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An Evaluation Approach to the Design Economics of Quality in Automobile Whole Life Cycle Using QFD, FEANP, and Multi-segment Goal Programming

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Abstract. Due to lack of comprehensiveness and consideration of customer requirements (CAs) in the design of economics of quality (EOQ) of automobile, we proposed a novel approach integrating quality function deployment (QFD), fuzzy extended analytic network process (FEANP) and multi-segment goal programming (MSGP) techniques to select automobile engineering characteristics (AECs) for designing EOQ in whole life cycle of automobiles (WLCA) to make up these drawbacks. In this paper, QFD is used to translate CAs into engineering characteristics of automobile and the impreciseness and vagueness with human judgments and information during the design process are handled by FEANP. The priorities of AECs with the consideration of the interrelationships between criteria are calculated by the framework of QFD incorporated with FEANP. In addition, a multi-segment goal programming (MSGP) model is formulated by considering the outcome from QFD-FEANP and other automobile goals to select AECs. Finally, a typical application is presented to show the advantage of the approach including the consideration of various automobile goals and the flexibility of setting multi-aspiration levels of evaluation criteria.

Keywords: automobile whole life cycles, economics of quality, fuzzy extended analytic network process, multi-segment goal programming, quality function deployment

1 Introduction

Economics of quality (EOQ) refers to the provision of satisfactory product quality for customers to obtain the most benefits for the least labour by Ovretveit [1] and focuses mainly on investments and costs, intended to address a number of important, popular and urgent economic problems [2], rather than attempting to quantify the benefits of improved quality in the market by Visawan, and it involves to the whole life cycle of products. EOQ in whole life cycles of automobiles (WLCA) has attracted substantial interest in recent years. Furthermore, the evidence that there is untapped potential for increasing profits if EOQ are researched and improved in automobile manufacturing industry was showed by Kenol [3]. The essence of EOQ in WLCA is to create value for customers, and to enhance customer satisfaction and loyalty, so as to expand market share, increase profits and create value for the relevant automobile manufacturing parties. In order to improve EOQ in WLCA, its design determines if the actual operations will ensure customer satisfaction and automobile manufacturing enterprise profits.

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The design of EOQ in WLCA includes three groups (manufacturers, distributors, and users), and are mainly reflected in comprehensive management of quality improvement and cost control, such as: design, manufacture, use, maintenance, and recycling: it is multi-object, multi-stage process. Research about EOQ in the automobile industry mainly focuses on one aspect only about its cost of quality, such as: automobile design, a related technology or a manufacturing process, etc. Ertay [4] aimed to study the basic product planning stage and Ju [5] proposed a cost reduction method in a car design stage. Lim used zero-one polynomial programming to minimize the expected total quality costs in the manufacturing stage [6]. These researchers have made a thorough investigation of quality or cost at their given stages of interest, but not to analysis EOQ in its essential significance: Ju used a reduction method for automobiles to reduce cost [5]; Omachonu examined the components of quality cost (internal failure, external failure, appraisal cost, and prevention cost) in the context of materials and machines to analyze the variable cost that impact quality [7]; Starkov identified economic criteria of production quality management and determined the methods of loss minimization [2]. Due to the limited resources being capital, time, and labour, which prompt enterprises to improve EOQ, these, therefore, are aimed at the community contradiction between the pursuits of self-interest, putting the benefit maximization of manufacturers and users as the goal to design EOQ in WLCA, but not have been integrated them from the study of existing literatures. Teli developed a knowledge management strategy to reduce the cost of quality for the automobile industry [8]. Amrina [9] proposed a set of initial key performance indicators for sustainable manufacturing evaluation believed to be appropriate to automotive companies. These researches gave an evaluation method for manufacturing industry from enterprise innovation mechanism, collaborative design scheme products and sustainable lean and green manufacturing performance by Yin [10], Guo [11] and Aminuddin [12]. Safety and price are the customers most important criteria for automobile selection after comparing the internal and external products was obtained by Yousefi [13]. Yun [14] established a set of evaluation model for measuring the service quality of automobile 4S stores to provide valuable benefits to enhance its service quality for customers. Research into the evaluation of different groups in the automobile industry [13-19], and customer satisfaction [13-14], only considered some aspects and lacked any integration with the design of EOQ in WLCA. In conclusion, these existing literatures have two drawbacks for EOQ in WLCA: these literatures considered the cost of quality on a process of production from manufacturing side, but not the whole life cycles of automobiles, and to analysis use cost or optimize cost of quality from separated groups (customers and manufacturers), failed to translate customer requirements (CAs, CAs refer to the customer goals, needs, desires and expectations determine whether the customer is satisfied. In the design of EOQ of WLCA, it aiming to meet CAs at a greater degree.) into the design system of EOQ in WLCA.

Based on analysis, a novel approach for designing EOQ in WLCA by integrating quality function deployment (QFD), fuzzy extended analytic network process (FEANP), and multi-segment goal programming (MSGP) was proposed to fill the gap. The design of EOQ in WLCA in this research comprehensive considered the most economic quality level of processes from production plan to scrap, and translated customer requirements into technical requirements for each stage of product development to integrate CAs and AECs by QFD [15]. Also the process has to deal with uncertainty, descriptive, and fuzzy, information by FEANP, which not only handles the epistemic uncertainty in human judgment, but also accounts for dependencies across all criteria. The next is to solve the selection of AECs for ECQ design by multi-segment goal programming (MSGP) [16], which is used to represent decision-making problems which contain multi-segment aspiration levels (MSAL) of evaluation criteria for selecting suitable AECs. The rest of this paper is organized as follows: Section 2 covers the theory behind QFD, FEANP, and MSGP, specific procedures are expounded in Section 3 to validate the proposed method, a numerical example is used to show its applications in Section 4, and conclusions are presented in Section 5.

2 Theoretical Background

2.1 The Fuzzy Extended Analytic Network Process and Its Application in QFD

The design of EOQ in WLCA needs to consider the interrelationship between CAs and AECs, and the interdependence and the relationship between CAs and AECs therein, therefore, the process has to deal with uncertainty, descriptive, and fuzzy, information.

QFD is a systematic method that provides a means of translating customer requirements into technical requirements for each stage of product development. In recent decades, QFD was adopted by the companies situated in many parts of the world [15]. It was applied while carrying out many activities which like product design, quality management, decision making and team building in various industries (manufacturing, construction and service) [17]. So far, several researchers published the outcome of QFD when it was applied in practice and reported several benefits of applying QFD. Therefore, QFD aids in improving product quality and reliability, reducing the product development lead time and designing customer friendly products.

A decision making problem in analytic network process (ANP) technique is modeled through a net structure and the interactions between factors during the modeling process, feedbacks between factor clusters and inside dependencies in factor clusters are being considered. In addition, as ANP is widely applied to various fields, many authors found its weak in dealing with ambiguous information or data. Even though people who make the comparisons are aware of the subject, their different perspectives may result in discrepancies on information. In order to eliminate this ambiguity, fuzzy logic methods have been utilizing possibility [19]. Fuzzy logic provides numerical information on the situation where there is no certainty, so it helps to get a more realistic result on defining the existence of a relation in between. Some researchers have applied the fuzzy ANP based approach to solve complex decision making problems and evaluations [18].

