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A Novel Platform for Controlling Outsourcing Quality of a Complex Product

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***Abstract*—A complex product (Cop) is structurally complicated and highly integrated. It usually needs to order the global suppliers' components and realize final assembly. Therefore, quality management of outsourcing components plays an important role in improving the comprehensive quality level of complex products. To assist the main manufacturers of a complex product to comprehensively consider the demand for control measures, objectives, resources, and other aspects of the outsourcing quality management, a novel house framework for outsourcing quality was built. The framework consists of six modules, each of which performs different functions. The data requirements and characteristics involved in each module are analyzed in this paper, and the uncertain information in quality control are mined deeply. Finally, the operational flow of implementing the platform is proposed. This framework can furnish a new method and idea for the outsourcing quality control of a complex product.**

Keywords: quality control, supply chain management, quality house

I. INTRODUCTION

A complex product is a large-scale product or system with complex structure and high integration. It usually needs to order the global suppliers' components and realize final assembly [1]. Therefore, the quality competitiveness of complex products depends on the outsourcing quality level of the global supply chain, especially important components. In recent years, there are many serious quality issues caused by unsatisfied outsourcing quality, such as battery explosion of Samsung Note 7, the deadly crashes of Boeing 787, etc., which give warnings to the outsourcing quality control of manufacturing enterprises. As a category of manufacturing industry, complex products have stricter requirements on the outsourcing quality. In order to occupy a leading position in the fierce market competition, the main manufacturers of complex products need to consider the demand for external quality control measures, objectives, resources, etc., and improve the quality for the supply chain in producing a complex product under the constraints of limited resources.

However, the outsourcing quality control activities of complex products are extremely complicated. The main manufacturer should be aware that the quality importance of outsourcing components is different, in which some critical components should be considered in priority in quality strategy arrangement. Additionally, there are various outsourcing quality improvement solutions or projects that are related to each other with resources conflicts. What's more important, the relationship between outsourcing quality improvement and potential solutions are complicated as well. A systematic analysis framework for describing the relationship between them and making a reasonable evaluation and decision should be established from the perspective of global supply chain. Guidance from the framework, the main manufacturer can comprehensively design quality improvement plan and evaluate on the option of alternative quality improvement projects under limited quality improvement resources.

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Recently, many researchers have contributed to the domain of the supply chain control for complex products. Some typical aspects are given as below:

(1). Research on quality management methods of complex product. This field mainly refers to the design and application of quality management methods for complex products. Li Y P proposed a model for overall parameter design of the large complex product based on multi-participant collaborating [1]. Cynthia Akwei advocated the development of a quality management system consisting of two sub-processes of quality control and quality development [2]. To improve the closed loop control capability and collaboration of the quality problem, Duan G J put forward a quality problem processing model based on the zero-remains model in the development of complex products mode [3]. An J and Peng S X established a quality evaluation model of large complex products [4].

(2). Research on construction and application of improved quality house model. In recent years, scholars have developed traditional quality house model, which can analyze functional quality characteristics. Zhai L Y and Khoo L P proposed a novel extension to the fuzzy Quality Function Deployment (QFD) method based on rough set theory, and established a QFD-based expert system for product design [5]. Morteza Y and Cengiz K proposed a multi attribute decision support system, and provided a QFD platform for simplifying the decision-making process with Grey Relational Analysis (GRA) [6]. Fang H and Tan J R explored the customers' requirement regularities through grey sequence operators to deal with adverse influence from incomplete, uncertain and uncoordinated requirement information on QFD [7]. Li Z K, Feng Y X and Tan J R analyzed the dynamic characteristics of requirement information, and put forward a dynamic requirement analysis method in house of quality by integrating multi-attribute decision and trend prediction [8].

Throughout the relevant literatures, scholars have conducted much valuable research on various aspects. However, they mainly focused on dealing with the quality control activity independently and partially. There is a lack of comprehensive consideration on outsourcing quality plans, potential quality improvement projects, expected resources and effects, interrelationship between schemes and outsourcing quality. In practical work, a complex product quality control system should be a comprehensive system covering many departments and intersecting with work lines, other than the department of quality management only. Consequently, a systemic analysis framework needs to be built to integrate variable quality control information, such as quality level, quality weight, which can help the main manufacturer design reasonable quality improvement plans, comprehensively reflect the relationship between quality improvement projects, and integrate limited quality information for obtaining satisfied outsourcing quality improvement effect.

