Multi-conflict Problem Mining and Solving Process Model for Complex Product

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Abstract: The classical TRIZ theory has its limitations in solving multi-conflict problems in complex products, this study through explores problems in complex product, identify the key problem and normalize described, by analyzing the influence parameters of key problems and the relations among them, turning multiple problems into conflict networks. Then, the relevance between multiple conflicts in the conflict network is analyzed and the key conflicts are identified. TRIZ tool is applied to solve the key conflicts and propose solutions, which greatly reduces the difficulty of solving multiple conflicts. The identification method of key problems, the construction process of problem network and conflict network are given. Finally, the multi-conflict mining and solving process model for complex product innovation is established, and the validity of the process model is verified by taking the bridge erecting machine as an example for innovative design.

1. Introduction

Finding and solving conflicts in product design is just a basic idea of using the Theory of Inventive Problem Solving (TRIZ) to solve innovative problems[1,2]. Currently, in the process of solving innovation problems based on TRIZ, solving a pair of conflicts often dominates the solution direction. However, in the process of innovative design of complex products, the complexity of design problems is gradually increasing, and the number of conflicts is also dynamically increasing[3]. Therefore, complex product innovation problems often have multiple pairs of mutual restriction and overlapping conflicts, and these conflicts will even change dynamically with the progress of the problem solving process, which is more difficult to solve. For this kind of multi-conflict problem, traditional TRIZ conflict resolution tools have limitations [3,4,5].

Earlier, Khomenko[6,7]proposed the General Theory of Powerful Thinking OTSM (Russian acronym, English General Theory of Powerful Thinking) for solving complex interdisciplinary innovative problems by utilizing the characteristics of complex correlations in multi-conflict problems and starting from how to reduce the number of problems to solve complex problems. OTSM theory uses problem flow network technology to analyze and solve multi-conflict problems[7], which is a process of gradual problem selection, decomposition and solution, and evaluation iteration.

Systematic analysis of a problem is the premise of problem solving, Czinki [8]believe that the success of solving complex problems largely depends on the analysis of the initial problems. Cavalluci[9]adopted the problem flow network technology to study the process of solving multi-conflict problems: problem domain - partial solution domain - conflict domain- parameter domain. Each domain uses the form of network graph to express the dynamic relationship between problems or conflicts, and extracts key conflicts from the parameter network for solving. However, the establishment and transformation process of each network flow diagram in this process is relatively complex.

Literatures [10] and [11] respectively adopt qualitative and quantitative methods to identify key conflicts, so as to reduce the number of conflicts to be solved. Wei[4]combined the current implementation tree in the constraint theory with the fault tree analysis to form a design obstacle tree method for the analysis of multi-conflict problems in product design, which is used to analyze the root cause of product design problems. Literature [12] constructed the problem flow network based on graph theory, further analyzed the evolution of the problem flow network, and established a pyramid-type problem flow network process model, which can clearly describe the relationship between problems.

For the determination of key conflict, based on the evolution theory of TRIZ and necessary tree of constraint theory, Ma[13]established a macroscopic process model for conflict determination in the design process, proposed a conflict importance ranking method based on the design obstacle tree, and used the path set of the obstacle tree to find the optimal path for multi-conflict solution. Zhang [14] proposed a fast method to solve multiple conflicts according to the frequency of TRIZ invention principle recommended by multiple pairs of conflicts, but this method did not consider the relevance between multiple conflicts.

In view of the above problems, this paper analyzes the problems existing in the complex product system firstly, and conducts a standardized description, and constructs a problem network based on the correlation between problems and the knowledge of graph theory. Then the key problems in the problem network are identified, the key problems are transformed into conflicts, and the conflict network is constructed according to the correlation relationship between the control parameters and evaluation parameters of multiple conflicts. Then, the key conflicts in the conflict network are identified, and the TRIZ tool is applied to solve the conflicts. The specific construction process and transformation rules of problem network and conflict network are given, and the process from problem network construction - key problem turn into conflict network - key conflict solving is formed. Finally, a multi-conflict problem mining and solving process model for complex products is established.

2. Problem network construction

2.1 Problem normalized expression

The discovery of the problem can be obtained by analyzing the adverse effects of the current state of the product and predicting the future target state of the product [12]. In complex products, problems are numerous and the relationship between problems is complex. The solution of one problem will lead to another problem, and these problems are sometimes unpredictable.

In order to facilitate the analysis and solution of the problem, the standardized description of the problem is very important and should have three characteristics: integrity, accuracy and clarity. The matter-element model of extenics[15]takes things *N*, their feature c and their corresponding magnitude v into comprehensive consideration, and takes ordered triples as the basic unit to describe things, which is referred to as matter-element for short, denoted by $R=(N,c,v)$.

A thing often has multiple features, each feature has its own magnitude, such as the number of n features: $c_1, c_2, \ldots\ldots c_n$ and the corresponding quantities: $v_1, v_2, \ldots\ldots v_n$, the matter-element model is n-dimensional matter-element, denoted as:

$$\boldsymbol{R}=\begin{pmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_n & v_n \end{pmatrix}=\begin{pmatrix} R_1 \\ R_2 \\ \cdots \\ R_n \end{pmatrix}$$

The application of matter-element model in extension theory to describe the problem can accurately reflect the essence of the problem and accurately summarize the adverse effects. Moreover, the adoption of matter-element model also has certain revelatory effect on problem solving. The thing of matter-element model is the object of problem study. The feature of thing is the attribute of the research object, which is the specific location of the adverse effect. The quantitative value refers to the quantity, degree or range of a certain attribute in the research object of the problem. The innovative solution of the problem can be achieved by modifying the quantitative value.