The integration approaches of QFD with related ANP method have been studied in many fields. Ertay [4] aims to implement of QFD with ANP to prioritize design requirements by taking into account the degree of the interdependence between the customer needs and design requirements and the inner dependence among them to study the basic product planning stage of a car design. Afsharkazemi [20] used an empirical study of QFD implementation when fuzzy numbers are used to handle the uncertainty associated with different components of the proposed model. A method of QFD and fuzzy analytic network process (FANP) is adopted to calculate the relative importance of engineering characteristics to design a green and low-carbon product by Lin [21]. Natee [22] proposed the knowledge-based decision support system QFD tool to design framework in the early stage. Sivasamy [17] conducted to study the characteristics of QFD with fuzzy logic, ANP and AHP. Although many approaches are available, some problems still exist. For example, existing methods are unable to address the dependencies among the attributes while in practical applications, expensive computation, questionable idempotency requirement and so on, so Zhang [19] proposed FENAP method which is a more general and efficiency framework. In the method, triangular fuzzy numbers (TFNs) are applied to construct pairwise comparison matrices according to the linguistic comparisons benchmarked by the experts. According to ANP, FENAP formulate a supermatrix composed by the weights of the corresponding attribute. After its convergence, the weight associated with each attribute can be obtained, providing a natural way of dealing with problems in which the source of imprecision is the absence of a sharply defined criterion of class membership. These main literature reviews being reported here was begun by validating the existing researches, which is enumerated in Table 1.

Table 1. Representative literatures on existing researches of QFD and FEANP

items	methods	literature sources	merits and drawbacks
1	Data envelopment analysis and fuzzy mathematics computing model	Yousefi (2010) [13] and Yin (2013) [10]	These papers used AHP 、fuzzy theory 、and many other methods to solve the problem of comprehensive evaluation and decision-making in the manufacturing industry. They failed to take customer requirements into consideration.
2	Fuzzy and comprehensive evaluation	Guo (2012) [11]	
3	ANP	Aminuddin (2014) [12]	
4	QFD and ANP	Ertay (2005) [4]	More researchers used QFD to translate customer needs into design, with the methods of ANP or AHP. With the appearance of FANP and FAHP, they integrated them together to handle uncertainly information.
5	QFD and FANP	Afsharkazemi (2012) [20]	
6	QFD, FANP and goal programming	Lin (2015) [21]	
7	QFD and knowledge-based decision support system	Natee (2016) [22]	
8	QFD, fuzzy logic, ANP and AHP	Sivasamy (2016) [17]	
9	Fuzzy extended analytic network process	Zhang (2015) [19]	FEANP address both the uncertain information involved and the interrelationships among the attributes.

As is shown in Table 1, from the summaries of merits and drawbacks, QFD should be used to design the EOQ in WLCA, because these studies failed to take customer requirements into consideration. This paper used QFD as a method for satisfying customers by translating their demands into design targets and quality assurance points, and uses ANP, to be used with QFD, to optimize the result. There are many available approaches to solve complex decision-making problems, but these existing methods are unable to address the dependencies among attributes in practical applications and suffer from expensive computational demand; questionable idempotency requirements, etc. The implication of the FENAP method is twofold. First, FENAP can handle the epistemic uncertainty during the evaluation making process. For example, experts' judgments and preferences on the alternatives might be uncertain because the evaluation criteria are subjective and qualitative in nature. Second, by accounting for the dependencies across the criteria, FENAP is quite general and applicable because of dependencies are quite common in many real-world problems. Therefore, in order to take the impreciseness and vagueness in human judgments and information into account, FENAP is applied in the QFD.

In this section, a comparison of literatures about methods of translating customer needs into design and handling vague or incomplete in the inherent uncertainty and imprecision of expert's perception are analyzed and listed. This paper proposed to integrate QFD with FEANP based on these studies and analysis, and briefly introductions of major process and integration concepts of QFD-FEANP was offered in the next contents.

2.2 Multi-segment Goal Programming

Meanwhile, the method QFD-FEANP cannot satisfied the design of EOQ in WLCA, which is a multi-objective 、multi-segment process. Multi-objective programming, known as multi-criteria or multi-attribute optimization, is the process of simultaneously optimizing two or more conflicting objectives [23]. Goal programming (GP) is one of the most powerful methods of multiple objective optimizations and has been widely applied to solve various decision-making problems, when the decision makers aim to minimize the deviation between the achievement of goals and their aspiration levels.

The achievement function that represents a mathematical expression of the unwanted deviation variables is the key element of a GP model, and many methods have had been proposed, such as: weighted GP, fuzzy GP, and multi-choice GP. Although these functions offer a simple concept for the vague phenomena in goal levels, the important area of decision variables coefficients analysis (e.g., the different contribution levels of decision variable coefficients, or multi-segment aspiration levels) is still open, these problems cannot be solved using a traditional GP approach when MSAL exist, such as "something more/higher is better" or "something less/lower is better". Regarding this matter, Liao [16] proposed MSGP method to solve the MSAL problems in which decision makers can set multiple aspiration levels for each segment level. MSGP simultaneously takes many objectives into account while the decision-making algorithm seeks the best solution from a set of feasible solutions derived from goal programming [14]. MSGP just solve whether the criteria should be selected, but for analyze it fatherly, none exploring the specific situation of its impaction on the target value. Because criteria weights are critical determinants of the final ranking of research alternatives, a sensitivity analysis can be used to examine the stability of the rank order under different weighting schemes from vagueness and ambiguity of decision makers. MSGP can handle multiple objectives and minimizes the total deviation from the desired goals, and researchers integrated the other methods of FANP [24], which is used to obtain priority weights of criteria, with GP to select the best strategy because many criteria may conflict with each other which makes the decision making process complicated. Therefore, a model based on QFD-FEANP and MSGP to help decision-makers select the automobile engineering characteristics is proposed in this paper.

3 The Proposed Approach

For determining the optimal level of an automobile's EOQ based on customer requirements, QFD formed the framework for calculating the priorities of all criteria. In addition, for the outcome of the FANP-QFD analysis, there may be other goals that must be considered simultaneously in selecting the AECs. The proposed approach is detailed below.

3.1 Define the Unstructured Problem

The design of EOQ in WLCA should be stated clearly and be put in a broad context from product planning and design to environmental protection and recycling. The focus [13-14] have been on social, technical, economic, volume, shape, elegance, harmony, simplicity, comfort, attractiveness, and others to analyze user satisfaction from a customer perspective. In contrast, from an automobile manufacturer's perspective, it refers to the following of environmental protection rules, decreasing fuel consumption, creating new techniques, and improving product quality with regard to elegance, convenience, applicability, and service quality [9-12]; however, these factors only consider the one aspect of quality or cost and fail to integrate them. The automobile industry can-not only take some measures but ignore their economic benefit so they employed economic benefit analysis to measure whether, or not, such actions should be adopted in practice. In the present work, the criteria were de-noted by quality factors, meanwhile, the economic factors to also be considered were included among the criteria, and were defined as the CRs and AECs by engineers and experts (Table 2 and Table 3, respectively).

