# Implementation of Low-end Disruptive Innovation based on OTSM-TRIZ

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**Abstract.** Low-end disruptive innovation has its own unique characteristics to develop product for simplicity, less cost and ease of use with maintained reliability and efficiency of the existing product. Disadvantaged enterprises can use it to attract a large number of low-end users with small investment to explore the new market. At present, the process of the low-end disruptive innovation based on classical TRIZ lacks quantitative solutions of multiple contradictions. In this research, combined with the analytic hierarchy process and Floyd-Warshall algorithm, a quantitative model of the low-end disruptive innovation is proposed based on the OTSM-TRIZ model. The proposed method is verified by an innovative case of tire breaker.

**Keywords:** Low-end disruptive innovation, OTSM-TRIZ, Multiple contradictions, Analytic hierarchy process, Floyd-Warshall algorithm, Tire breaker.
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## 1 INTRODUCTION

Low-end disruptive innovation (LDI) and new-market disruptive innovation (NDI) are two types of disruptive innovation methods [5]. LDI is a branch of technological evolution curves in the mature stage [19]. A product developed by LDI can attract low-end users in the market to gain profit [5, 20]. Disadvantaged enterprises in the market can use LDI to attract a large number of low-end users with a small investment. Based on the analysis of technology and system evolution of Invention Problem Solving Theory (TRIZ). Sun forecasted the potential opportunities of LDI [19], and developed a process model for LDI products [20]. Although many research efforts have been made, there is still a lack of a systematic design approach for LDI products.

This paper proposes a systematic approach to develop LDI products. At present, in the process of innovative product design based on TRIZ, solving a pair of contradictions often dominates the direction of problem solutions. However, there are often many pairs of contradictions in the LDI product development [5]. In order to solve multi-contradictions quantitatively, our proposed method is based on the OTSM-TRIZ (General Theory of Power Thinking) combined with the analytic hierarchy process (AHP) and Floyd-Warshall algorithm. The proposed method is used in the development of a LDI tire breaker.

## 2 RELATED RESEARCH

### 2.1 New-market Disruptive Innovation (NDI)

NDI develops a product or service with features valued by new consumers who have never bought or used the existing mainstream product or service, which creates a new network by changing the consumption and competitive environment to new dimensions [5]. Based on the technology system evolution theory, NDI belongs to an evolution branch of the mature stage on the S-curve of technological evolution that transfers a technology evolution trajectory to other performance dimensions [20]. Methods to generate the design scheme of new market disruptive products have been proposed based on the function differentiation [9].

### 2.2 Low-end Disruptive Innovation (LDI)

LDI is a process of the product technology evolution in the temporary retrogression with declining performances in a short-term for reducing the product price, and usually with unique characteristics such as the simple structure, less cost, ease of use, reliability and efficiency, and energy saving [5]. The difference of LDI from NDI is that it does not jump into the other S-curve of technological evolution in the third dimension, but to the low-end in the original technical performance dimension [20]. Although some solutions have been made in the field of LDI, compared to NDI, there is a lack of the systematic approach for LDI product development.

### 2.3 OTSM-TRIZ

OTSM-TRIZ is a method proposed to overcome some limitations of TRIZ and manage complex cross-discipline issues [12], which is still under development by many scholars for different applications [8,13,14]. Czinki proposed that the analysis of initial problems is the key to solve complex problems [4]. Hentschel established a structured problem description model to facilitate the selection of problem-solving tools [10]. Cavallucci used the form of a problem flow network to express the dynamic relationship between problems or contradictions [1], and combined OTSM-TRIZ with the graph theory in a process of the problem decomposition to obtain sub-problems and partial solutions [2]. We propose to combine the characteristics of LDI products with the OTSM-TRIZ and graph theory, so that the multi-contradictions of LDI products can be clearly analyzed for the solution.