2.2 Problem network construction

The solution of a problem is a process of continuous exploration, and the conceptual scheme to be improved in the process of problem analysis and solution is called semi-efficient solution or partial solution[6]. Problems are interrelated with each other or with partial solutions, all possible problems of the system are found and analyzed, and normalized description based on the matter-element model is carried out to identify where the problems occur. The attributes causing the problems and corresponding parameters of the attributes are analyzed, so as to explore the nature of the problems and the correlation between problems.

According to the correlation between problems, the problem network graph as shown in figure 1 can be constructed by applying the knowledge of graph theory. The problem or partial solution is the node of the graph, and the relationship between problems is the connection between nodes. In figure 1, v_1 to v_7 represent the problem, and there is an interaction relationship between them, which is represented by e_1 to e_9. For example, problem v_1 affects problem v_2, v_3 and v_4, while problem v_5 and problem v_6 affect each other.

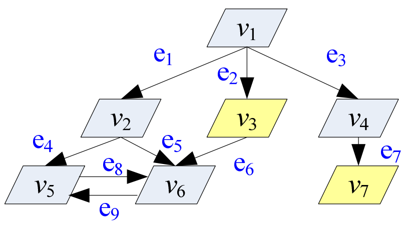


Fig. 1 Schematic diagram of problem network

2.3 Identification of key problems

For the completed problem network, the designer does not need to solve all the problems, but should further analyze the underlying causes and connections of the problems and solve the problems in the simplest way possible [20].The importance of a problem can be ranked, in order or priority to solve one or more problems, other problems may disappear or be simplified. After such a problem is solved, the complexity of the problem network can be reduced, which is called the key problem. Therefore, problems need to be identified and screened. Please refer to the following five questions to determine whether it is a key question.

(1) Are there more problems related to it?

(2) Does it affect the main functions of the system?

(3) Is it a problem in this field?

(4) Is it in the problem concentration area?

(5) Is it a required requirement set in the demand analysis?

If at least one of the answers to the above five questions is affirmative, the problem can be identified as a key issue. The process of screening key problems can reduce the work of the problem solving process, effectively improve the efficiency of the problem solving network, and provide more targeted solutions.

3. Transformation of conflict networks and construction of critical conflict networks

3.1 Conflict expression based on ENV model

According to the problem solving process of OTSM, to solve the key problem in the complex system, the key problem needs to be converted into the form of TC (Technical Conflict), and the ENV (element-name-value) model[6] is applied to represent the conflict. The problem is decomposed into multiple elements, each of which has a number of parameters, each of which has a number of quantum values.

The ENV model is shown in figure 2, where *E* is the element, *CP* is the control parameter, *EP* is the evaluation parameter, v_a is the positive value of the parameter, and $v_{\bar{a}}$ is the negative value of the parameter. If the positive value of the control parameter CP_1 is changed, it will lead to the positive change of the evaluation parameter EP_1 (improvement) and the negative change of the evaluation parameter EP_2 (deterioration). Control parameters correspond to physical conflicts in TRIZ, and evaluation parameters correspond to technical conflicts in TRIZ. The ENV model combines the technical conflicts and physical conflicts of the classic TRIZ as a whole to represent more complex conflict types.

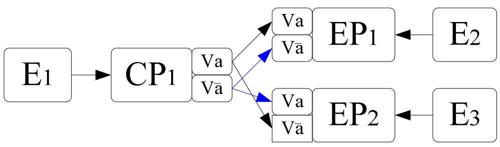


Fig. 2 ENV model [6]

In complex products, multi-conflict exists widely, which has the following three forms of expression:

(1) A control parameter can be evaluated by multiple evaluation parameters.

(2)Multiple technical conflict control parameters share one or more evaluation parameters.

(3) The control parameter in one technical conflict is the evaluation parameter in another technical conflict.

3.2 The transformation from critical problem to conflict network

Transforming problem network into conflict network is the basis of innovative solution using TRIZ tool. Firstly, the key problems described by the matter-element model were analyzed to extract parameters, a quantum value is a control parameter that describes a physical conflict, evaluation indexes such as performance effect caused by modification of control parameters can be used as evaluation parameters. Then the problem is built into the conflict expression form of ENV model, and by exploring the relationship between control parameters and evaluation parameters in each conflict, to establish the conflict network.

The establishment process of conflict network is shown in figure 3, which can be divided into the following steps:

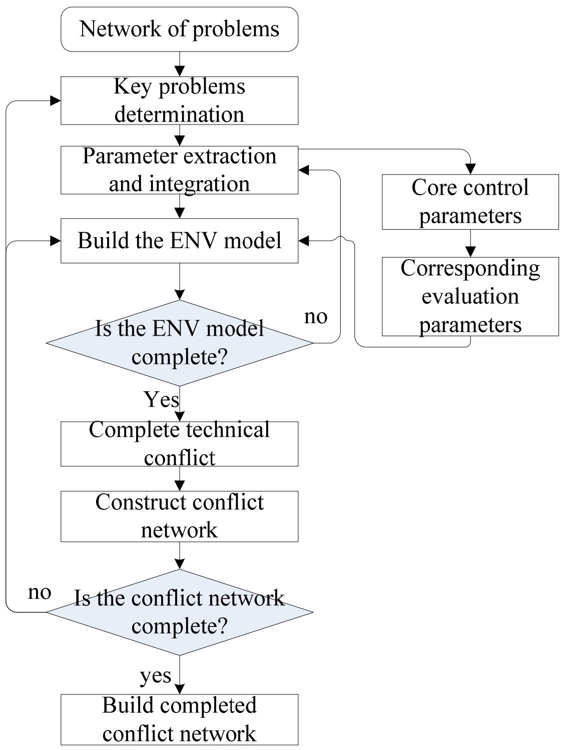


Fig. 3 Transformation process from problem network to conflict network

First, the key problems obtained from the above analysis process are decomposed, and the evaluation parameters and control parameters that cause the problems are found out, so as to build the parameter list.