Based on the considerations above, this paper contributes for introducing a outsourcing quality control platform for complex products, house of outsourcing quality (HoOQ) which uses direct and symbolized house framework with marked labels. In Section 2, a house framework with six modules is established in which the specific functions are introduced. In Section 3, Data requirements and characteristics, such as fuzzy, paired sort and grey data, are explored which can provide decision support information and realize proposed functions. In Section 4, the operational flow of implementing the platform is proposed, which can assist the main manufacturer to make quality control decisions and complete resource allocation with determined quality plan.

II. House of Outsourcing Quality and Components Preliminaries

In order to reflect main outsourcing quality control activities and their complicated relationships, a novel framework HoOQ for controlling the outsourcing quality of a complex product is designed, which is shown in Fig. 1. It is improved based on the house of supply chain quality(HSCQ) proposed in [9]. Compared with the HSCQ, it can help the main manufacturer consider the demand comprehensively, handle the fuzzy quality information, and provide information support for decision makers.

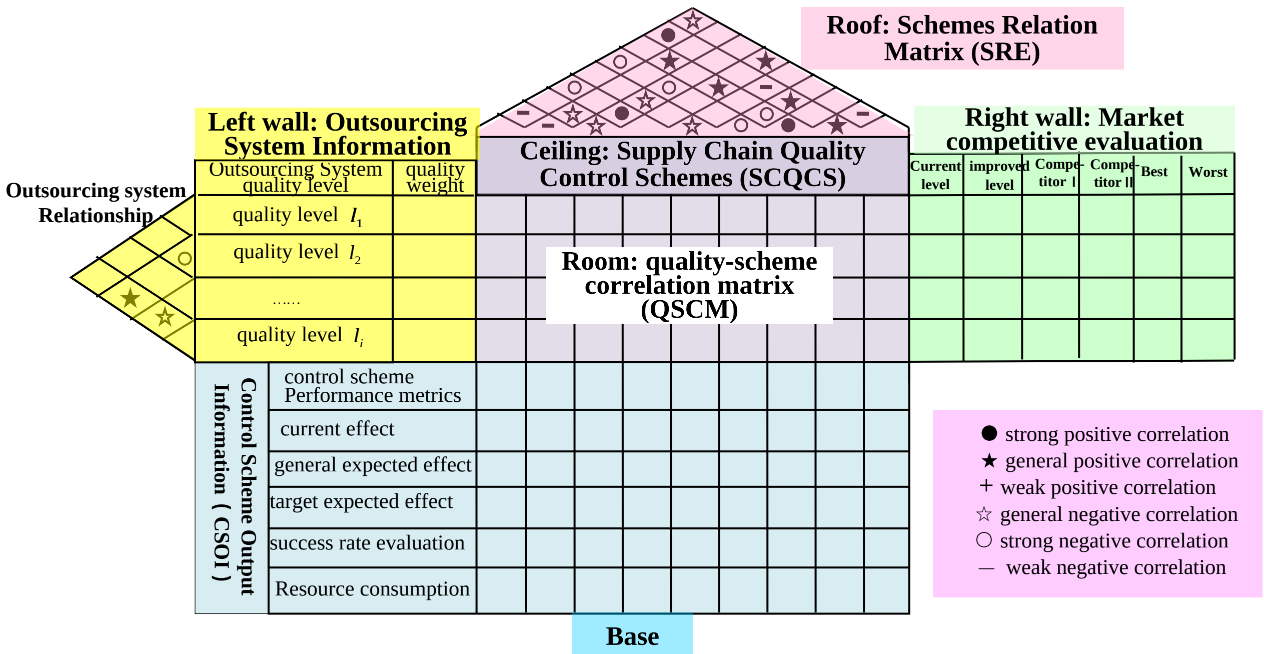

Fig. 1. HoOQ And its components.