### 2.4 Analytic Hierarchy Process (AHP)

AHP solves decision-making problems with prioritized alternatives [17]. AHP uses a pairwise comparison to obtain the priority of design alternatives. Numbers of 1 to 9 and their reciprocal are commonly used as the scale to establish a relatively important judgment matrix [18]. It basically consists of a three-levels hierarchical model. The first level sets goals and objectives, the second level is criteria and third is decision alternatives. After the hierarchy is established, alternatives are compared each other in pairs at each level. Each comparative judgment is mainly based on experience and knowledge of the users [16]. The assignment of preference is then checked for consistency of judgment matrix A and calculate CI (consistency index).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2.1}$$

$$CR = \frac{CI}{RI} \tag{2.2}$$

In the calculation of CR (consistency ratio) using Equation (2.2), CI must be rescaled by dividing it with a real number RI for a random index using Equation (2.1). RI values of an example are shown in Table 1.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 |

**Table 1**: RI Values of an example.

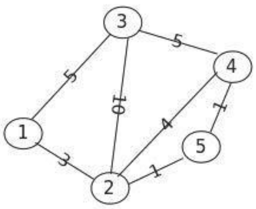
When CR<0.10, the consistency of the judgment matrix is acceptable, otherwise the judgment matrix should be modified appropriately [7]. In this research, combined with OTSM-TRIZ, AHP is applied to construct a network of product contradictions for LDI. The network is formed into a weighted directed graph, and the graph theory is then used to solve the problem.

## 2.5 Floyd-Warshall Algorithm

Floyd-Warshall algorithm can find the shortest paths between all pairs of vertices instead of a single shortest path [15]. The algorithm is described as follows.

- Starting at any one-sided path, the distance between two points is used as weight of the edge. If there is no edge connection between the two points, the weight is infinite M.
- For each pair of vertices u and v, they are connected to update the existing link if there is a vertex w where the path from u to w to v is shorter than the known path.

For example, Figure 1 shows a weighted graph (a), adjacency matrix (b) and distance matrix (c).




(a)

| D | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 0 | 3 | 5 | M | M |
| 2 | 3 | 0 | 10 | 4 | 1 |
| 3 | 5 | 10 | 0 | 5 | M |
| 4 | M | 4 | 5 | 0 | 1 |
| 5 | M | 1 | M | 1 | 0 |

(b)

| P | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 |
| 2 | 1 | 2 | 3 | 4 | 5 |
| 3 | 1 | 2 | 3 | 4 | 5 |
| 4 | 1 | 2 | 3 | 4 | 5 |
| 5 | 1 | 2 | 3 | 4 | 5 |

(c)

**Figure 1**: Example of using Floyd algorithm.

Floyd-Warshall algorithm provides an effective way to form a network of contradictions of design problems [11], which can be used to find the priority of the contradiction resolution path.

# 3 PROPOSED METHOD

The multi-contradictions problem solving process based on the problem flow network includes forming the problem domain, partial solution domain, contradiction domain and parameter domain, each domain expresses the problem or dynamic relationship between contradictions in the form of a network graph [2]. Key contradictions are extracted from the parameter network to solve the problem. The proposed method combines the analytic hierarchy process (AHP) and Floyd algorithm based on OTSM-TRIZ to form a systematic method for the development of LDI products, so as to drive the innovation of LDI products.

### 3.1 Network of Product Contradictions for LDI

An initial problem table can be formed for an LDI product. Related problems can then be transferred into a network of product problems using the OTSM-TRIZ tool as shown in Figure 2. The network is constructed using the graph theory, where nodes represent various LDI problems Pb or partial solutions Ps. Direct connections represent relations between nodes. Partial solutions are removed if they do not meet criteria of the LDI product. In the network, some problems may create new sub-problems and partial solutions. These partial solutions can be formed directly using innovative thinking in the detail design.

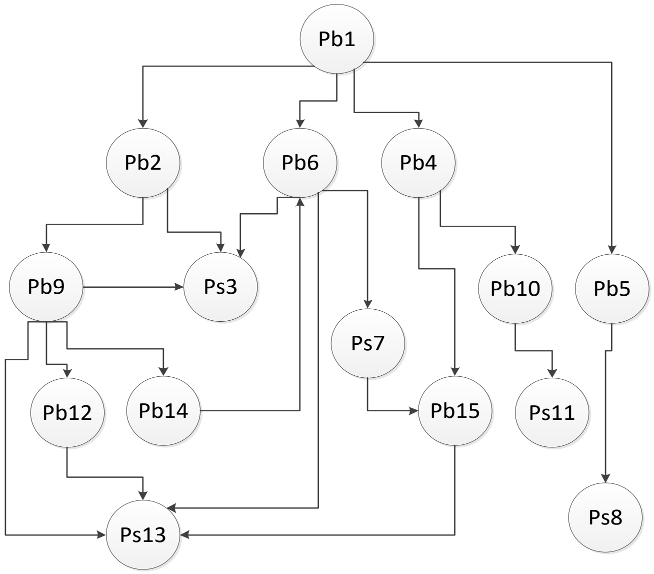



**Figure 2**: Network of problems.

Based on the network of problems, key problems can be identified as a series of contradictions. Each key problem is represented by an Element-Name-Value (ENV) model to analyze underlying causes of the key problem as shown in Figure 3.