Second, ENV transformation for key problems. According to the ENV model, appropriate evaluation parameters and control parameters are selected to decompose the problem into multiple single-conflict forms.

Thirdly, connect single conflicts into a network. The networking process is mainly based on the relevance of evaluation parameters, the relevance of control parameters and the correlation between elements.

Fourth, determine whether the conflict network is complete? If incomplete, repeat the above three steps until the conflict network is complete.

Figure 4 shows the schematic diagram of the conflict network. The nodes in the figure represent technical conflicts. The ENV model is studied as a whole, and the line represents the relationship between them. These relationships are explored through the extraction and integration of parameters, mainly including the relationship between CP and CP in different technical conflicts, the relationship between EP and EP, and the relationship between CP and EP.

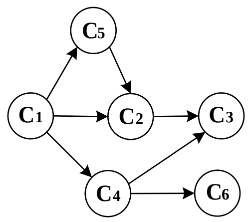


Fig. 4 Schematic diagram of conflict net

3.3 Construction of key conflict networks

After the conflict network is constructed, there are still problems to be solved because there are many relations between conflicts and the solving theory is still insufficient. Therefore, it is necessary to find the correlation between conflicts and the weight of conflicts, and take the major conflicts as the priority to solve the key conflicts. With the resolution of the key conflicts, some conflicts that depend on them will disappear or be solved at the same time. So, identifying key conflicts is an important step in simplifying the innovative design of complex product systems.

Qualitative analysis method and quantitative calculation method are used to determine the key conflicts. If conflicts satisfy the following two pattern relations, they can be identified as key conflicts [10] , and can be solved as a priority.

(1) Annular conflict mode: as shown in figure 5a, conflicts in the figure are interlinked end to end, affecting and interacting with each other, which is difficult to be completely solved by using the classical TRIZ theory.

(2) Multi-input conflict mode: as shown in figure 5b, a conflict is caused by multiple conflicts, and the solving process of this type of multi-conflict is complex.

(a) Annular conflict (b) Multi-input conflict

Fig. 5 Example of key conflict pattern [10]

The Analytic Hierarchy Process (AHP) can be used to determine the weight coefficient of the comprehensive evaluation of the technical conflicts which cannot be identified as the key conflicts through the above qualitative analysis, and quantitatively determine whether the technical conflicts are the key conflicts.

4. Multi-conflict problem mining and solving process model

4.1 Multi-conflict problem mining and solving principle process

The conflict solving process of TRIZ theory is to first transform the field problem into the TRIZ standard problem, use the invention principle or standard solution and other tools to solve the problem to obtain the general solution of TRIZ, and then combine with the practical engineering problems, the general solution of TRIZ is engineered to obtain the domain solution of the field problem.

However, in complex product systems, due to the high complexity of engineering problems, the TRIZ standard problem is composed of several problems. Therefore, it is necessary to combine the OTSM theory to decompose or partially solve the TRIZ standard problem to obtain sub-problems and partial solutions. Collecting partial solutions and extracting their beneficial effects, eliminating harmful effects, synthesizing into polymerization solutions, and theoretically and experimentally verifying the polymerization solutions. Finally, the solution passed the test will become the TRIZ general solution, and then combined with the actual engineering into domain solutions. As shown in figure 6.

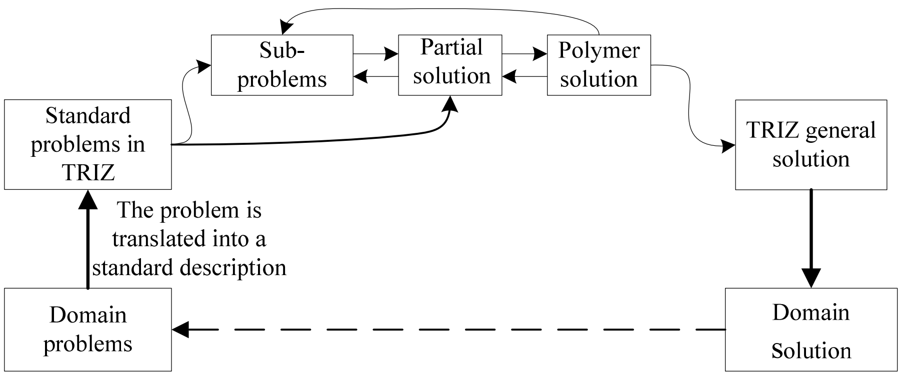


Fig.6 Invention problem solving process based on OTSM-TRIZ

In the above process, TRIZ tool is used to solve each sub-problem. In other words, the classical TRIZ process runs through the whole problem solving process. The innovative solution of complex product system is a process of continuous iteration by TRIZ tool until the problem is solved.

In complex products with numerous problems, the evolution and solution process of the problem is shown in figure 7. The invention problem is separated from the problem and the subsequent operation is carried out. In order to simplify the problem network, the key problems should be firstly screened and converted into conflicts represented by ENV. The conflict network should be constructed according to the relationship between control parameters, evaluation parameters and the manifestation of multiple conflicts. TRIZ tool is used to solve the problem iteratively and finally evaluate to obtain a high quality solution. This series of transformation processes keeps the problem constantly optimized, and along with the generation of the solution, from the problem to the partial solutions, after the partial solutions polymerization, a satisfactory solution is obtained after the evaluation.

