Title:
A Hybrid Model for Acquisition and Evaluation of Product Innovation Solutions

Authors:
Peng Shao, shaopengs@163.com, Hebei University of Technology, Tianjin, China
Runhua Tan, rhtan@hebut.edu.cn, Hebei University of Technology, Tianjin, China
Qingjin Peng, Qingjin.Peng@umanitoba.ca, University of Manitoba, Winnipeg, Canada
Chuan He, chuan_river@163.com, Hebei University of Technology, Tianjin, China
Fang Liu, lfzzh@hebut.edu.cn, Hebei University of Technology, Tianjin, China
Yafan Dong, dyafan@foxmail.com, Hebei University of Technology, Tianjin, China

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Introduction:

The quality function deployment (QFD) method identifies customer requirements in product lifecycle. Its key element is House of Quality (HOQ) that combines customer requirements with product characteristics to acquire the priority of customer requirements and ranking of product characteristics [3],[4]. As QFD has certain limitations in the product design, many scholars have fused the Theory of the Solution of Inventive Problems (TRIZ) and QFD for the customer requirement analysis and solution solving. However, the existing method has limitations. The conversion from customer requirements to technical characteristics relies heavily on the subjective vision of designers. Although there are some studies on functional structural units, new customer requirements cannot be formed based on functional units of the existing technical system. Some of evaluation indicators of the solution cannot be expressed precisely.

To cover up the existing deficiencies in acquiring technical characteristics and solution optimization using the fusion of QFD and TRIZ, this paper proposes a hybrid model of the innovative design based on the scenario evolution for the technical characteristics acquisition in HOQ, TRIZ tools for problem solving and mixed information for solution evaluation.

Main Idea:

The proposed model is shown in Fig 1.

Scenario-based technical characteristics acquisition
In the field of product design, a scenario is defined as the description of hypothetical states of actions of a product at some points of its life cycle, which is the product evolution driven from the initial state to expected state [1]. In the product design process, scenarios are composed of an initial scenario state (IS), a scenario evolution (SE), and an end scenario state (ES).

Each scenario state contains multiple scenario elements. Sets of scenario elements in IS and ES are referred as the pre-situation element set (Pre-Se) and post-situation element set (Post-Se). The scenario evolution process is expressed as a $\text{Pre-se} \xrightarrow{\text{SE}} \text{Post-se}$.

An entire product scenario as a scenario unit. A complete product scenario can be decomposed into multiple sub-scenario units according to order of the product function execution. Scenario nodes are also decomposed into $SN_i=\{SN_1,SN_2,\cdots, SN_n\}$, where $IS=SN_1$, $ES=SN_n$, and two adjacent scenario nodes and their evolution form a sub-situation unit, $SE_i=\{SE_1,SE_2,\cdots, SE_{n-1}\}$. The scenario evolution process is shown in Fig 2.

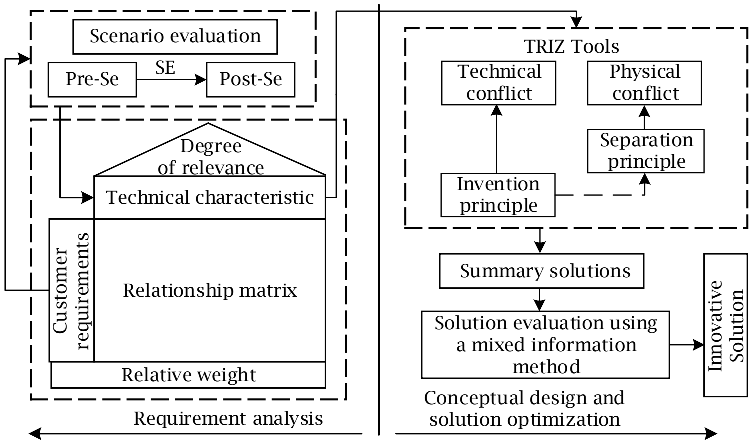

Fig. 1: A hybrid modeling of innovative design.