Table 2. Definition of customer requirements

CRs	Definition
Quality	Satisfying the basic parameters of vehicle travel, including different system operation situations
Security	Capability to avoid accidents and ensure the safety of all passengers and drivers
Economy	Capability to minimize payment *per* unit mileage
Handling	The degree of difference between the handling results (steering, braking, throttle, and the envisioned purpose of drivers due to vehicle problems or external factors emerging during driving)
After-sales service	After a customer order, all related services are to be provided for customer
Comfort	Capability to provide a comfortable, safe environment for drivers and passengers
Configuration of exterior/interior	The related parts should ensure: good condition, connecting and fastening parts work, defect-free parts, complete functionality, and satisfaction of user demand
Individuality demand	Comprehensive work to satisfy the demands of personalized needs

Table 3. Definition of automobile engineering characteristics

AECs	Definition
Rationality of product planning and design	EOQ of putting forward overall design scheme to provide vehicle parameters and design requirements for every component design
Evaluation accuracy	The difference between evaluation reports of the automobile and actual situations
Procurement	Match of purchasing quality and related total cost
Production	Match of quality and total cost in production
Reliability of vehicle assembly	EOQ of completing the required function under the specified conditions and in the stipulated time
Facilitation of sales plan	Influence of sales volume by sales plan implemented according to its cost
Order-to-delivery	Time from placing orders to delivery according to the cost thereof
Service	Difference between inputs and overall benefits it brings
Customer relationship management	EOQ to establish and maintain a valuable customer relationship by passing customer value tests
Reliability	EOQ to quality aspects
Operation stability	EOQ of performance to resist interference and remain stable under normal circumstances
Durability	Reaching limit wear values before the deadlines according to the cost thereof
Social	Efficiency, protection of the environment, and recycling
Innovation	Match of efficiency and cost input

In this step, the experts only needed to confirm whether, or not, there was interdependence or any inter-relationship between the factors, and the degree of importance was assessed by analysis of responses to a questionnaire. Accordingly, the house of quality (HOQ), which is an effective method of defining those necessary technologies that will satisfy CRs, is constructed by QFD process. The CRs and

AECs are listed in Fig. 1, then the inter-dependence among CRs, among AECs$\left(T_{kj}\right)$, and the inter-relationships $\left(R_{ij}\right)$ between CRs and AECs are found and the priority $\left(RI_j\right)$ and targets $\left(RI_j^*\right)$ of AECs can be found from:

$$RI_j = \sum_{i=1}^{n} w_i \otimes R_{ij} \ , \ j = 1,2,\cdots,m \tag{1}$$

where R_{ij} in the matrix represents the relationship between the j^{th} AECs and the i^{th} CRs. then, RI_j^* can be obtained as:

$$RI_j^* = RI_j \oplus \sum_{k=j} T_{kj} \otimes RI_k \ , j = 1,2,\cdots,m \tag{2}$$

where T_{kj} , $j, k = 1,2,\cdots,m, k \neq j$, in the matrix represent the correlation between the k^{th} and j^{th} AECs.

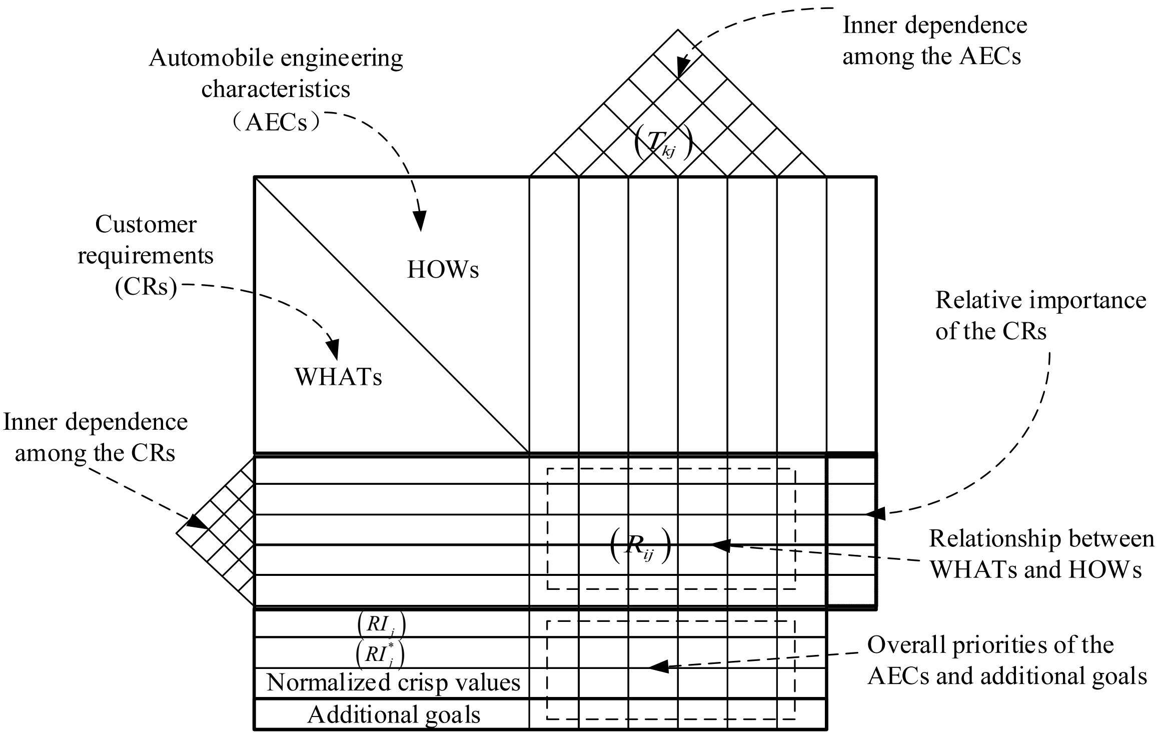


Fig. 1. HOQ- automobile engineering application

The design problem is decomposed into a rational system such as a network. A QFD network is then constructed based on the HOQ, and a general form thereof is shown in Fig. 2.

3.2 Priority Calculation given Different Goals

Formulate the questionnaire and construct the pair-wise comparison matrix. Based on the relationships between elements, and the QFD network constructed in Section 3.1, a questionnaire was formulated for the pair-wise comparison of the elements. The linguistic variables of this pair-wise comparison of each part of the committee members' opinions were collected and transformed into triangular fuzzy numbers based on Table 4. For example, with pair-wise comparison of CRs with respect to the overall objective, a matrix ($\tilde{A}_k$) for expert k can be obtained:

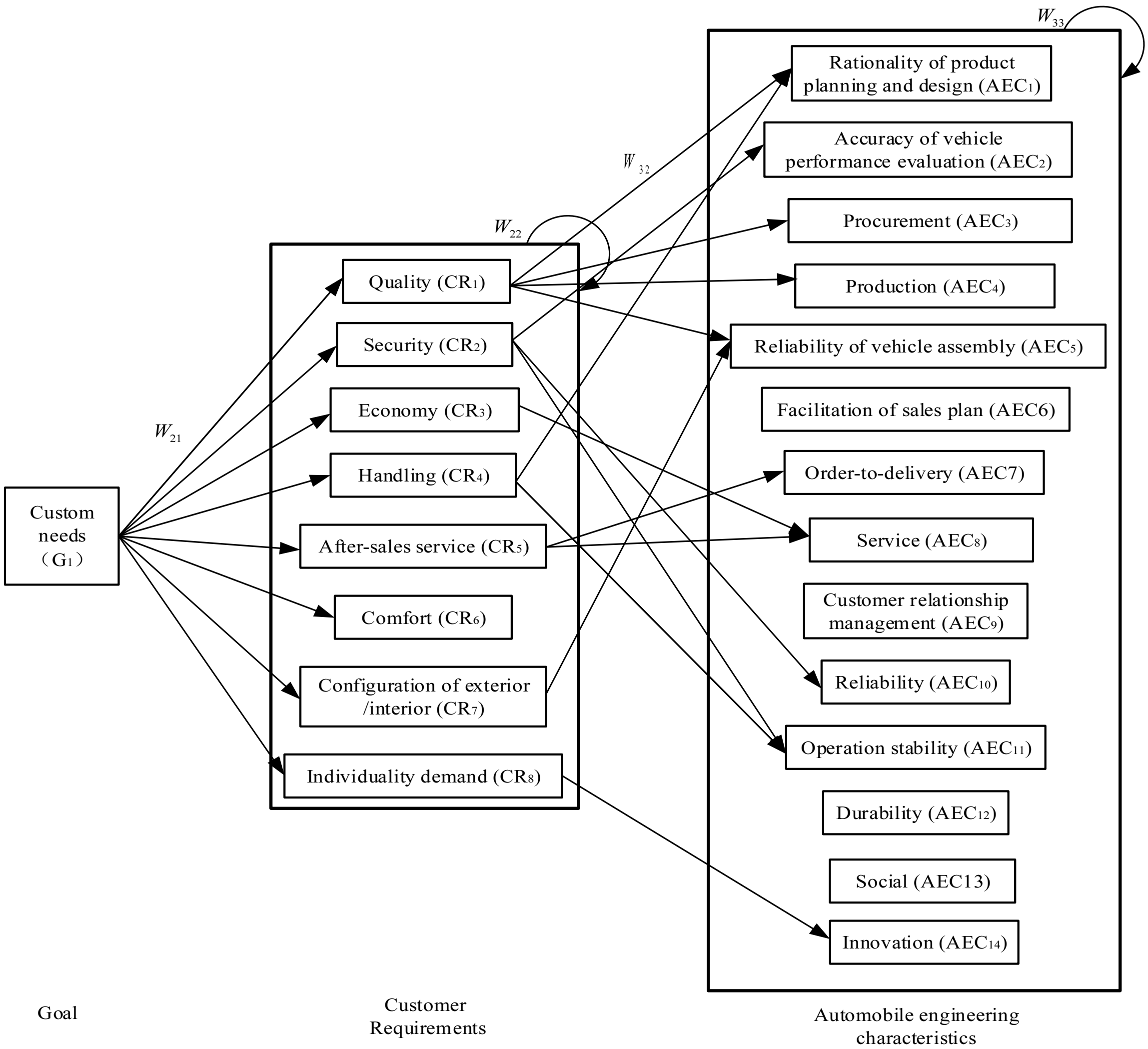


Fig. 2. A network structure for evaluation to EOQ in WLCA

$$\tilde{A}_k = \begin{array}{c} \\ CA_1 \\ CA_2 \\ \vdots \\ CA_m \end{array} \begin{array}{c} \begin{array}{cccc} CA_1 & CA_2 & \cdots & CA_m \end{array} \\ \begin{bmatrix} 1 & \tilde{a}_{12k} & \cdots & \tilde{a}_{1mk} \\ 1/\tilde{a}_{12k} & 1 & \cdots & \tilde{a}_{2mk} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1mk} & 1/\tilde{a}_{2mk} & \cdots & 1 \end{bmatrix} \end{array}$$

where m is the number of CRs.

Table 4. Definition of automobile engineering characteristics

Linguistic variables	Positive TFNs	Positive reciprocal TFNs	Linguistic variables	Positive TFNs	Positive reciprocal TFNs
Equally important	(1, 1, 1)	(1, 1, 1)	Important	(3, 5, 7)	(1/7, 1/5, 1/3)
Weakly important	(1, 1, 3)	(1/3, 1, 1)	Very important	(5, 7, 9)	(1/9, 1/7, 1/5)
Moderately important	(1, 3, 5)	(1/5, 1/3, 1)	Extremely important	(7, 9, 9)	(1/9, 1/9, 1/7)

Aggregate expert opinions and build aggregated pair-wise comparison matrices. If there were k members, a total of k sets of pair-wise comparison matrices should be available. Let A represent a fuzzy aggregated pair-wise comparison matrix that can be expressed as:

$$\tilde{A}=\left[\tilde{a}_{ij}\right]=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1\end{bmatrix}, i,j=1,2,\cdots,n$$

then triangular fuzzy number $\tilde{a}_{ij}$ can be obtained by combining all expert opinions,

$$\tilde{a}_{ij}=\left(m_{ij}^{-},m_{ij},m_{ij}^{+}\right) \quad \textbf{(3)}$$

where $m_{ij}^{-}=\sqrt[k]{\prod_{k=1}^{k}x_{ijk}^{-}}$, $m_{ij}=\sqrt[k]{\prod_{k=1}^{k}x_{ijk}}$, $m_{ij}^{+}=\sqrt[k]{\prod_{k=1}^{k}x_{ijk}^{+}}$, and $\left(x_{ijk}^{-},x_{ijk},x_{ijk}^{+}\right)$ is the importance weight from expert k , and $i,j=1,2,\cdots,n$.

The relative importance weights (priority vectors) for CRs can be obtained using FEANP. After normalizing w_i' , the normalized weight vectors of CRs are w_i . The following briefly introduces the major process and integration of QFD-FEANP related thereto according to existing researches [17, 19]:

Let $X=\{x_1,x_2,\cdots,x_n\}$ be an object set, and $U=\{u_1,u_2,\cdots,u_n\}$ be an objective set: each object is taken and subjected to extent analysis for each goal, g_i. Therefore, m extent analysis values for each object can be obtained, with the following signs: $M_{gi}^{1},M_{gi}^{2},\cdots,M_{gi}^{m},i=1,2,\cdots,n$, where all $M_{gi}^{j}(j=1,2,\cdots,m)$ are triangular fuzzy numbers.

The value of fuzzy synthetic extent with respect to the i^{th} object is defined thus:

(1) Experts with three different careers are required to fill in survey sheets. The dissimilarity of the survey data has represented different opinions and thus has allowed a conclusion to be drawn which included a wide view of the network structure.

(2) The fuzzy synthetic extent value (S_i) with respect to the i^{th} object is defined as:

$$S_i=\sum_{j=1}^{m}M_{gi}^{j}\otimes\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M_{gi}^{j}\right]^{-1}, i=1,2,\cdots,n \quad \textbf{(4)}$$

To obtain $\sum_{j=1}^{m}M_{gi}^{j}$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m}M_{gi}^{j}=\left(\sum_{j=1}^{m}n_{1j},\sum_{j=1}^{m}n_{2j},\sum_{j=1}^{m}n_{3j}\right), i=1,2,\cdots,n \quad \textbf{(5)}$$

To obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M_{gi}^{j}\right]^{-1}$, perform the fuzzy addition operation of M_{gi}^{j} ($j=1,2,\cdots,m$) values such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m}M_{gi}^{j}=\left(\sum_{i=1}^{n}n_{1i},\sum_{i=1}^{n}n_{2i},\sum_{i=1}^{n}n_{3i}\right),(j=1,2,\cdots,m) \quad \textbf{(6)}$$

(3) Two triangular fuzzy numbers can be defined as: $M_1\left(m_1^{-},m_1,m_1^{+}\right)$ and $M_2\left(m_2^{-},m_2,m_2^{+}\right)$. As $M_1\left(m_1^{-},m_1,m_1^{+}\right)$ and $M_2\left(m_2^{-},m_2,m_2^{+}\right)$ are two triangular fuzzy numbers, the degree of $M_1\left(m_1^{-},m_1,m_1^{+}\right)\geq M_2\left(m_2^{-},m_2,m_2^{+}\right)$, the ordinate of the highest intersection point can be calculated as:

$$V\left(M_2\geq M_1\right)=hgt\left(M_1\cap M_2\right)=\mu\left(d\right)=\frac{m_1^{-}-m_2^{+}}{\left(m_2-m_2^{+}\right)-\left(m_1-m_1^{-}\right)} \quad \textbf{(7)}$$

for comparison of M_1 and M_2 , both the values of $V\left(M_1\geq M_2\right)$ and $V\left(M_2\geq M_1\right)$ are required.