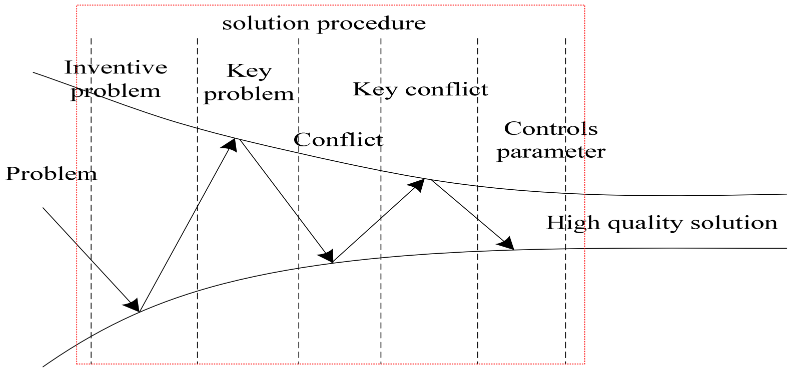


Fig.7 Multi-conflict problem mining and solving principle process

4.2 Multi-conflict problem mining and solving process model

Based on the above contents, a multi-conflict problem mining and solving process model based on OTSM-TRIZ was established, which was divided into three stages and twelve steps, as shown in table 1.

The first phase is the problem network construction phase. It mainly includes the following steps 1 to 5.

The second stage is conflict transformation and conflict network construction. It mainly includes the following steps 6 to 9.

The third stage is the innovation solution and evaluation stage. It mainly includes the following steps 10 to 12.

Table 1 Problem network model construction and solution process

Stage	Step	Operation
The first stage	1	Select the system to be improved
	2	System cognition, functional analysis and root cause analysis of the system
	3	Problem generation, summarizing problems, building a list of issues, and standardizing descriptions
	4	Find the relationship between problems and construct the problem network
	5	Qualitatively identify key issues
The second stage	6	Extract useful parameters, classify and integrate them into control parameters and evaluation parameters
	7	Build technical conflicts according to ENV model
	8	Construct a conflict network based on the relationship between technical conflicts and their parameters
	9	Identify key conflicts and build conflict networks based on parameter relationships between critical conflicts
The third stage	10	TRIZ tool is used to solve the conflict network
	11	Evaluate the solution
	12	Determine the optimal solution

5. Application cases

Bridge erecting machine is an important set of mechanical equipment for high-speed railway construction. It can accurately erect prefabricated beams between the piers and quickly and efficiently complete the erection of railway Bridges.TTSJ900 bridge erecting machine is a widely used bridge erecting equipment [17], which is mainly composed of bridge erecting machine main engine, supporting ultra-low beam transport vehicle and crane, as shown in figure 8. The main frame of the bridge is mainly composed of two main girders and the front, middle and rear transverse connection, the front supporting leg, the middle supporting leg, the rear supporting leg, the walking supporting leg, the power, hydraulic and control systems.

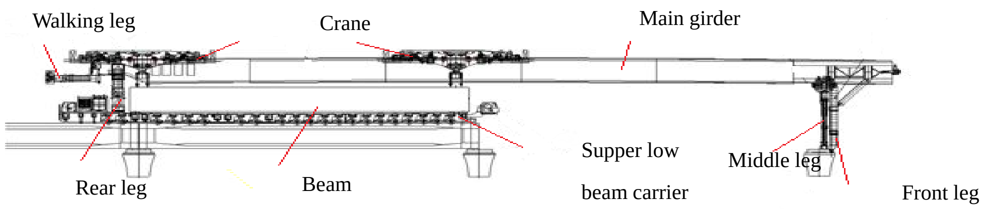


Fig. 8 TTSJ900 bridge erector main structure diagram[17]

The main erection operations of the bridge frame beam are: beam carrier feeding beam, crane lifting beam, moving beam and falling beam, middle leg contracting, moving forward and falling, front leg contracting, bridge erecting machine passing hole, front leg falling, etc.

5.1 TTSJ900 bridge erector product problem analysis

Based on the functional model analysis of TTSJ900 bridge erecting machine, the adverse effects are mainly focused on the beam feeding condition, that is, the influence of the moving form and supporting position of the beam plate on the safety performance. According to the enterprise design requirements to improve the erection efficiency and energy saving. The main part of the problem, the influencing parameters and the situation of problem were analyzed in depth. According to the matter-element model of extension theory, the standard description of the problem was carried out, and the list of main initial problems shown in table 2 was obtained.

Table 2 Standard description form of problems in TTSJ900 type bridge erector

Question	Problem scenario	Standard description
Pb1	When feeding the beam, it is supported by the front and middle legs, and there is no support at the back.	(The end of the main beam, bending deformation, large)
Pb2	The crane beam lifts the beam forward, and the bridge machine has two spans of simple support, the span is large, the middle part has large bending moment and the deformation is serious.	(The middle part of the main beam, curved and deformed, large)
Pb3	The lifting beam of the crane moves forward	(Moving beam, speed, slow)

	and feeds the beam at a high position. The moving speed is slow and the cable strength is required to be high.	
Pb4	When the bridge machine passes through the hole, the walking leg is driven, the middle leg roller supports the front part, and the front half of the main beam is in a cantilever state.	(The front part of main beam, bending deformation, large)

Pb (Problem)

Make an in-depth analysis of the main parts, influencing parameters and the situation of the above problems, and the main problems were decomposed. According to the matter-element model of extension theory, each sub-problem was described in a standardized way, and the problem list as shown in table 3 was obtained.