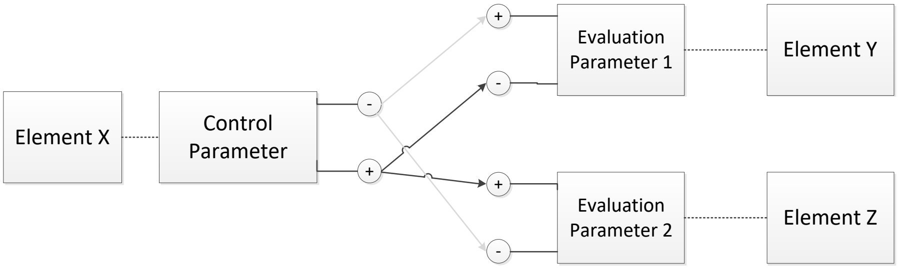



**Figure 3**: Elementary model of a contradiction according to the OTSM-TRIZ formalism [6].

ENV models include two types of parameters: control parameters (CP) that can be leveraged by decision makers in order to obtain a specific outcome, i.e. to implement a specific partial solution; and evaluation parameters (EP) that allow to assess the positive or negative implications of choices [6]. The positive change (improvement) of CP will lead to the positive change (improvement) of EP1 and the negative change (deterioration) of EP2, and vice versa [3]. The ENV model combines technical contradictions and physical contradictions of the classical TRIZ method, which can represent more complex contradiction types. All the ENV models are integrated to build a network of contradictions for the LDI product qualitatively revealed the relationship between contradictions as shown in Figure 4.

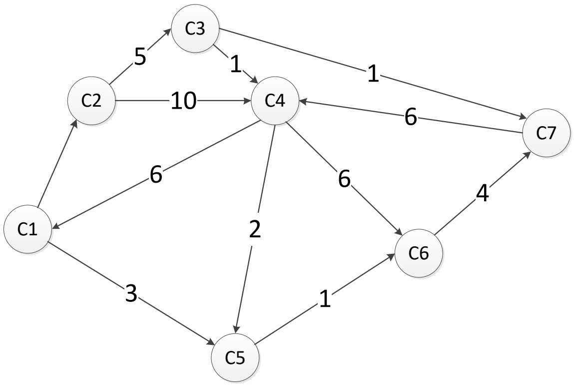



**Figure 4**: Example of the network of contradictions.

### 3.2 Evaluation of Weight Coefficients of Contradictions

The above qualitative analysis cannot determine the importance of contradictions and the solution priority path. A quantitative analysis of the network of product contradictions is conducted using an analytic hierarchy process (AHP) as follows.

#### *3.2.1 Weight coefficient*

The hierarchical structure model is built using the ENV model and network of product contradictions. Each contradiction occupies a certain proportion in practice. Number 1~9 and its reciprocal are cited as a scale to establish a relatively important judgment matrix. Experts use a 1~9 scaling method to compare different contradictions in pairs and then score them. For example, a14 indicates the result of C1 versus conflict C4. The weight coefficient of Ck can be calculated by importing the judgment matrix A after the expert score in the AHP.

#### *3.2.2 Model parameters*

According to the ENV model, a technical contradiction consists of one control parameter and two or more evaluation parameters as follows.

$$TC_k = (CP_k, \mathrm{E}P_{j1}, EP_{j2} \cdots) \tag{3.1}$$

The proportion of control and evaluation parameters in each contradiction is different in the measurement. Similarly, we use the number 1~9 and its reciprocal as a scale to define the judgment matrix B. Control and evaluation parameters of the same contradiction are compared in pairs by using the 1~9 scaling method. A judgment matrix is formed after the expert discussion and scoring. Weight coefficients of CPk, EPj1 and EPj2 are calculated by importing judgment matrix B in the AHP.

#### *3.2.3 Evaluation of weight coefficient of contradictions*

The comprehensive evaluation weight coefficient WOk is Wk (the weight coefficient of Ck) multiplied by the sum of WEPki (the weight coefficient of all the corresponding evaluation parameters EPki) as follows.

$$W_{Ok} = \sum_{i=1}^{n} W_k * W_{EPki} \quad (3.2)$$

Where N is the number of evaluation parameters. When the judgment matrix is CR < 0.1 or λ max = n, CI=0, it is considered that it has satisfactory consistency, otherwise, elements in the matrix need to be adjusted for the satisfactory consistency. Because the expert score is very subjective and the scoring matrix is often inconsistent or missing, the AHP is used to modify the expert scoring matrix.