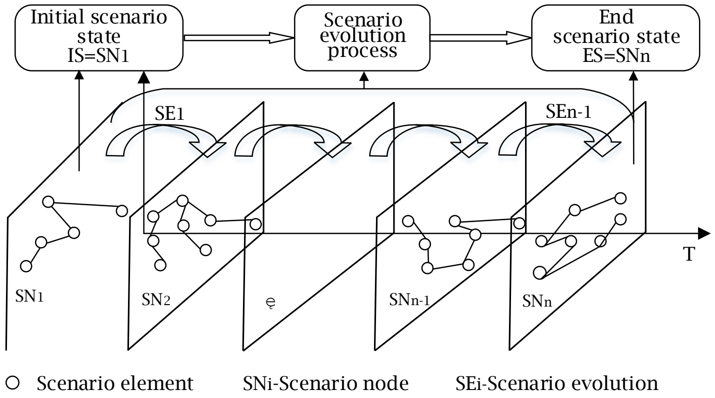

Fig. 2: Product scenario evolution process.

In the product innovation design process, SE_i can be considered as the total function that changes the state of a scenario of the product from SN_i to SN_{i+1}. Customer's need arises from the inadequate performance of a SE_i in the scenario evolution process. In order to meet customer requirement CR_i, the evolutionary process SE_i is improved and executable operations correspond to technical characteristics C_{ij}. Each scenario state SN_i contains element E_{ij} and corresponding value V_{ij}. The process extracts technical characteristics based on customer requirements as shown in Fig 3.

When a customer requirement is not based on the improvement of a scenario evolution state of the existing system, a new scenario is required. It is necessary to convert this need into a functional description and use a function-oriented search to find technical characteristics C_{ij} to achieve the function. Technical characteristics acquired according to the scenario analysis are further analyzed in a HOQ. According to their relations of parameters, the roof of the HOQ is established.

The relationship between customer requirements, scenario evolution and technical characteristics are illustrated by the example of a nail clipper, as shown in Figure 4. The process of the cutting nail consists of two scenarios. One is the open nail clipper. In this scenario, the nail fits link with the nail clipper in its long length. The second is a closed nail clipper. In this scenario, the nail is separated from the nail clipper in short. The evolution of two scenario states is achieved by actions of the relevant technical characteristics for completing the process of cutting nail.

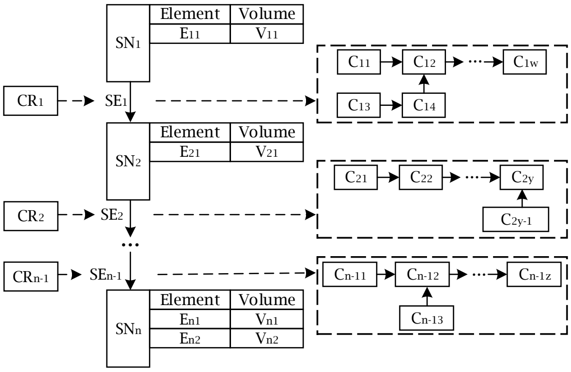

Fig. 3: Conversion of customer requirements to technical characteristics.

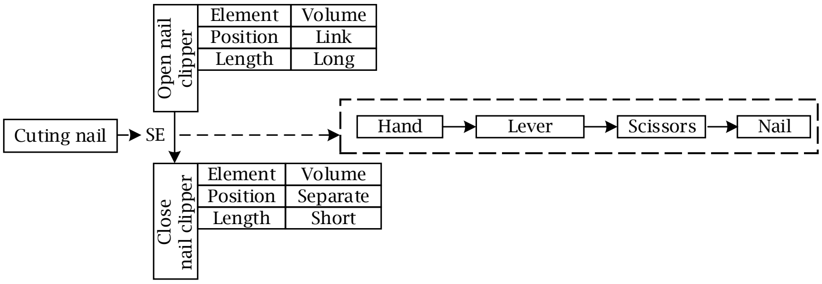

Figure 4: Scenario evolution for a nail clipper.