Table 3 Problem list of TTSJ900 type bridge erector

Question		Sub-problem	Standard description
Pb1	Pb1.1	Rear leg does not support	(Rear leg hydraulic cylinder, state, contraction)
	Pb1.2	Walking legs does not support	(Walking leg hydraulic cylinder, state, contraction)
	Pb1.3	The width between the two columns of the rear legs cannot accommodate the beam pieces and the beam carrier	(Two columns of the rear legs, distance, short）
Pb2	Pb2.1	The distance between the front leg and the rear leg is too large	(Span between front and rear legs, distance, long)
	Pb2.2	The crane is too heavy	(Crane, weight, heavy)
	Pb2.3	The beam is too heavy	(Beam, weight, heavy)
	Pb2.4	Insufficient strength of main beam structure	(Main beam, strength, insufficient)
Pb3	Pb3.1	Insufficient power for longitudinal movement of crane	(Crane, power, small)
	Pb3.2	The longitudinal movement of the crane is too long	(Crane moving longitudinally, distance, long)
Pb4	Pb4.1	The front end of the main beam is heavy	(Front end of the main beam, weight, heavy)
	Pb4.2	The front leg is heavy	(Front leg, weight, heavy)

5.2 Construction of the problem network of bridge erector

Based on the analysis of the sub-problems in table 3, the preliminary solution to some problems is a partial solution, and the partial solution itself has some problems. The process of problem decomposition and the partial solution solving is shown in figure 9. According to the relationship between various problems and between problems and partial solutions, the problem network model is constructed, as shown in figure 10. The problem or partial solution is the node in the figure, the dotted line indicates the relationship between the problems and the partial solution.

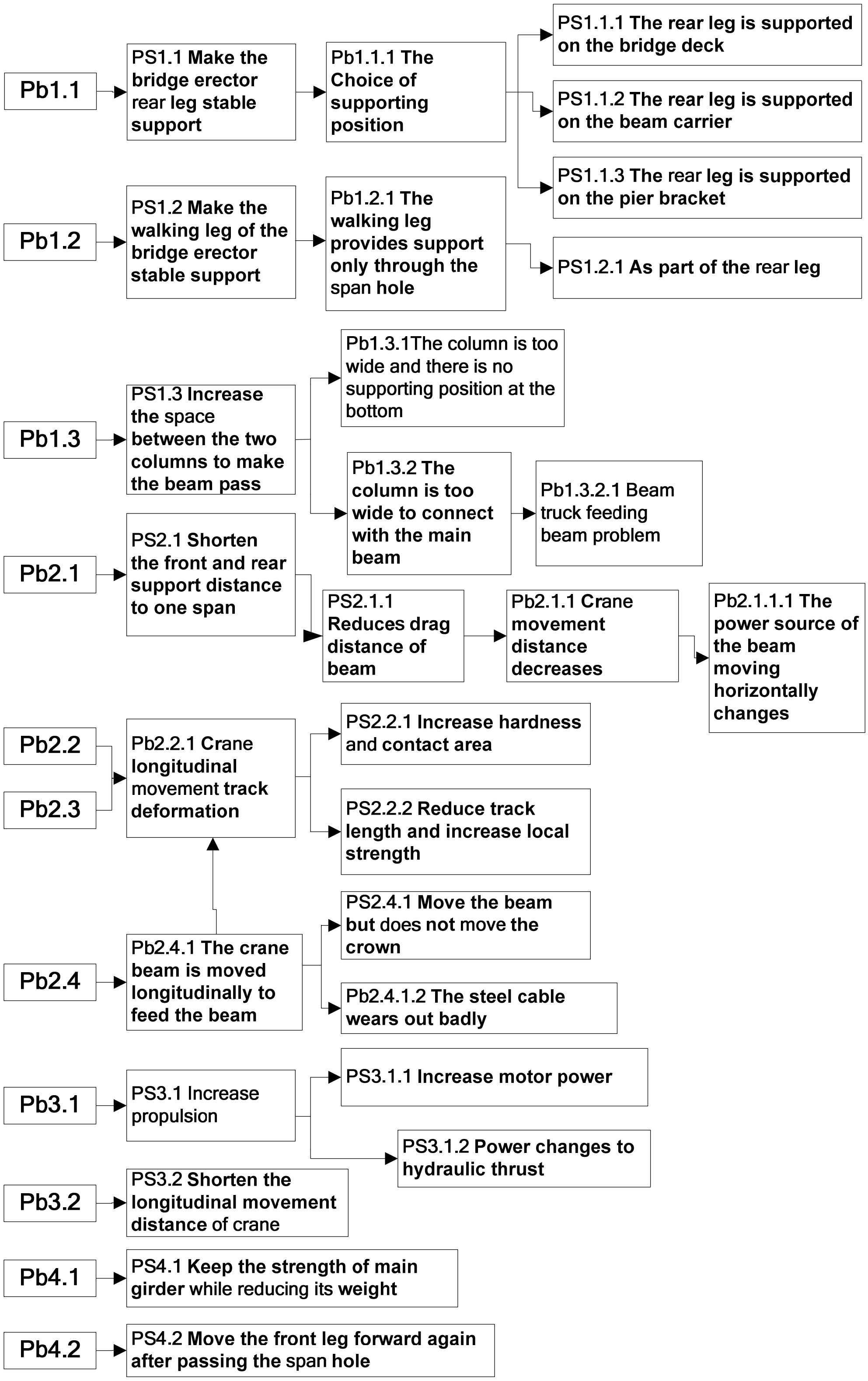


Fig. 9 The process of problem decomposition and the partial solution solving of bridge erector