(4) The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers

$S_i(i=1,2,\cdots,k)$ can be defined by:

$$V\left(S \geq S_1, S_2, \cdots, S_k\right)=V\left[\left(S \geq S_1\right) ve\left(S \geq S_2\right)\ and \cdots and\left(S \geq S_k\right)\right]=\min V\left(S \geq S_i\right)\ i=1,2,\cdots,k . \quad \mathbf{(8)}$$

Assume

$$d'\left(A_i\right)=\min V\left(S_i \geq S_k\right), \text{ for } k=1,2,\cdots,n ;\ k \neq i , \quad \mathbf{(9)}$$

Then the weight vector is given by:

$$W'=\left(d'\left(A_1\right), d'\left(A_2\right), \cdots, d'\left(A_n\right)\right)^T \quad \mathbf{(10)}$$

where $A_i(i=1,2,\cdots,n)$ are n elements.

(5) By normalization, the normalized weight vectors are:

$$W=\left(d\left(A_1\right), d\left(A_2\right), \cdots, d\left(A_n\right)\right)^T \quad \mathbf{(11)}$$

where W is a non-fuzzy number and this gives the priority weights of one alternative over another.

In this way, although they are represented by triangular fuzzy numbers, the weights of the criteria at different levels can be obtained.

The general network representation of the QFD model is shown in Fig. 3. Where W_1 is a vector on the CRs that expresses the impact of the goal, namely that the product satisfies the customer; W_2 is an outer dependency matrix including the column eigenvectors with respect to each CR; W_3 and W_4 are the inner dependency matrices of the CRs and AECs, respectively.

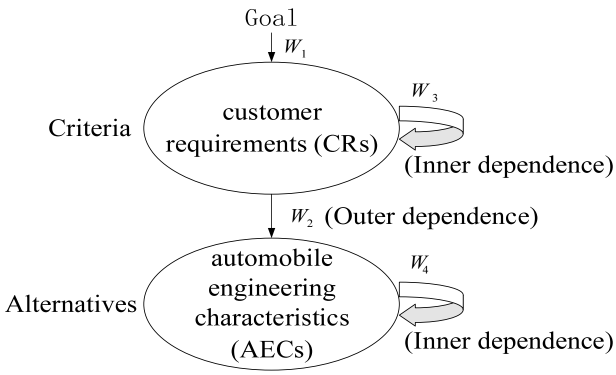


Fig. 3. Network representation of the HOQ model

Super-matrix formulation. The super-matrix denotes the interdependencies that exist among the elements of a system. To obtain global priorities with interdependent influences, the super-matrix was constructed from the pair-wise comparison matrices of these interdependencies. From Fig. 4 to Fig. 6, and the super-matrix representation of the QFD model, a super-matrix (before convergence) may be given by:

$$M=\begin{array}{c} \\ G \\ \text{CR} \\ \text{AEC} \end{array}\begin{array}{c} \begin{array}{ccc} G & \text{CR} & \text{AEC} \end{array} \\ \left[\begin{array}{ccc} \text{I} & & \\ W_{21} & W_{22} & \\ & W_{32} & W_{33} \end{array}\right] \end{array}$$

where W_{21} is a vector that denotes the impact of the goal on CRs, W_{32} is a matrix that denotes the impact of CRs on AECs, W_{22} represents the interdependency of CRs, W_{33} represents the interdependency of ECs, I is the identity matrix, and entries of zero denote elements of no influence.

Make the super-matrix converge. The supermatrix is raised to the power of $2\rho+1$ to achieve convergence of the importance weights, where ρ is an arbitrarily large number, the super-matrix will then converging to a stable value. The priority weights of AECs can be found in the AEC-to-goal block, *i.e*. block (3, 1).

Obtain the priorities of additional goals. In this step, MSGP can be incorporated to consider other automobile goals, such as cost, ability, and time. These goals help in determining priorities and directions for improvement. Comparing goals pair-wise with regard to their contributions optimizes the ultimate goal of this QFD problem and also comparing AECs pair-wise with respect to each additional goal as identified by prepared questionnaire is useful here. Expert opinions are collected, and the priority weights of goals (w_g) and of ECs (e_{gv}) with respect to each additional goal are acquired.

3.3 Construct the MSGP Model by Use of a Sensitivity Analysis

Although the aforementioned model can be solved quite efficiently when the model size is moderate, with multiplication terms of binary variables, it becomes difficult to implement when the problem size increases. Adding upper ($s_{ij}^{\max}$) and lower ($s_{ij}^{\min}$) bounds for the i^{th} aspiration level and y_i as a continuous variable, such that $s_{ij}^{\max} \le y_i \le s_{ij}^{\min}$.

The objective function and constraints of MSGP were as follows:

$$\text{Min} \quad S=\sum_{i=1}^{n} w_i\left(\left(d_i^+ + d_i^-\right)+\left(e_i^+ + e_i^-\right)\right) \tag{12}$$

$$\text{s.t.} \quad \sum_{j=1}^{m} s_{ij}B_{ij}\left(b\right)\cdot x_i + d_i^+ - d_i^- = g_i \tag{13}$$

$$1/L_i\left(b_i s_{ij}^{\max} + (1-b_i)s_{ij}^{\min}\right) - e_i^+ + e_i^- = 1 + i/L_i\left(s_{ij}^{\max}\, or\ s_{ij}^{\min}\right) \tag{14}$$

$$L_i = s_{ij}^{\max} - s_{ij}^{\min} \tag{15}$$

$$s_{ij}B_{ij}\left(b\right) \in R_i\left(x\right) \tag{16}$$

$$b_i \in \{0,1\},\ d_i^+, d_i^-, e_i^+, e_i^- \ge 0,\ X \in F\ (F \text{ is a feasible set}) \tag{17}$$

where e_i^+ and e_i^- are the positive and negative deviations, $i=1,2,\cdots,n$ and $j=1,2,\cdots,m$; $f_i\left(x\right)$ is the goal function, w_i represents the weight attached to the deviation and d_i is the positive, or negative, deviation from the target value g_i ; $d_i^+ = \max(0, f_i\left(x\right) - g_i)$ and $d_i^- = \max(0, g_i - f_i\left(x\right))$, represent under- and over-achievements of the i^{th} goal, respectively; s_{ij} is a variable coefficient that represents the MSAL of the j^{th} segment of the i^{th} goal; $B_{ij}\left(b\right)$ represents a function of a binary serial number, and $R_i\left(x\right)$ is the function of resource limitations. Meanwhile, in the current work, the MSGP model needed to be modified to one of the following two alternative types:

(1) Something more/higher is better in the aspiration levels (maximization of $B_{ij}\left(b\right)$), the flexible membership function segment with an aspired level of 1 was used as follows:

$$\left(s_{ij}B_{ij}\left(b\right) - s_{ij}^{\min}\right)\Big/\left(s_{ij}^{\max} - s_{ij}^{\min}\right) + d_i^+ - d_i^- = 1 \tag{18}$$

(2) Something less/lower is better in the aspiration levels (minimization of $B_{ij}\left(b\right)$), the flexible

membership function segment with an aspired level of 1 was used as follows:

$$\left(s_{ij}^{\max} - s_{ij}B_{ij}\left(b\right)\right) \Big/ \left(s_{ij}^{\max} - s_{ij}^{\min}\right) + d_i^{+} - d_i^{-} = 1 \quad \textbf{(19)}$$

These functions can then be denoted as the set of benefit criteria (*i.e.*, QFD-FEANP, ease of manufacturing, *etc*.) or the set of cost criteria, as applied in this work. In addition, to test the stability of the priority ranking under unique answers and explore the specific impact on the goals, a sensitivity test was applied.