TRIZ tool for problem-solving
The conflict problem is first identified based on the relevance of the technical characteristics of the HOQ. The solution is then acquired by solving the conflict using the invention principle or separation principle.

Solution evaluation using a mixed information method
When TRIZ tools are used to solve conflicts of technical characteristics, several technological innovation solutions may be generated. When these solutions are aggregated, several aggregated solutions may be formed. The solution with the highest overall indicator needs is selected as the final design solution. Indicators of evaluating the solutions include precise number a, interval number $[a^L, a^U]$ and fuzzy number (a^L, a^M, a^U), which are collectively called mixed information [2]. $\tilde{a} = a^L, a^M, a^U$ is the triangular fuzzy number and affiliation function is $f_a(x)$. Fuzzy values and linguistic expressions are listed in Tab 1.

In order to eliminate the influence of different evaluation indicators in decision-making, evaluation decision matrix $A = (a_{ij})_{n\times m}$ is normalized into matrix $B = (b_{ij})_{n\times m}$. According to weight ω of each evaluation indicator, weighted normative matrix $R = (r_{ij})_{n\times m}$ is acquired. For each indicator, the optimal value of the indicator is selected as the positive ideal solution. The worst value is the negative ideal solution from all the solutions to be evaluated.

Serial number	Language evaluation	Triangular fuzzy number
1	Low	(0,0.1,0.3)
2	Medium	(0.3,0.5,0.7)
3	Upper middle	(0.5,0.7,0.9)
4	High	(0.7,0.9,1)

Tab. 1: Trigonometric fuzzy number expression.

The relative closeness of each solution to the positive ideal solution is decided using Eqn (1-3). The solution with the greatest relative closeness is selected as the final design solution.

$$d_i^+ = d(X_i \quad X^+) = \sqrt{(d_{i1}^+)^2 + (d_{i2}^+)^2 + \cdots + (d_{ik}^+)^2} \tag{1}$$

$$d_i^- = d(X_i \quad X^-) = \sqrt{(d_{i1}^-)^2 + (d_{i2}^-)^2 + \cdots + (d_{ik}^-)^2} \tag{2}$$

$$d_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{3}$$

Case study

Design of the 045 car satellite antenna is conducted to verify the proposed method. According to the customer feedbacks in the product use, there are following four main problems for improvement: 1). rain decay is serious; 2). rainwater beads on the parabolic surface in rainy days; 3). there is a blind area for signal search; 4). the height of the antenna is too high when it is not working, which is difficult to store. A technical characteristics acquisition model of customer requirements for 045 satellite antenna is built as shown in Fig 5.

Customer requirements and technical characteristics are formed in HOQ to analyze the relevance of each technical characteristics. When a conflict is resolved with TRIZ tools, two aggregated innovative solutions are formed. The original solution and two aggregated innovative solutions are evaluated. The evaluation indicators are horizontal rotation angle, paraboloid height, paraboloid caliber and cost. The evaluation decision matrix is as follows.

$$A = \begin{bmatrix} [-90,260] & 26 & 45 & (0.3,0.5,0.7) \\ [-90,265] & 17 & 52 & (0.5,0.7,0.9) \\ [-90,290] & 17 & 52 & (0.7,0.9,1) \end{bmatrix}$$

After normalizing decision matrix A and deriving weighted decision matrix R, the positive ideal solution and negative ideal solution are determined as follows.

$$X^+ = \begin{bmatrix} [-0.0764, 0.7442] & 0.0960 & 0.1809 & [0.0345, 0.0742, 0.1612] \end{bmatrix}$$

$$X^- = \begin{bmatrix} [-0.0764, 0.6672] & 0.1468 & 0.1556 & [0.0242, 0.0412, 0.0691] \end{bmatrix}$$

The relative closeness of each solution to the positive ideal solution is decided using to Eqn. (1-3).

$$d_0 = 0.452 \qquad d_1 = 0.539 \qquad d_2 = 0.548$$

It can be found that the relative closeness of two new design solutions is greater than the original solution, and solution 2 is greater than solution 1, solution 2 is therefore chosen as the final design solution as shown in Fig 6.