### 3.3 Use of Floyd-Warshall Algorithm

The Floyd-Warshall algorithm finds the optimal starting point and the shortest path from multiple sources for a given weighted graph. It can also determine the priority of the solution path and the scheme priority of each path.

TRIZ tools are used to solve key contradictions sequentially based on specific problems of the LDI product. The network of contradictions can be transformed into a corresponding network of parameters. According to the product control and evaluation parameters in the network of parameters, a product can be redesigned based on the structure modification and operation improvement using adding, deleting or replacing operations. A general network of parameters can then be formed using the objective law and knowledge of the field. The overall flow of the implementation of LDI based on OTSM-TRIZ is shown in Figure 5.

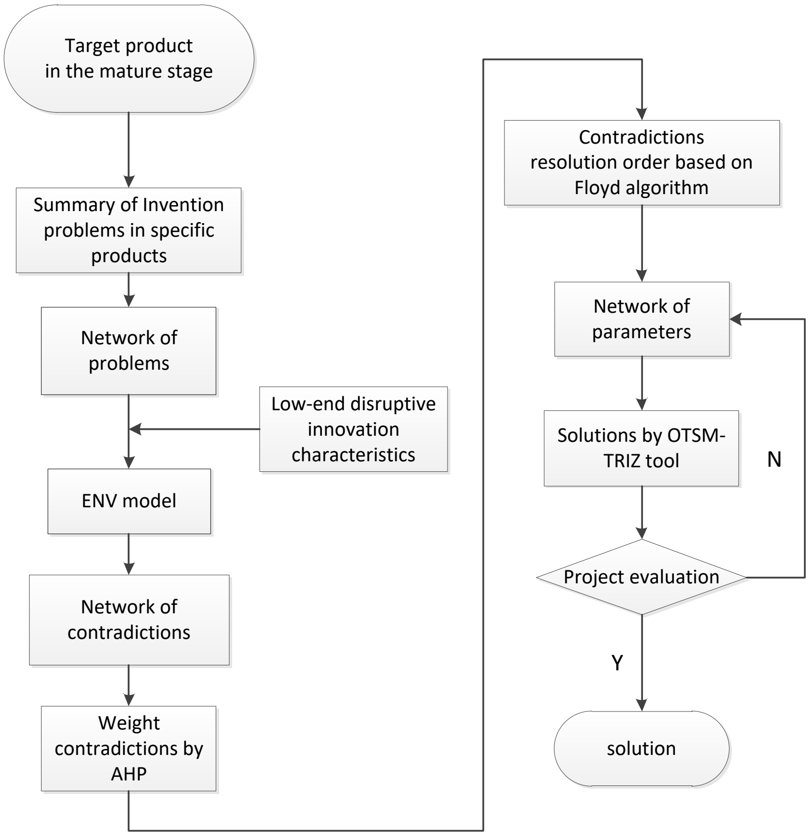



**Figure 5**: LDI process based on OTSM-TRIZ.

## 4 CASE STUDY

Tire breakers are common security devices used in maintaining public order and stopping violations of the law. The existing reducer-based tire breakers are usually fixed on the ground. Their structures are complex and not easy for use and operation as shown in Figure 6. They are also easy to accumulate dust and water, and hard for maintenance.

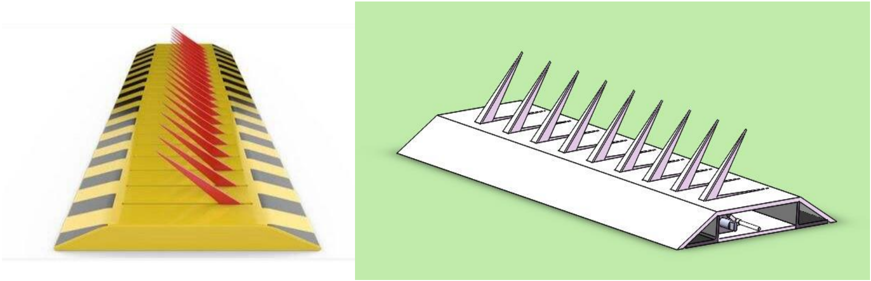


**Figure 6**: Existing tire breakers.

Through the technology maturity prediction and analysis of development of tire breakers in their mature stage of product technologies, an LDI product of the tire breaker is identified to have the low cost with reduced height in dimension. Based on the analysis of problems of the existing tire breakers, their structures are abstracted to meet the need of the LDI product.