Aimed at characteristic of the design EOQ in WLCA, which is whole life cycle, customer needs, vague or incomplete in the inherent uncertainty and imprecision of experts' perception, multi-objective and multi-segment, this paper arranged the existing researches to list the AECs, used QFD to translate customer requirements into design system, integrated QFD with FEANP to calculate the priority of criterion given different goals, and utilized MSGP to select AECs.

4 Numerical Example

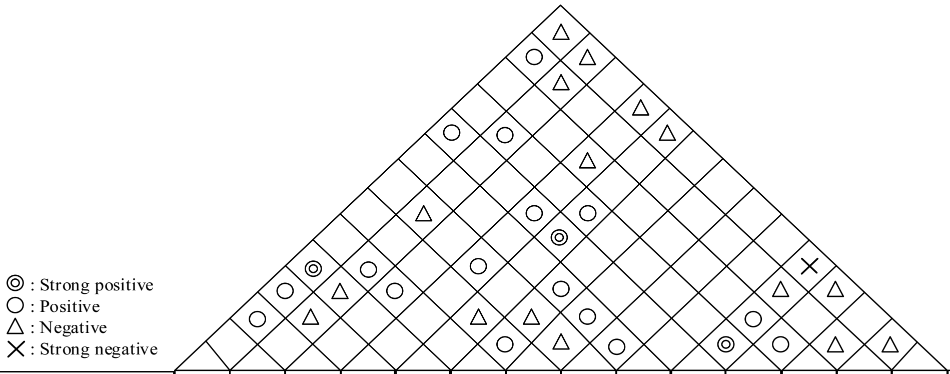
4.1 Numerical Example Description

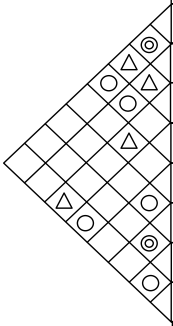
Experts and engineers were asked to determine whether, or not, there was any inter-dependence among CRs, among AECs, and the inter-relationship between each CR and AEC on a four-point scale: they were asked to complete a questionnaire based on the pair-wise comparison of elements based on Table 4. Based on the formed HOQ (Fig. 1) and constructed QFD network (see Fig. 2), FEANP was applied to calculate the relative priorities (Section 3.2) as shown in Fig. 4.

Since the objective was to maximize satisfaction levels regarding automobile engineering between CRs and AECs, the QFD-FEANP (G_1) was the major goal. The unweighted super-matrix was transformed into a weighted super-matrix. The weighted super-matrix was raised to certain powers to capture all the interactions and to obtain a steady-state outcome. The long-term stable values of the limit super-matrix were calculated. The priority weights of the AECs can be found in the (3, 1) block of the limit super-matrix (see Fig. 4). WLCA cost (G_2) refers to the total process cost of automobile engineering actions that may be incurred while developing a specific AEC. Manufacturability (G_3) is the expected ability to manufacture an automobile with the specific AEC. TLCOA time (G_4) is the time that may be required to develop a specific AEC. Technological advances (G_5) indicate the technological benefits that can be obtained from developing a specific AEC. By applying the FEANP method, the priority weights of AECs with respect to automobile engineering goals (G_2 to G_5) can be obtained, and the results are shown in the bottom four rows of Fig. 4. Similarly, the priorities of the goals of QFD-FEANP, WLCA cost, manufacturability, WLCA time, and technological advances were 0.223, 0.203, 0.071, 0.314, and 0.189, respectively.

In order to validate the advantage of the proposed approach QFD-FEANP, Fig. 5 presents calculation results comparing with Ertay's method (QFD-ANP) [4]. From Fig. 5, the interdependencies play an important role in the calculation of priority weight can be found. The priority weight for AEC1 is 0.114, which is 0.0132 more than the result of QFD-ANP. Also, the weights for other AECs are also different from that of QFD-ANP. The differences of the results between the proposed method and QFD-ANP reflect the role that the interdependencies are playing in the model. It can be seen that there is a 13.2 % level of combined interdependencies in the priority weights for AEC_1, and other AECs. Therefore, the advantage of the FEANP is the control given to the decision makers. The TFNs express the uncertain information efficiently. Both the uncertain information and the interdependencies are taken into consideration in the model by applying FEANP in this paper.

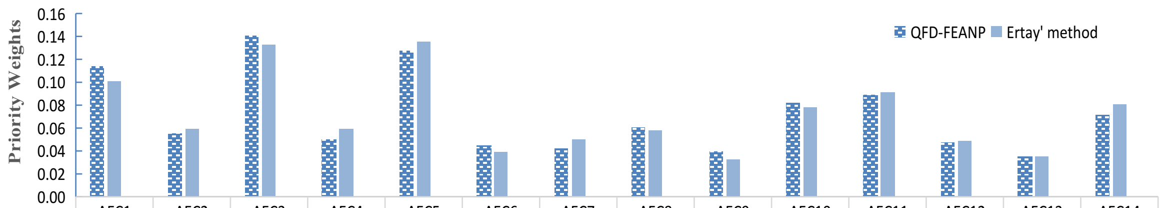
An evaluation of the MSGP model for the EOQ in WLCA was then set by using Equations (12) to (19). According to automobile cost records in the last five years, an automobile budget is typically between $6,250 and $8,000 (USD); however, considering business strategy, managers in the automobile industry want to create a balance between quality and cost, namely, they want to realize the lowest cost consistent with the premise of guaranteed quality, and to satisfy customers as much as possible, which could be denoted as follows:





Customer requirements (CRs) \ Automobile engineering characteristics (AECs)	Rationality of product planning and design (AEC_1)	Accuracy of vehicle performance evaluation (AEC_2)	Procurement (AEC_3)	Production (AEC_4)	Reliability of vehicle assembly (AEC_5)	Facilitation of sales plan (AEC6)	Order-to-delivery (AEC7)	Service (AEC_8)	Customer relationship management (AEC_9)	Reliability (AEC_{10})	Operation stability (AEC_{11})	Durability (AEC_{12})	Social (AEC_{13})	Innovation (AEC_{14})	Relative weights w_i
Quality (CR_1)	◎	○	△	△	◎		△	○		◎	○	◎	○	△	0.334
Security (CR_2)	○	○	○	○	◎		△			○	○			✕	0.232
Economy (CR_3)			◎	○		○		○		○		○	○	○	0.13
Handling (CR_4)	○	○		△	○					○	◎				0.095
After-sales service (CR_5)						○	○	△	◎						0.068
Comfort (CR_6)	○		△			○					○				0.062
Configuration of exterior and interior (CR_7)	○		△			○			○		○			△	0.049
Individuality demand (CR_8)	○	○	△	△	○	○	✕	△	○					△	0.029
(RI_j)	(0.405, 0.651, 0.772)	(0.345, 0.452, 0.69)	(0.467, 0.679, 0.801)	(0.138, 0.287, 0.36)	(0.165, 0.317, 0.513)	(0.219, 0.379, 0.576)	(0.438, 0.669, 0.791)	(0.015, 0.123, 0.146)	(0.087, 0.237, 0.355)	(0.376, 0.483, 0.712)	(0.271, 0.391, 0.591)	(0.296, 0.435, 0.599)	(0.034, 0.179, 0.338)	(0.183, 0.353, 0.566)	
(RI_j^*)	(0.73, 1.213, 1.432)	(0.461, 0.783, 0.962)	(0.879, 1.531, 1.786)	(0.376, 0.593, 0.937)	(0.845, 1.352, 1.69)	(0.296, 0.486, 0.873)	(0.271, 0.436, 0.816)	(0.501, 0.814, 0.979)	(0.191, 0.372, 0.682)	(0.617, 0.912, 1.045)	(0.638, 1.013, 1.263)	(0.342, 0.567, 0.912)	(0.098, 0.123, 0.531)	(0.543, 0.871, 0.998)	
QFD-FEANP	0.114	0.055	0.141	0.051	0.127	0.045	0.042	0.061	0.039	0.082	0.088	0.047	0.035	0.072	
TLCOA Cost	0.082	0.041	0.136	0.088	0.068	0.043	0.054	0.084	0.082	0.048	0.045	0.046	0.075	0.109	
Manufacturability	0.057	0.034	0.051	0.108	0.125	0.036	0.068	0.061	0.056	0.102	0.098	0.073	0.042	0.091	
TLCOA Time	0.063	0.038	0.057	0.12	0.04	0.06	0.113	0.107	0.069	0.045	0.05	0.126	0.047	0.064	
Technology advances	0.101	0.042	0.052	0.078	0.073	0.045	0.083	0.054	0.048	0.08	0.092	0.075	0.063	0.115	