The platform consists of six basic modules: left wall, ceiling, roof, room, right wall and base room. Further explanation and function analysis of the six modules are given as follows:

(1) The left wall module is used to describe the relevant quality information of the outsourcing system (OSI). Since many outsourcing systems may contribute differently to the final product, the weight of outsourcing system should be evaluated in the left wall, which can distinguish and evaluate the quality control priorities. The left wall module contains the quality management objects, their interact quality relationship and quality weights on final product. The quality correlation of the outsourcing system can be represented by a series of symbolic labels, which can then be quantified by the trapezoidal fuzzy numbers. The quality weights can be

determined by fuzzy analytical hierarchy process (FAHP), which is based on relative importance comparison and consistent check.

(2) The ceiling module represents supply chain quality control schemes (SCQCS), which contains various outsourcing quality control projects for selection, which are mainly from QC team or six sigma improvements. These outsourcing quality control schemes can be proposed by the quality control team and each scheme can be refined into sub-schemes from different aspects according to practical quality management requirements. In general, outsourcing quality control can be carried out from engineering technology and management measures, which is implemented as quality control programs.

(3) The roof module represents Schemes Relation Matrix (SRE), which is composed of the association information between the quality control schemes. The roof can present the relationship between the quality control schemes, which helps the quality control team to describe the mutual internal relationship between schemes and make comprehensive considerations. For the relationship of each two schemes, it can be represented by a series of symbolic labels, which can be quantified by the trapezoidal fuzzy numbers.

(4) The right wall module is mainly employed for market competitive evaluation (MCE), which can help the main manufacturer determine a proper outsourcing quality improvement plan. The current quality performances of each outsourcing system are presented in column, which is compared with domestic and foreign competitors' acceptable quality level. According to the comparison result, the current outsourcing quality competition can be obtained by the weighted effect and quality improvement plan can be developed by discovering the performance gaps of each outsourcing system. The competition evaluation can be analysed with Technique for Order Preference Similarity to Ideal Solution (TOPSIS) method based on fuzzy number. The fuzzy TOPSIS method is based on the fuzzy number representation of the different attribute evaluation values of each scheme, and is ranked according to the closeness of the evaluation object and the idealized target.

(5) The room module represents the quality-scheme correlation matrix (QSCM), which is determined by the correlation between the quality control scheme and the quality of the outsourcing system. According to the relationship between the control schemes and the outsourcing quality, the quality control team can select quality control schemes in a targeted manner. Similar to the roof, one can utilize the symbol to describe their relationships and quality them with trapezoidal fuzzy numbers.

(6) The base room module represents the control scheme output information (CSOI). The base room can be used to describe the comprehensive effect, current effect, general expected effect and target expected effect, success rate evaluation, resource consumption, target conversion and other information, which can provide decision information for the implementation of the quality control schemes. The Delphi technique can be used to evaluate the three effects as the most optimistic value (OD), the most pessimistic value (PD), the maximum possible value (HD). The comprehensive effect can be (OD +4HD + PD) /6 [10].

III. The Data Requirements and Characteristics

In the early design stage of complex products, house of outsourcing quality can help the main manufacturer effectively recognize, supervise and control the quality situations. However, due to the subjectivity and ambiguity of artificial judgment, the quality related information in the early design stage is mostly fuzzy and uncertain. For example, in the relationship analysis, the expressions of "strong relationship" and "weak relationship", as well as the expressions of the comparison in FAHP, are classified according to the data characteristics.