Conclusion:

Customer requirements are mapped into the scenario evolution process. Technical characteristics are analyzed in the scenario evolution process. For new customer requirements mapped into the scenario evolution process without corresponding technical characteristics, a function-oriented search is used to find relevant technical characteristics from the patent or effect database. For existing but insufficient customer requirements mapped to the scenario evolution process, searching for the corresponding technical characteristics for improvement.

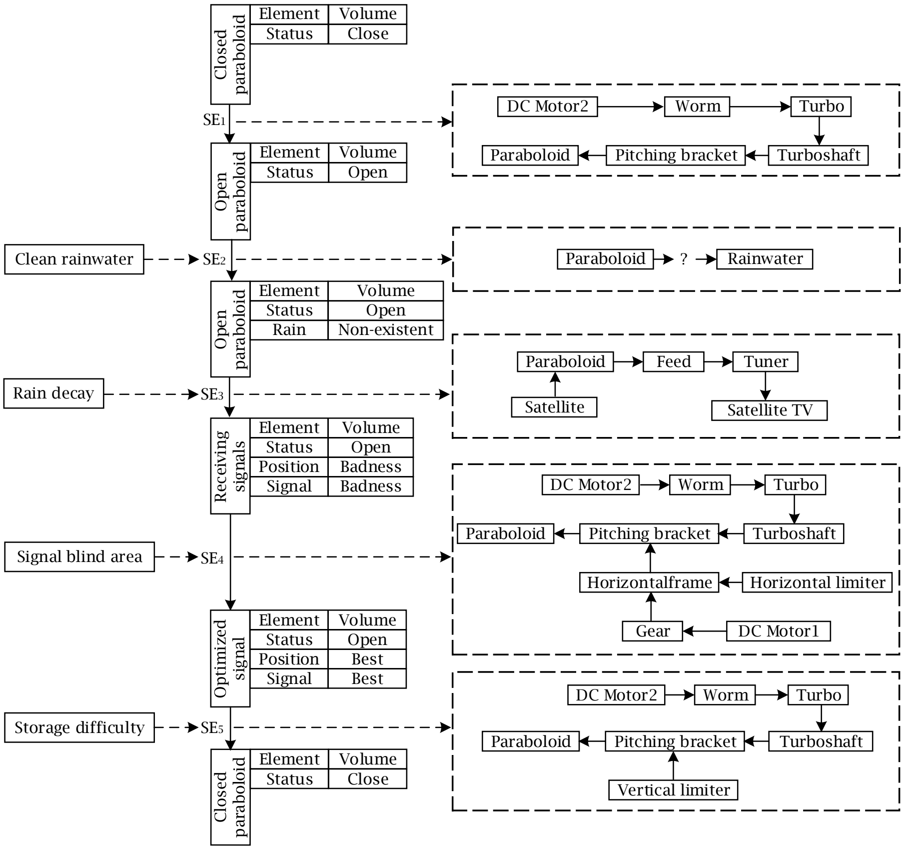

Fig. 5: Modeling of customer requirements for technical characteristics acquisition.

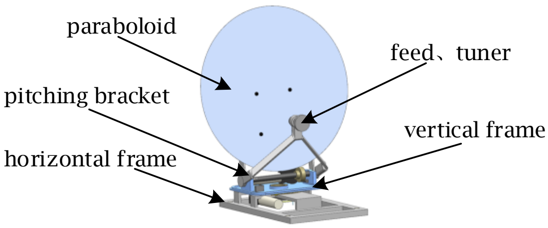

Fig. 6: Final innovative design solution.

A mixed-information type of evaluation method is adopted for the screening of innovative design solutions, which improves the singularity of the type of solution evaluation indicators after the fusion of QFD and TRIZ. Based on this, a hybrid model of the solution acquisition and evaluation is developed for product innovative design.

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