Fig. 4. QFD-FEANP of the case study and its application



	AEC1	AEC2	AEC3	AEC4	AEC5	AEC6	AEC7	AEC8	AEC9	AEC10	AEC11	AEC12	AEC13	AEC14
QFD-FEANP	0.114	0.055	0.141	0.051	0.127	0.045	0.042	0.061	0.039	0.082	0.088	0.047	0.035	0.072
Ertay' method	0.1009	0.0589	0.1329	0.0589	0.1359	0.0387	0.0499	0.0578	0.0329	0.078	0.0911	0.0482	0.0349	0.081
Interdependencies	13.2%	3.6%	8.3%	8.3%	8.8%	6.0%	7.6%	3.4%	5.9%	4.4%	2.9%	1.1%	0.4%	9.2%

Fig. 5. Priority weights for various AECs

G_1: $f_1(x)=1$, and is to maximize the QFD-FEANP;

G_2: $f_2(x)=0$, and is to minimize the WLCA cost;

G_3: $f_3(x)=1$, and is to maximize the manufacturability;

G_4: $f_4(x)=0$, and is to minimize the WLCA time;

G_5: $f_5(x)=1$, and is to maximize any technological advances.

According to their request, the following MSGP model was formulated:

$$\text{Minimize} \quad Z = 0.223\left(d_1^+ + d_1^-\right) + 0.203\left(\left(d_2^+ + d_2^-\right) + \left(e_1^+ + e_1^-\right)\right) \\ +0.071\left(d_3^+ + d_3^-\right) + 0.314\left(d_4^+ + d_4^-\right) + 0.189\left(d_5^+ + d_5^-\right) \quad \textbf{(20)}$$

$$\text{s.t. } 0.114X_1 + 0.055X_2 + 0.141X_3 + 0.051X_4 + 0.127X_5 + 0.045X_6 + 0.042X_7 + 0.061X_8 \\ +0.039X_9 + 0.082X_{10} + 0.088X_{11} + 0.047X_{12} + 0.035X_{13} + 0.072X_{14} - d_1^+ + d_1^- = 1; \quad \textbf{(21)}$$

$$0.082X_1 + 0.041X_2 + 0.136X_3 + 0.088X_4 + 0.068X_5 + 0.043X_6 + 0.054X_7 + 0.084X_8 \\ +0.082X_9 + 0.048X_{10} + 0.045X_{11} + 0.046X_{12} + 0.075X_{13} + 0.109X_{14} - d_2^+ + d_2^- = 0; \quad \textbf{(22)}$$

$$(1/1750)\left(b_1 8000 + (1-b_1)6250\right) - e_1^+ + e_1^- = 4.571*; \quad \textbf{(23)}$$

$$0.057X_1 + 0.034X_2 + 0.051X_3 + 0.108X_4 + 0.125X_5 + 0.036X_6 + 0.068X_7 + 0.061X_8 + 0.056X_9 \\ +0.102X_{10} + 0.098X_{11} + 0.073X_{12} + 0.042X_{13} + 0.091X_{14} - d_3^+ + d_3^- = 1; \quad \textbf{(24)}$$

$$0.063X_1 + 0.038X_2 + 0.057X_3 + 0.12X_4 + 0.04X_5 + 0.06X_6 + 0.113X_7 + 0.107X_8 + 0.069X_9 + 0.045X_{10} \\ +0.05X_{11} + 0.126X_{12} + 0.047X_{13} + 0.064X_{14} - d_4^+ + d_4^- = 0; \quad \textbf{(25)}$$

$$0.101X_1 + 0.042X_2 + 0.052X_3 + 0.078X_4 + 0.073X_5 + 0.045X_6 + 0.083X_7 + 0.054X_8 + 0.048X_9 \\ +0.08X_{10} + 0.092X_{11} + 0.075X_{12} + 0.063X_{13} + 0.115X_{14} - d_5^+ + d_5^- = 1; \quad \textbf{(26)}$$

$$b_1 \in \{0,1\};\ d_i^+, d_i^- \geq 0,\ i = 1,2,\ldots,5;\ e_i^+, e_i^- \geq 0,\ i = 1. \quad \textbf{(27)}$$

Objective (20) aims to minimize the total weighted deviation from all goals. Constraint (21) aims to maximize the QFD-FEANP results. Constraint (22) aims to minimize automobile cost. Constraint (23) aims to minimize the total WLCA cost ($*1 + \frac{1}{L_i}\left(s_{ij}^{\max} or\ s_{ij}^{\min}\right) = 1 + \frac{6250}{8000-6250} = 4.571$, where $L_i = s_{ij}^{\max} - s_{ij}^{\min}$, $s_{ij}^{\max} = 8000$ and $s_{ij}^{\min} = 6250$). Constraint (24) aims to maximize manufacturability. Constraint (25) aims to minimize the WLCA time. Constraint (26) aims to maximize any technological advances. Eqn (27) define the variables of the model.

4.2 Model results

The MSGP model is solved by using the LINGO software package based on Equations (20) to (27): the results may be summarized as: $X_1 = 1$, $X_2 = 0$, $X_3 = 1$, $X_4 = 0$, $X_5 = 1$, $X_6 = 0$, $X_7 = 1$, $X_8 = 1$, $X_9 = 1$, $X_{10} = 1$, $X_{11} = 1$, $X_{12} = 0$, $X_{13} = 1$, and $X_{14} = 1$. From the results, G_1 has a 0.802 achieved reached the aspiration level 1, G_2 has a 0.781 achieved reached the aspiration level 0, G_3 has a 0.749 achieved reached the aspiration level 1, G_4 has a 0.656 achieved reached the aspiration level 0, G_5 has a 0.76 achieved reached the aspiration level 0. Moreover, the results of weighted GP [16] are calculated, which is used to compared with MSGP, where the decision variable coefficients, variables and target values are defined the same as MSGP. The optimal solutions is obtained as: $X_1 = 0.3264$, $X_2 = 0.5969$,

$X_3 = 0.3954$, $X_4 = 0.7219$, $X_5 = 0.8205$, $X_6 = 0.5133$, $X_7 = 0.0817$, $X_8 = 0.1592$, $X_9 = 0.3167$, $X_{10} = 0.5772$, $X_{11} = 0.0187$, $X_{12} = 0.1113$, $X_{13} = 0.5019$, and $X_{14} = 0.0355$. From the results, G_1 has a negative value (-0.231) under aspiration level 1, G_2 has a 0.088 achieved reached the aspiration level 0, G_3 has a negative value (-9.466) under aspiration level 1, G_4 has a negative value (-3.031)under aspiration level 0, G_5 has a 0.055 achieved reached the aspiration level 0.