A. Fuzzy Relationship

In traditional house of quality, precise numbers are usually used to reflect the statistical relationships, such as "strong positive correlation" and "weak positive correlation". However, these expressions can neither completely reflect experts' actual judgements, nor effectively deal with the subjectively fuzzy appraisal information. For example, Likert scale with data range from 1 to 5 is used to indicate the quality correlation degree between two different outsourcing systems. If an expert selects 3 to express a relationship, his subjective appraisal is round 3 other than exact 3, which is a fuzzy and hesitant attitude. In the fuzzy environment, fuzzy sets theory is more effective to solve the problem. Therefore, the fuzzy numbers are introduced into HoOQ, in which fuzzy relations expressed in subjective appraisal can be presented and quantitatively described with more precise effect. In order to determine relational correlation matrices, experts can choose linguistic variables to describe six relationships by symbols in HoOQ. They are strong positive correlation ●, general positive correlation ★, weak positive correlation ＋, general negative correlation ☆, strong negative correlation ○, weak negative correlation −. Since linguistic variables are difficult to directly perform operations and processing such as addition, subtraction, multiplication, and division, this paper uses fuzzy sets to represent their appraisal preferences. Similar operation can also be utilized for calculating the weights. The most common fuzzy sets are triangular and trapezoidal forms. Triangular fuzzy number only considers the most pessimistic, most optimistic and most likely estimated values. The shape of the membership function is relatively simple but with good distinguished effect. Developing from triangular fuzzy set, the trapezoidal fuzzy number is more sensitive to reflect the uncertainty of the factors, which is recommended to represent subjective opinions with the left end point, the first center point, the second center point, and the right end point.

Assume that the language variable x of the nth category is subject to the membership function l , it can be written with $l_x : x \longrightarrow [0,1]$ indicates that x belongs to the membership of l . Let the expert review level be n , in the nth level, the membership of an element belonging to the language variable is r_n , then the membership parameter is $r_1, r_2, r_3 \cdots r_n$. According to the method proposed in [11], the membership parameter is represented by a trapezoidal form. Then the trapezoidal fuzzy set corresponding to the linguistic variable can be expressed as $(r_{n,1}, r_{n,2}, r_{n,3}, r_{n,4})$ related to four position points. Taking the linguistic variable "weak negative correlation" as an example, "weak negative correlation" belongs to the second category of the related relation linguistic variable, then the representation of the trapezoidal fuzzy set corresponding to the linguistic variable can be described as $(r_{2,1}, r_{2,2}, r_{2,3}, r_{2,4})$. Similarly, the membership of each rating for linguistic variables can be shown in Fig. 2.

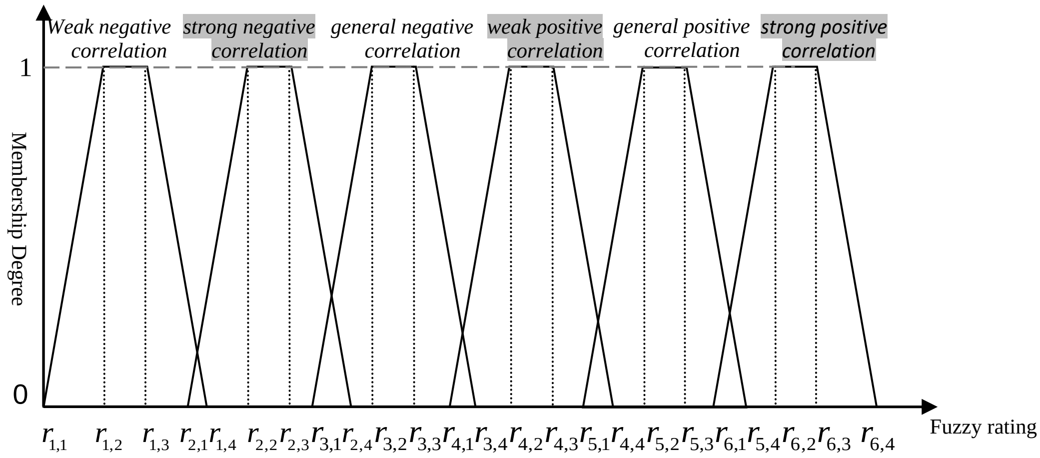

Fig. 2. Fuzzy rating and their membership functions to different linguistic variables.

B. Paired Sort Data

The Fuzzy analytic hierarchy process (FAHP) will be utilized to solve the quality weights, which can combine qualitative and quantitative information and make decisions in a simple way. According to the influencing factors and internal logical relationships of the quality level, a hierarchical analysis structure model is established in this paper, respectively:

Target layer: Quality evaluation of the outsourcing systems.