### 4.1 Network of Product Contradictions

According to analysis of the existing tire breakers for new design requirements, problems of the existing tire breakers and possible partial solutions are listed in Table 2.

| Pb or Ps ref. | Description | Pb or Ps ref. | Description |
|---|---|---|---|
| Pb1 | Tire breaker over height and weight | Pb14 | Internal space becomes smaller |
| Pb2 | Lower shell is thick | Pb15 | Insufficient shell strength |
| Pb3 | Upper shell is thick | Ps1 | Reduce drive shaft diameter |
| Pb4 | Drive shaft diameter is long | Ps2 | Reduce shell thickness |
| Pb5 | Shaft bracket too many | Ps3 | Use new material |
| Pb6 | Drive shaft easy to break | Ps4 | Proportionally reduced tire breaker |
| Ps7 | Poor reliability of support structure at work | Ps5 | Modularization of tire breaker |
| Ps8 | Debris is easy to fall into | Ps6 | Reduce the number of drive shaft bracket |

| | | | |
|---|---|---|---|
| Pb9 | Strength is not enough for thinner tire breaker needle | Ps7 | Not use drive shaft to withstand pressure |
| Pb10 | Shell deformation | | |
| Pb11 | Cost increase | | |
| Pb12 | Working height of the tire breaker needle is not enough. | | |
| Pb13 | Impact force becomes larger when working | | |

**Table 2**: Problems and Partial solutions of tire breaker.

Problems and partial solutions of the tire breaker can be transferred into a network of product problems using the OTSM-TRIZ tool as shown in Figure 7. The network is constructed using the graph theory, where nodes represent various tire breaker problems Pb or partial solutions Ps, and direct connections represent relations between nodes.

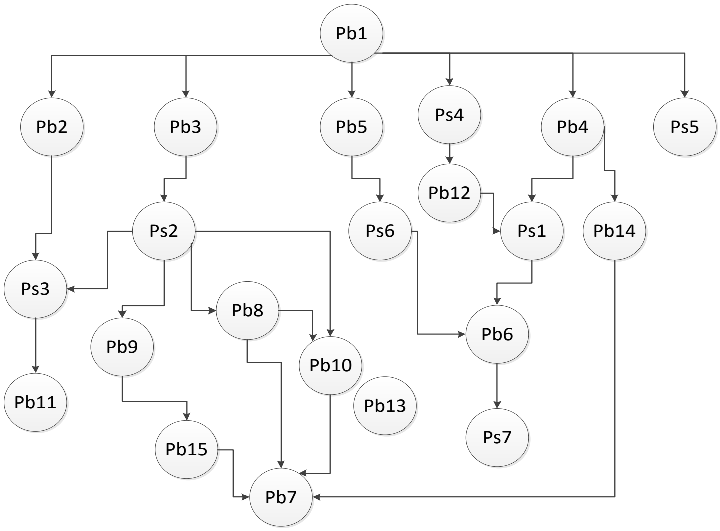



**Figure 7**: Network of problems for tire breaker.

Ps3, Ps4 and Pb11 are removed for those that cannot meet requirements of the LDI product. In the network of problems for the tire breaker, some problems can create new sub-problems and partial solutions like Ps5. These partial solutions may be found directly using innovative thinking in the detail design. Based on the network of problems, key problems can be identified as a series of contradictions. Each key problem is represented by an Element-Name-Value (ENV) model to analyze underlying causes of the key problem as shown in Figure 8.