From the result, we can realize that the solution of MSGP is better than weighted GP, because the solution of Example is indeed balanced on the goals, the more the aspiration contribution levels the better the solutions found in the proposed MSGP method. Therefore, in the best interest of the EOQ in WLCA, it should select rationality of product planning and design (AEC_1), procurement (AEC_3), reliability of vehicle assembly (AEC_5), order-to-delivery (AEC_7), service (AEC_8), customer relationship management (AEC_9), reliability (AEC_{10}), operational stability (AEC_{11}), social (AEC_{13}), and innovation (AEC_{14}) for EOQ design in AWCL.

Table 5 shows the preference ranking of AECs under different goals and the final selection using MSGP. Note that, the optimal solution is not only obtained according to the results of G1, G2, G3, G4, or G5, but also needs to consider other goals. For instance, even though durability (x_{12}) was ranked at number one and has the top priority of 0.126 in WLCA time analysis, it was not selected in the end due to the fact that it had a rather low ranking under the goals of QFD-FEANP (ranked 10^{th}) and WLCA cost (ranked 11^{th}). The advantage of proposed method was that it allowed decision-makers to take MSAL (*e.g.*, qualitative and quantitative criteria) for selection of AECs in WLCA, and the goals: "is the value of *x* a case of more/higher is better?" (*e.g.*, a benefit criterion) or "the less/lower the value of *x*, the better?" (*e.g.*, a cost criterion) could also be used [21]. In consequence, an MSGP model can indeed solve the problems of evaluation of EOQ in WLCA by simultaneously considering CRs on AECs and also other important goals: it was flexible and practical in that it coped with the criteria which were both qualitative, and quantitative, while still being able to minimize MSAL.

Table 5. Rank of automobile engineering characteristics (AECs) by MSGP, FEAHP-QFD, etc.

Automobile engineering characteristics (AECs)	MSGP selection	Rank by G_1	Rank by G_2	Rank by G_3	Rank by G_4	Rank by G_5
Rationality of product planning and design (x_1)	selected	3	5	9	7	2
Evaluation accuracy (x_2)		8	14	14	14	14
Procurement (x_3)	selected	1	1	11	9	11
Production (x_4)		9	3	2	2	6
Reliability of vehicle assembly (x_5)	selected	2	8	1	13	8
Facilitation of sales plan (x_6)		11	13	13	8	13
Order-to-delivery (x_7)	selected	12	9	7	3	4
Service (x_8)	selected	7	4	8	4	10
Customer relationship management (x_9)		13	6	10	5	12
Reliability (x_{10})	selected	5	10	3	12	5
Operational stability (x_{11})	selected	4	12	4	10	3
Durability (x_{12})		10	11	6	1	7
Social (x_{13})		14	7	12	11	9
Innovation (x_{14})	selected	6	2	5	6	1
Considering selection criteria – qualitative	Yes	Yes	No	Yes	No	Yes
Considering selection criteria – quantitative	Yes	No	Yes	No	Yes	No
Multiple choice aspiration levels	Yes	No	No	No	No	No

Accordingly, the best selection was obtained. However, since schedulers generally cannot determine the exact values of these variables, it was important that they had an influence on the results when some changes occurred in their values: a sensitivity analysis on MSAL was therefore provided (see Fig.6).

"Unselected" meant that the AEC chose an inverse answer but other AECs formed the right selections. "Selected" meant that all AECs chose the right selection. Fig. 6 shows that, choosing, or not choosing, each AEC will change the value of the MSAL. The AECs of procurement (x_3), reliability of vehicle assembly (x_5), and rationality of product planning and design (x_1) exerted the most significant influence on the MSAL: this should be taken into consideration, especially when designing the EOQ in WLCA.

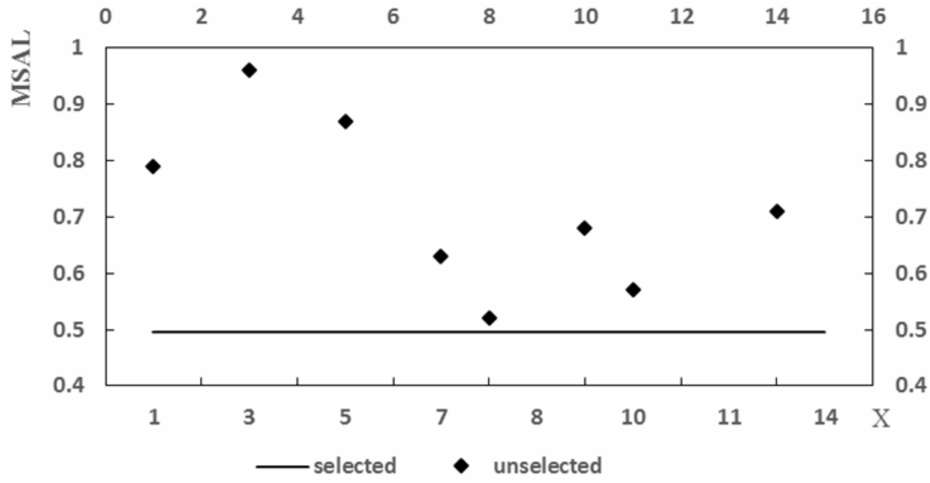


Fig. 6. Changing values of MSAL with values of selected AECs

5 Conclusions Remarking

In an increasingly competitive business environment, a business needs to improve its EOQ with limited resources under the constraint of achieving customer satisfaction. This research proposed a novel approach for designing the EOQ in WLCA, and its contribution are depicted from three aspects. First, the existing literatures fail to consider the total life cycle cost of quality with customer requirements into account during the design phase. This paper proposes the concepts of WLCA based on EOQ attributes and the method to translate customer requirements into technical requirements for each stage of EOQ in WLCA to integrate CAs and automobile engineering characteristics (AECs) to fill this gap. Second, QFD-FEANP was proposed to calculate the weight associated with each attribute, and FEANP took the imprecision and vagaries of human judgments, and allied information, into account and handled the epistemic uncertainty during the evaluation and decision-making process. Third, MSGP is used to address multi-segment aspiration levels (MSAL) problems of evaluation criteria and select suitable AECs by the priorities of all criteria based on the calculation of FEANP-QFD. In a conclusion, a novel approach for designing EOQ in WLCA by integrating QFD, FEANP, and MSGP was proposed. Finally, a numerical example was presented to show the selection of the most suitable AECs with the compares of existing methods, and a sensitivity analysis with all selected AECs for MSAL was performed.

The proposed novel approach in this paper not only handle the design EOQ in WLCA, but also can be applied to the design of products, system or project and evaluation problems in whole life cycle, which need to take customer needs into consideration, deal with uncertainty, descriptive, and epistemic, information, and make the best selection by minimizing the total deviation from the desired goals from multiple objectives. Due to the extremely important of improving sostenuto economics of quality for a company, this paper presents a method, which has important theoretical value and practical value, to design the EOQ in WLCA, and testifies its advantages, and an appropriate method should be put forward to evaluate its effects in the next work.

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