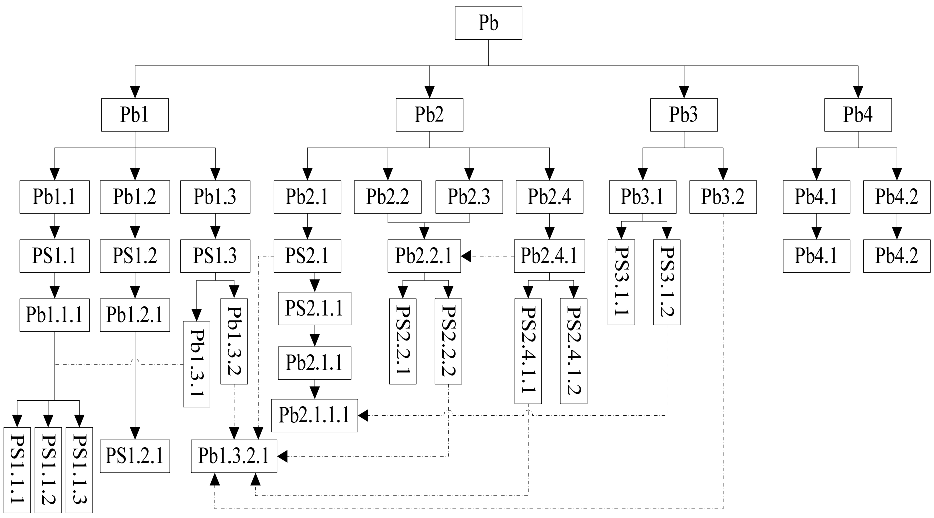


Fig. 10 Problem network model of TTSJ900 bridge erector

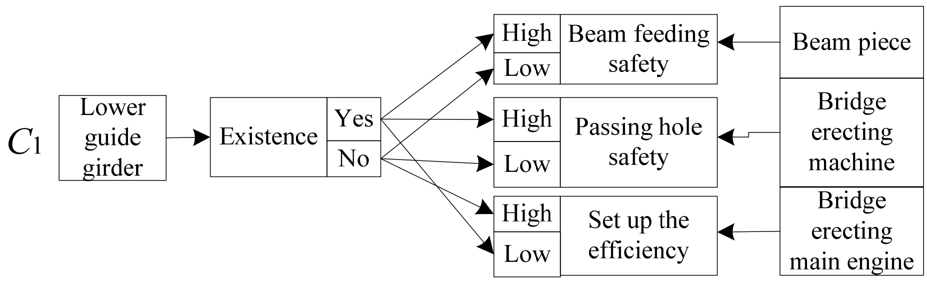
5.3 Identification of key issues in the problem network of bridge erector

Analysis of the problem network, and the sub-problems were determined according to the five determination methods of the key problems. Finally, four key problems were obtained: Pb1.3.2.1 beam carrier truck feeding beam problem, Pb2.1.1.1 changing the power source of horizontal movement of the beam plate, PS1.1.3 supporting the rear leg on the pier bracket, PS4.1 keep the strength of main beam while reducing its weight.

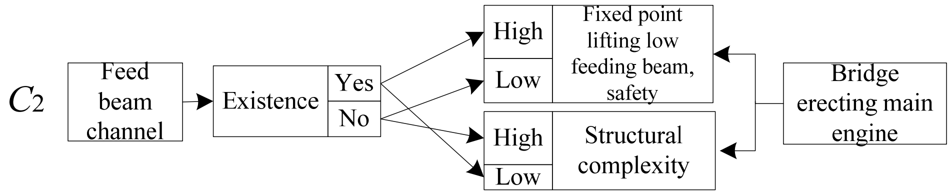
5.4 Key problem network convert into conflict network

Extract the conflicts that exist in the above key issues. For example, the beam carrier truck needs to run on the lower guide girder to ensure the safety of erection. However, the lower guide girder is not connected to the bridge erecting machine, and needs to be across the span hole independently, which reduces the erecting efficiency and forms the conflict C_1.

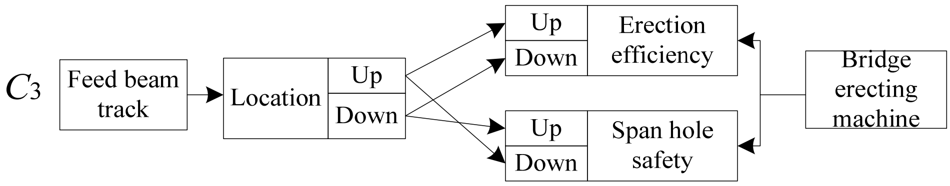
Problems are analyzed one by one. Seven conflicts of C_1 to C_3 and C_6 to C_9 are extracted from the key issue Pb1.3.2.1, one conflict of C_4 is extracted from the key issue Pb2.1.1.1, one conflict of C_5 is extracted from the key issue PS1.1.3, and two conflicts of C_{10} and C_{11} are extracted from the key issue PS4.1.Represent key issues as conflicts using the ENV model, as shown in figure 11.