Criteria layer: Factors affecting the quality level of the outsourcing system.

Factor layer: The specific factors that affect the quality level.

Then, based on the analysis structure of each level, the experts compare the indicators of each layer with each other in the hierarchical analysis structure, and judges according to a certain scale criterion to give the score data. The importance of one factor relative to another is represented quantitatively, and an intuitionistic fuzzy judgment matrix is formed.

In order to quantitatively describe the relative importance of two factors under a certain criterion, corresponding evaluation criteria need to be defined. Firstly, according to the experience of experts, the relationship between the evaluation set and various influencing factors is determined; The evaluation statements are defined as: equally important, slightly important, obviously important, strongly important, extremely important, slightly unimportant, obviously unimportant, and strongly unimportant, then the corresponding scale for each definition is given. Due to the subjectivity and ambiguity of artificial judgment, precise numbers are difficult to reflect experts' actual judgments, and the subjectively fuzzy appraisal information. Therefore, the numerical scale is expressed as interval trapezoidal fuzzy number. Finally, the evaluation scales are obtained based on trapezoidal intuitionistic fuzzy numbers and its meaning according to historical data and experts' experience. Referring to the foregoing conversion rules, the evaluation trapezoidal fuzzy set corresponding to each evaluation sentence under the linguistic variable can be expressed as, $(r_{n,1}, r_{n,2}, r_{n,3}, r_{n,4})$, $n = 1,2,3,4,5,6,7.$

According to the numerical scale above, the factors can be compared in pairs, and the fuzzy judgment matrix can be obtained as follows:

$$A=\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

And the matrix A= $(a_{ij})_{n\times n}$ satisfies the definition: assuming that the elements in the fuzzy matrix A= $(a_{ij})_{n\times n}$ satisfy $a_{ij}+a_{ji}$ =1, the matrix A is called fuzzy Complementary matrix. From this, it can be judged that A= $(a_{ij})_{n\times n}$ is a fuzzy complementary judgment matrix.

C. Grey Number Data

In some traditional decision models, decision parameters are processed into exact numbers. However, due to the complexity of the social system and the limitations of human cognition, decision makers can hardly evaluate with precise numbers, but only give a range of decision intervals. Furthermore, during the implement of HoOQ, QFD team members can use pre-defined linguistic truth-values to express their views, definitions, and assessments. Since the boundaries of the linguistic truth-values are uncertain, not all elements in the fuzzy set have a fixed value. In some practical situations, it is not possible to directly define a viewpoint to a fixed value. Therefore, some elements that only know the approximate range are represented as grey numbers.

Since Professor Deng Julong proposed the grey system theory in 1982 [12], the relevant theory of grey number has been widely used in theory and practice. Among them, as the mark of the grey system, the grey number, the grey element and the grey relation are all features of the grey phenomenon. A number that contains incomplete information and only knows the approximate range without knowing its exact value is called grey number, which is a set of numbers, can be expressed as $\otimes$; the element with incomplete information is called grey element; and the grey relation refers to the relationship of incomplete information [13].

In the novel HoOQ proposed in this paper, the quality weights, the market competitive evaluation and the matrices of trapezoidal fuzzy criterion evaluation all involve such data, which can be represented as grey numbers. By analyzing the evaluation data given by experts in the corresponding fields, the boundary values of elements in the fuzzy sets can be obtained. First, the two factors are compared with each other in the judgement of quality weights. Then the scale with the trapezoidal intuitionistic fuzzy number is determined and the boundary value is represented with the grey number. The fuzzy TOPSIS method is used to solve the market competitive evaluation of quality level. According to the judgments made by experts on different schemes, a standard decision matrix represented by interval fuzzy numbers is established, and the boundary values of fuzzy numbers are represented as grey numbers. In addition, in the quality control scheme relation matrix or the quality-schema correlation matrix, the scales for the correlations can be expressed by grey numbers, such as strong positive correlation, general positive correlation, weak positive correlation, strong negative correlation, etc.

IV. The Implementation Process of HoOQ

The implementation of the Outsourcing Quality House framework can follow the following steps. The flow chart is shown in Fig. 3.