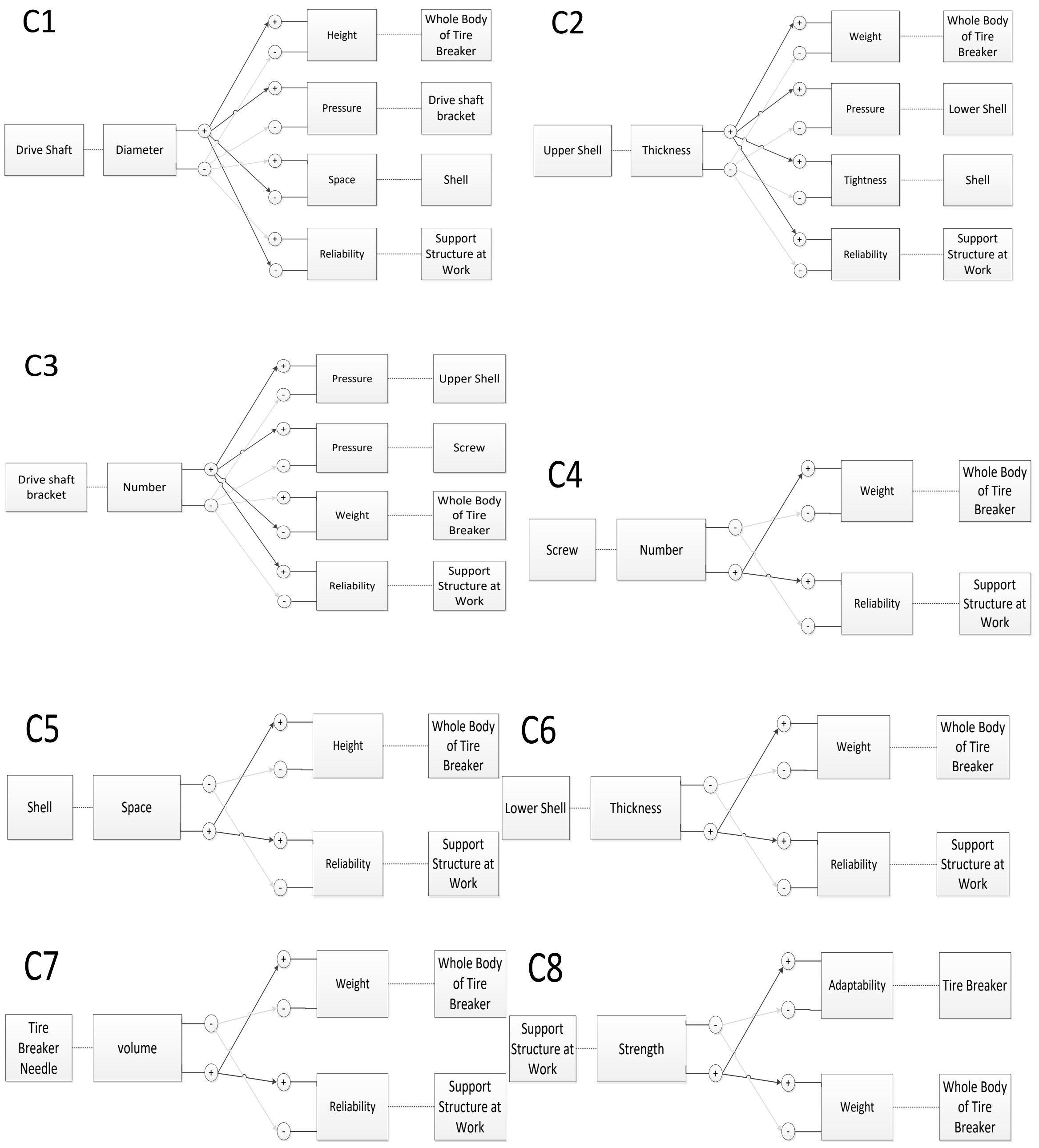



**Figure 8:** Elementary models of contradictions for tire breaker.

All the ENV models are integrated together to build a network of contradictions for the LDI product to qualitatively reveal the relationship between contradictions as shown in Figure 9.

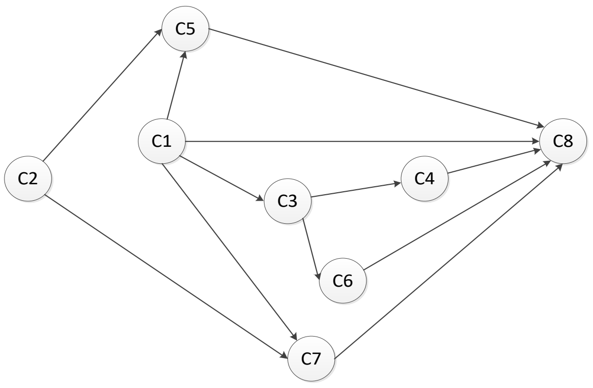



**Figure 9**: Network of contradictions of tire breaker.

## 4.2 Comprehensive Evaluation of Weight Coefficients of Contradictions

The quantitative analysis of the network of product contradictions is conducted using an AHP as shown in Figure 10.