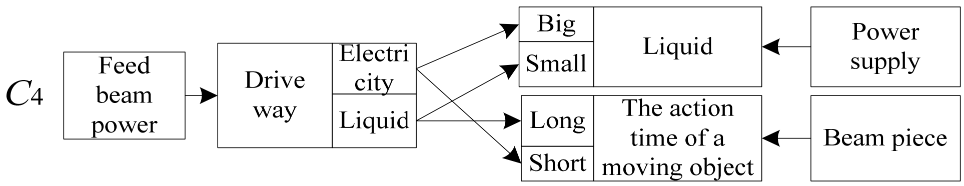
(a) Conflict C_1 represented by ENV



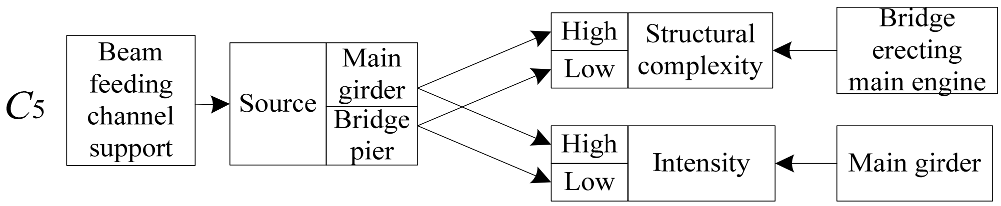
(b) Conflict C_2 represented by ENV



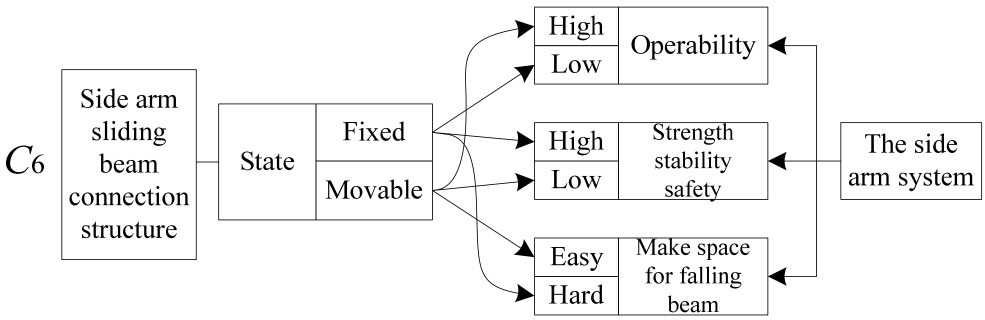
(c) Conflict C_3 represented by ENV



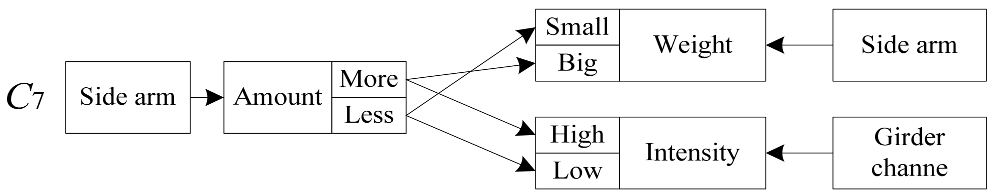
(d) Conflict C_4 represented by ENV



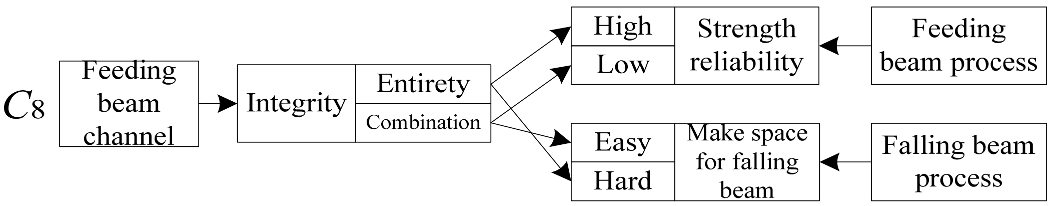
(e) Conflict C_5 represented by ENV



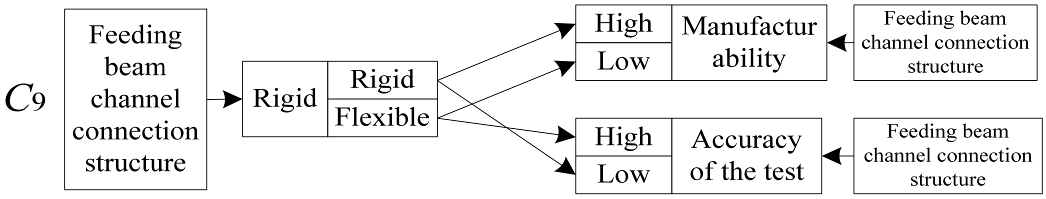
(f) Conflict C_6 represented by ENV



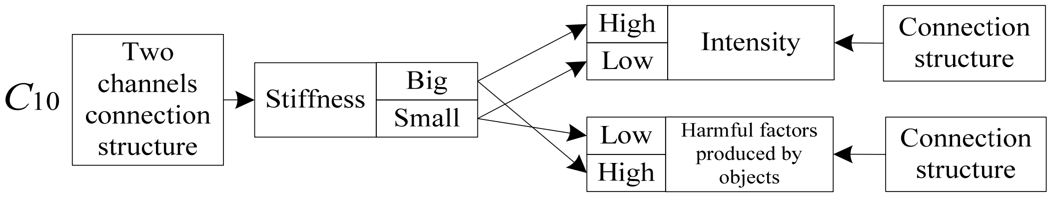
(g) Conflict C_7 represented by ENV



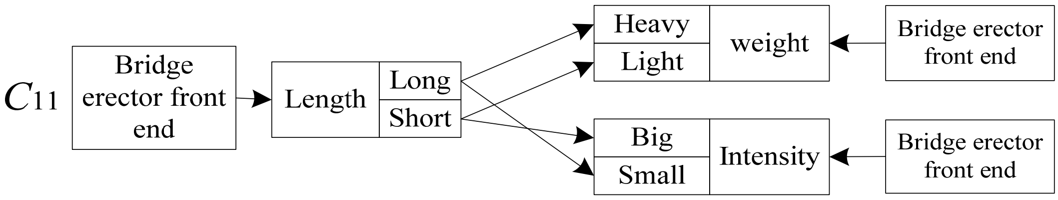
(h) Conflict C_8 represented by ENV



(i) Conflict C_9 represented by ENV



(j) Conflict C_{10} represented by ENV



(k) Conflict C_{11} represented by ENV

Fig.11 Conflict represented by ENV

According to the relationship between the control parameters and the evaluation parameters in each conflict, conflict network is constructed as shown in figure 12. The conflict network is in the form of a graph, nodes C_1 to C_{10} in the graph are conflicts, and directed connections are their mutual relations, they constitute a multi-conflict network. C_{11} is not associated with the network and is a separate conflict.

