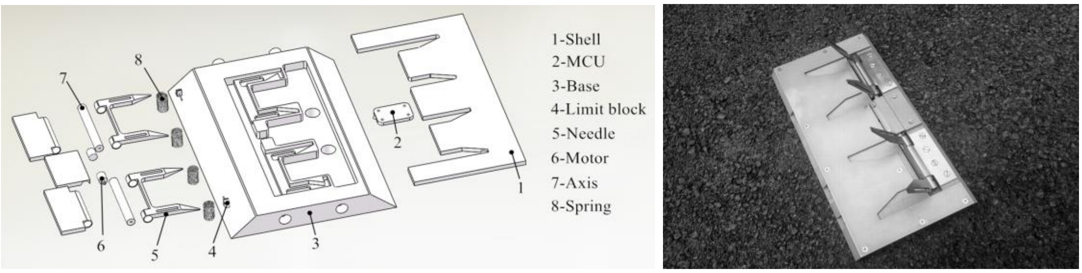
Table 7: Results and weights of criteria comparison.

Criteria	*Weightings*	*Design I*	*Design II*	*Design III*	*Design IV*
M	0.07	7	7	3	5
R	0.35	5	3	5	7
P	0.07	7	5	5	7
B	0.07	7	3	7	7
S	0.28	5	3	3	7
C	0.21	7	5	3	5
Total score		6.09	3.99	4.27	6.79
Rank		2	4	3	1

Table 8: Concept scoring matrix.

4.5 Design Result of Tire Breaker

The new design combines the advantages of concept solutions I and IV. Comparing the new design with the existing products of the cooperative enterprise, it is found that the new design has a lower height and is very friendly to low chassis vehicles. Inner parts of the shell are equipped with a single chip computer and a Bluetooth transmitter module, which can be remotely controlled by the mobile phone application. The needle is quickly pulled up to the working angle by the spring if required. After the task is completed, the motor drives the needle to be reset and locked. Figure 11 shows the new design and prototype of the tire breaker.



(a) (b)

Figure 11: New tire breaker: (a) The explosion figure, (b) The prototype.

5 CONCLUSIONS

In order to solve multi-contradiction problems in product design, this paper proposed a new process of innovative product design inspired by the OTSM theory. Compared to the existing methods, the proposed process has following features: (1) The problem network is a core of the OTSM theory, which is also new compared to the classical TRIZ theory. In the existing methods, the construction of a problem network depends on the experience of designers. However, not all users of the OTSM theory are experts. Especially when the product to be improved is complex, the problem network will be many times more complex than that shown in Figure 7. The dynamic problem network proposed in this paper is based on valuable patent documents, which lays the foundation for the follow-up analysis process. Patent documents can be analyzed by computers, which creates opportunities for computer-aided design. The future research is to quickly and accurately identify bottlenecks and core contradictions with an automatic process to reduce the workload of designers. (2) Neither the TRIZ theory nor OTSM theory provides an evaluation method. But in a general design process, many solutions can be generated. If the optimal design cannot be decided, the problem that enterprises initially face cannot be solved, that is, the method is ineffective. In this paper, the concept scoring matrix is introduced to provide an effective way to obtain an optimal design, which improves the efficiency of the original theory. (3) The proposed method deletes the parameter network, and clarifies criteria of the bottleneck problem and core contradiction. A new tire breaker has been developed for a local manufacturer. The manufactured design prototype has verified the effectiveness of the proposed process for the innovation design.

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