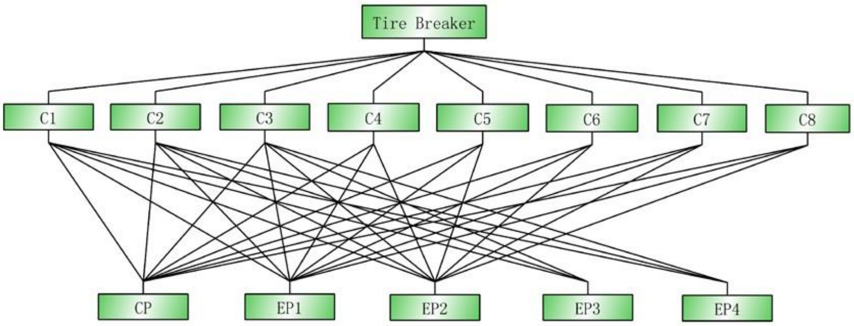



**Figure 10**: Hierarchical structure model of tire breaker.

### *4.2.1 Weight coefficient*

The 1~9 scaling method is used to grade the tire breaker contradictions to form a matrix. The weight coefficients of Ck are calculated using the judgment matrix A as shown in Table 3.

| | $W_1$ | $W_2$ | $W_3$ | $W_4$ | $W_5$ | $W_6$ | $W_7$ | $W_8$ |
|---|---|---|---|---|---|---|---|---|
| Weight | 0.2721 | 0.1308 | 0.0538 | 0.0285 | 0.1365 | 0.0501 | 0.1086 | 0.2196 |

**Table 3**: Weight coefficients of Ck of tire breaker.

### *4.2.2 Decision Parameters*

Using AHP, weight coefficients of parameters C1, C2, C3, C4, C5, C6, C7 and C8 of the tire breaker are obtained as shown in Table 4.

| | $W_{CPk1}$ | $W_{EPk1}$ | $W_{EPk2}$ | $W_{EPk3}$ | $W_{EPk4}$ | $\lambda_{max}$ | CI | CR |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.1205 | 0.3399 | 0.0898 | 0.2249 | 0.2249 | 5.2991 | 0.0747 | 0.0668 |
| C2 | 0.1177 | 0.2607 | 0.0740 | 0.2163 | 0.3313 | 5.2991 | 0.0747 | 0.0668 |
| C3 | 0.1012 | 0.0956 | 0.0956 | 0.3193 | 0.3882 | 5.2949 | 0.0737 | 0.0658 |
| C4 | 0.1150 | 0.4796 | 0.4055 | -- | -- | 3.0291 | 0.0145 | 0.0280 |
| C5 | 0.1294 | 0.3191 | 0.5514 | -- | -- | 3.0812 | 0.0406 | 0.0781 |
| C6 | 0.1578 | 0.1867 | 0.6555 | -- | -- | 3.0291 | 0.0145 | 0.0280 |
| C7 | 0.6333 | 0.1062 | 0.2605 | -- | -- | 3.0385 | 0.0193 | 0.0370 |
| C8 | 0.4055 | 0.1150 | 0.4796 | -- | -- | 3.0291 | 0.0145 | 0.0280 |

**Table 4**: Weight coefficients of Ck of tire breaker.

*4.2.3 Comprehensive evaluation of contradictions*

Because the expert score is very subjective and the scoring matrix is often inconsistent or missing, AHP is used to modify the expert scoring matrix. Equation (3.2) is used to calculate WOk as shown in Table 5.

| | $W_{O1}$ | $W_{O2}$ | $W_{O3}$ | $W_{O4}$ | $W_{O5}$ | $W_{O6}$ | $W_{O7}$ | $W_{O8}$ |
|---|---|---|---|---|---|---|---|---|
| Weight | 0.2393 | 0.1154 | 0.0484 | 0.0252 | 0.1188 | 0.0422 | 0.0398 | 0.1306 |

**Table 5**: Comprehensive evaluation weight coefficient of contradictions of tire breaker.

## 4.3 Priority of Contradictions Resolution

Values of WOk are added into the tire breaker network of contradictions to form the weighted directed graph as shown in Figure 11.