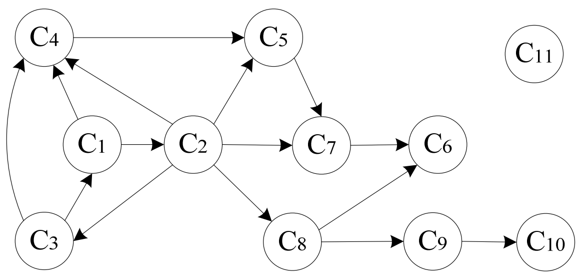


Fig. 12 Conflict network of beam feeding structure of bridge erector

5.5 Identification of key conflicts

In the conflict network, $C_1C_2C_3$ constitutes the circular conflict, and C_4 is the form of multi-input conflict, which are all carried out as the key conflicts to be solved in the priority of qualitative analysis. Other conflicts use analytic hierarchy process for weight calculation to determine the solution order. The weight coefficient of each conflict was calculated by paired comparison, and the control parameters and evaluation parameters of the conflict were compared in pairs. The weight coefficient of the control parameters of the conflict on the evaluation parameters was calculated, and then the total weight of each conflict was determined. According to the calculation, C_8, C_6 and C_9 are the three conflicts with the highest weight value, which should be solved first.

Finally, the order of solving the key conflicts was determined to be C_{11}, C_1, C_2, C_3, C_4, C_8, C_6 and C_9.

5.6 Multi-conflict resolution

According to the conflict network model shown in figure 12, TRIZ conflict resolution tool is used to solve the conflict network. The conflicts need to be solved sequentially, with the resolution of conflicts, the conflict network changes dynamically, as shown in figure 13. The independent conflict C_{11} is solved first, then the annular conflict $C_1C_2C_3$ is solved, and then the multi-input conflict C_4 is solved, and finally C_8, C_6 and C_9 are solved successively.

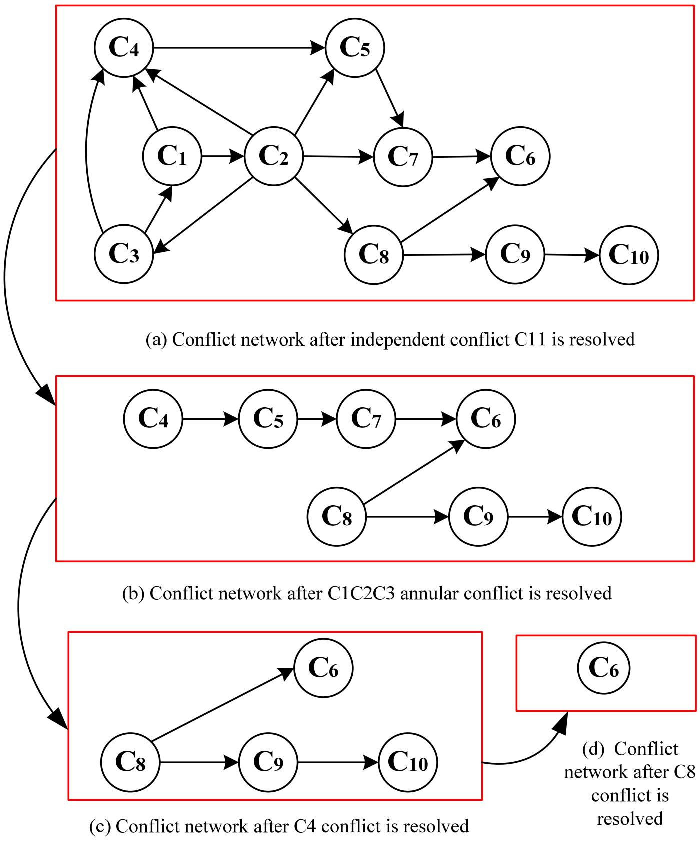


Fig.13 Iterative process of conflict network solution

5.7 Conceptual scheme of a new type bridge erector

According to the above solution process, combined with engineering practice, a solution is obtained, and its conceptual model is shown in figure 14[18]. In view of the shortcomings of the existing technology, this scheme provides a push beam type fixed point lifting bridge machine and its bridge erection method. In the process of bridge erection, the bridge erector can solve the conflict between fixed point lifting and lower guide girder, and reduce the number of motors and energy consumption, has the advantages of simple, easy to operate, safe and reliable.

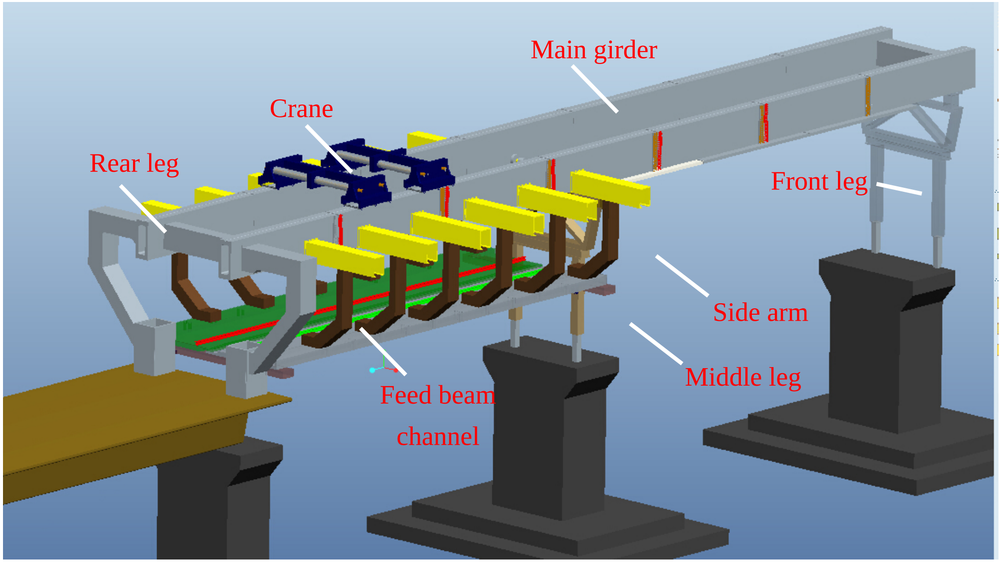


Fig. 14 Conceptual model of push beam type bridge erector

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