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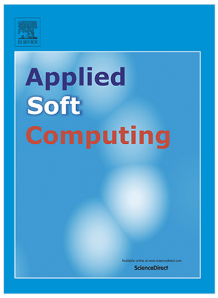

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PII: S1568-4946(22)00020-5
DOI: https://doi.org/10.1016/j.asoc.2022.108445
Reference: ASOC 108445

To appear in: *Applied Soft Computing*

Received date : 29 March 2021
Revised date : 25 October 2021
Accepted date : 5 January 2022

Please cite this article as: A. Karasan, E. Ilbahar, S. Cebi et al., Customer–oriented product design using an integrated neutrosophic AHP & DEMATEL & QFD methodology, *Applied Soft Computing* (2022), doi: https://doi.org/10.1016/j.asoc.2022.108445.

Customer–oriented Product Design Using an Integrated Neutrosophic AHP & DEMATEL & QFD Methodology

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Abstract

With the increasing product variety, companies aim to become better than their competitors by providing a superior product developed with a customer–oriented product design approach and a quality strategy. In order to achieve this, companies should well understand customer expectations and quickly be able to convert these expectations to technical characteristics. Since the expectations consist of mostly subjective judgments, this evaluation process contains vagueness and impreciseness. A triplet represents the uncertainty in subjective judgments: the degrees of belongingness or Truthiness (T), non-belongingness or Falsity (F), and indeterminacy (I). For this reason, in this paper, a neutrosophic Quality Function Deployment (QFD) methodology based on neutrosophic AHP and neutrosophic DEMATEL is developed and applied to the design of a car seat. In this methodology, the weighting of customer requirements is performed by neutrosophic AHP.

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The relationships among the technical characteristics are determined by neutrosophic DEMATEL for the customer-oriented product design, considering both impreciseness in the data and indeterminacy of the decision-makers. In other words, the contribution of this paper is that the proposed methodology provides better integration of the voice of customers into technical characteristics through a practical fuzzy multi–criteria decision analysis. Based on the results, it is revealed that seat height is the most important technical characteristic, followed by vertical travel range and horizontal travel range. Moreover, validity and verification of the proposed methodology have been tested with other methods presented in the literature. Also, sensitivity analyses have been carried out to show the flexibility of the given decisions under different cases. Lastly, possible implications on theoretical and managerial aspects have been discussed.

Keywords: product development, neutrosophic sets, AHP, DEMATEL, QFD

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1. Introduction

After the second half of the 19th century, enterprises tried to gain superiority against their competitors by developing their products based on the quality strategy because of the drastic increase in the competitive environment among enterprises. Today, enterprises try to gain superiority over their competitors in the market by making a significant difference in their products with a customer-oriented product development strategy as well as a quality strategy. In particular, the rapid developments and growth in technology have increased the speed of offering products to the market. Nevertheless, this shortened the life cycle of the products in the market. For this reason, businesses should provide their product to the market in a short time by understanding customer expectations well, and these expectations should be quickly transferred to the technical characteristics of the product during the new product development stages. QFD has been proposed to literature by Akao et al. [1, 2] in order to develop products by adapting customers' requirements into the technical characteristics of the products [2]. QFD methodology is represented by a scheme called the house of quality (HoQ). The HoQ consists of six main parts, which define

- Customer Requirements (CRs)
- Technical Characteristics (TCs)
- Relationship matrix among TCs
- Relationship matrix between TCs and customer requirements
- Marketing matrix
- Design targets

Quality Function Deployment (QFD)is one of the most commonly used methods in order to provide a customer-oriented product design. In the literature, there are lots of studies that present applications of QFD on product development [3–11]. Furthermore, some researchers present some modifications and extensions to develop the performance of QFD by improving the data representation and reflecting parts of HoQ. When the mentioned extensions are reviewed, the reason for these new versions is mainly based on the different kinds of uncertainties in the data set. Since the data set may consist of vagueness, impreciseness, indeterminant and hesitant information, different types of fuzzy set extensions are used to handle the uncertainty. In the traditional set theory, an element can belong to a set or not; in optimization, a solution is either feasible or not; and in Boolean logic, a statement can be true or false, but nothing in between [12]. But in real-life conditions, almost nothing is precise and everything is a matter of degree and cannot be defined by the traditional logic. In order to deal with this kind of uncertainty, Zadeh introduced the fuzzy sets theory [13]. Since its first introduction in 1965, it has been extended in various forms. Type-2 fuzzy sets, again, were introduced by Zadeh to enhance the representation of impreciseness of the data in the mathematical operations [14]. Then, in 1986, Atanassov introduced intuitionistic fuzzy sets, which is a concept that corporates membership and non-membership degrees simultaneously [15]. Then, neutrosophic sets are presented by Smarandache, which offers a domain area that consists of three independent subsets to represent types of uncertainties [16]. Neutrosophic sets are defined as the sets where each element of the universe has a degree of truthiness, indeterminacy, and falsity, which are between 0 and 1, and these degrees are subsets of the neutrosophic sets which are independent of each other [16]. In the neutrosophic sets, impreciseness is represented as truth and falsity functions where degrees of belongingness and non-belongingness and distinguish of absoluteness and relativeness is represented by indeterminacy function. With this notation, neutrosophic sets handle the uncertainty of the system and reduce the indecisiveness of inconsistent information. Therefore, this capability can be said as the most important advantage of the neutrosophic sets among the other types of fuzzy extensions. Using these three functions, neutrosophic sets provide a domain area, which enables the conduct of different types of uncertainties in the mathematical operations independently.