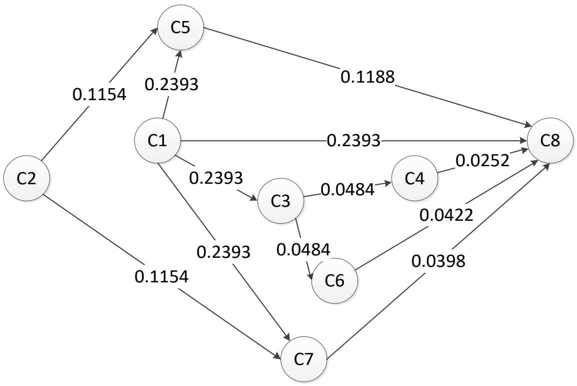



**Figure 11**: Weighted directed graph of tire breaker.

The Floyd-Warshall algorithm is then used to search the shortest path. Because the optimal path is the most weighted path, the scheme priority of each path is opposite to the result of calculation. It is found that the path C1-C5-C8 is the optimal path. TRIZ tools are used to solve key contradictions sequentially based on specific problems of the tire breaker. The solution is shown in Figure 12.

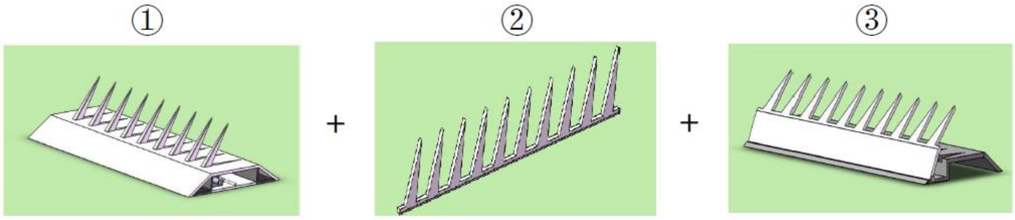



**Figure 12**: Sequence schemes of low-end disruptive scheme of the tire breaker.

A new design of the LDI tire breaker is proposed as shown in Figure 13. Comparing with the existing breakers, the new design reduces the number of parts and cost, weight, and folded height of the tire breaker. It simplifies the structure of the device, improves installation and operation processes to meet design requirements of this LDI product as shown in Table 6.

<table>
<tr><th></th><th>Number of parts</th><th>Cost (RMB/m)</th><th>Weight (kg/m)</th><th>Height (cm)</th><th>Simplified structure</th><th>Improved installation</th><th>Operation easy</th></tr>
<tr><td>Existing breakers</td><td>6</td><td>447.09</td><td>60</td><td>75</td><td rowspan="2">↑</td><td rowspan="2">↑</td><td rowspan="2">↑</td></tr>
<tr><td>New design breaker</td><td>3</td><td>353.20</td><td>46</td><td>60</td></tr>
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**Table 6:** Comparison of the existing and new designed breakers.

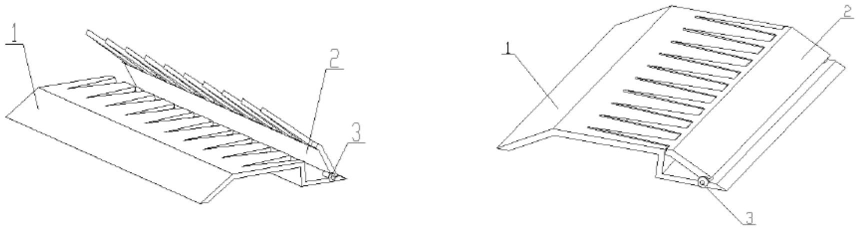


**Figure 13**: New design of a tire breaker [21].

## 5 CONCLUSIONS

A systematic method of the LDI product development was proposed based on OTSM-TRIZ. The solution search of multi-contradictions of LDI products demonstrated that the method can provide a guarantee solution for the contradiction problem. AHP was applied in the construction of a network of product contradictions with a weighted directed graph. The comprehensive LDI evaluation was conducted for solving contradictions. The Floyd-Warshall algorithm was used in searching the optimal path in the weighted directed graph. TRIZ tools were applied in solving contradictions sequentially based on the optimal path. The proposed method was verified in the development of a new LDI tire breaker product.

Further research will use more cases to improve the proposed approach and the development of a computer-aided innovation software tool. The quantitative analysis of LDI product characteristics in this paper was based on the experience of experts. The development of a quantitative standard for the characteristics of LDI products is also needed to apply OTSM-TRIZ in both the selection of problem networks and evaluation of the LDI product design.

## 6 ACKNOWLEDGEMENTS

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