Step 1: Input the outsourcing system information into left wall. Fuzzy AHP can be utilized to calculate the weights of outsourcing system on the quality of final product.

Step 2: Analyze the fuzzy quality relationship between the outsourcing systems.

Step 3: Determine potential outsourcing quality control projects displayed on the ceiling.

Step 4: Describe the relationship between quality control schemes and the mutual interaction between quality levels and control schemes, which can be reflected by the form of correlation matrices shown in the roof and room.

Step 5: Conduct the comparison on the outsourcing quality performance of components between the main manufacturer and his main competitors. According to the difference, outsourcing quality plan can be made. Additionally, TOPSIS can be employed to evaluate the related competitiveness.

Step 6: Determine the control scheme output information in the basement, such as effects, success rate evaluation, resource consumption, and so on.

Step 7: Design quality improvement plan comprehensively and evaluate on the option of alternative quality improvement projects considering limited quality improvement resources under the guidance of the framework.

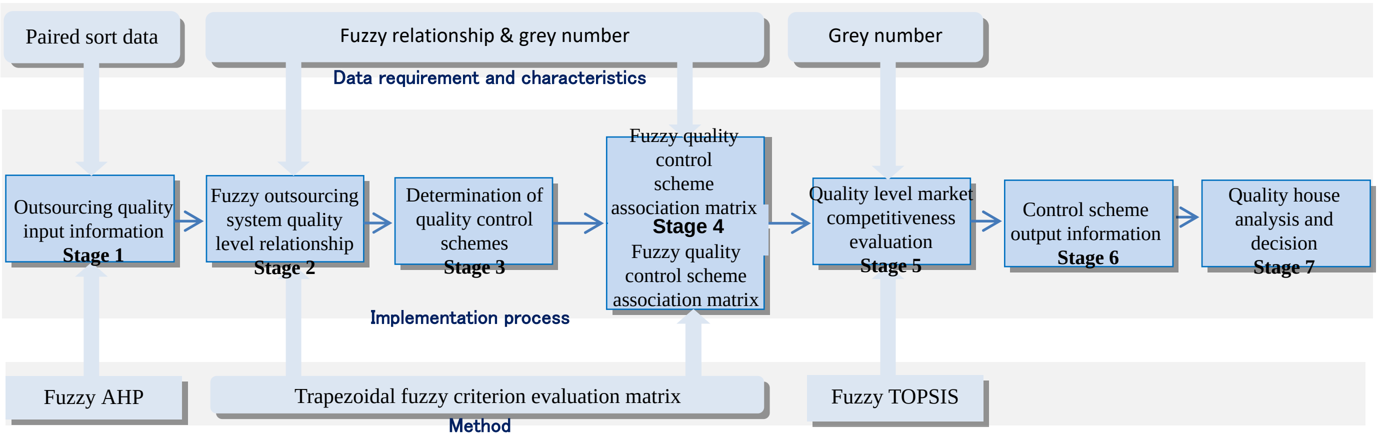

Fig. 3. The implementation process of the novel HoCQ.

V. Conclusions

Quality control of outsourcing system is the core issue in the field of quality management. However, the outsourcing quality control activities of complex products are extremely complicated; it is difficult for the main manufacturer to realize the quality improvement under the constraints of limited resources and to rationally allocate control resources. Insufficient processing of fuzzy information involved in the decision-making process cannot achieve satisfied control effects.

A novel house of outsourcing quality (HoOQ) are designed in this paper, which can help decision makers collect the information needed, determine every module of HoOQ and conduct quantitative analysis to provide decision support for outsourcing quality control. This paper not only provides a solution for the optimal quality control scheme under the constraints of limited resources, but also solves the problem of resource allocation after the scheme is determined. In addition, it also makes a practical and effective treatment for the conversion of subjective hesitating information to quantitative information, so as to achieve the optimal quality control effect.

Based on the quality data and related program information in the framework, how to select the appropriate combination of quality control schemes under resource constraints from a quantitative perspective to maximize the quality improvement effect is an urgent problem to be solved. This will be another valuable research work in the future.

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