Analytic Hierarchy Process (AHP), proposed by Saaty [17], is a well-known method for handling complex problems by dividing them into sub-problems and then putting the solutions of these sub-problems together. In this method, which is based on pairwise comparisons of experts, ensuring the consistency of the evaluations has an important place. DEcision MAking Trial and Evaluation Laboratory (DEMATEL) method, introduced by Fontela and Gabus [18], is one of the widely used decision making methods when there is dependency among decision criteria. AHP and DEMATEL have been widely used in the literature as standard methods [19–29], so their application steps are not provided in this study. As different from the literature, a new methodology consisting of AHP, DEMATEL, and QFD extended by interval-valued neutrosophic sets is proposed. Even though customer requirements, TCs and competitor assessment are taken into account in classical QFD, to the best of our knowledge, there is no study calculating the weights of customer requirements and the coefficient of competitor assessment with neutrosophic AHP which can represent uncertainty of customers based on three parameters. Moreover, neutrosophic DEMATEL has not been used to model the relationship between TCs when considering uncertainty. With the proposed approach, uncertainty in the assessment of customer requirements and the relations between TCs and customer requirements, and the dependecies between TCs might be represented more precisely. In this way, it is expected to reflect the voice of customer into the design process by better associating the customers requirements with the TCs. The representation of the proposed methodology is given in Figure 1.

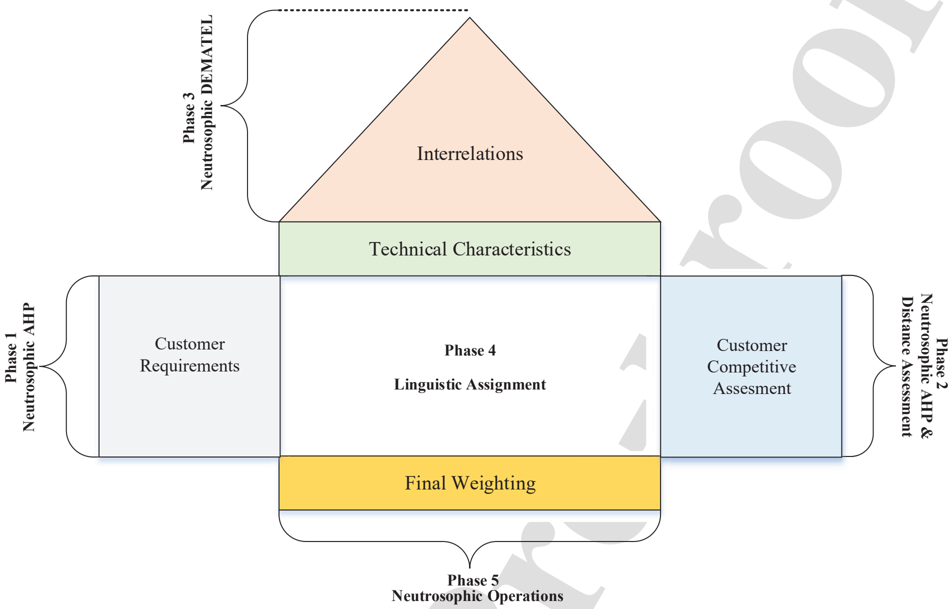

Figure 1: Framework of the proposed method

As in Figure 1, AHP is used to determine the weights of the customer requirements for the decision-making process with a hierarchical structure in Phase 1. For the direct comparison of the design with the competitor, AHP is conducted to find the differences in Phase 2. Moreover, the DEMATEL technique is conducted to determine the interrelations of the TCs based on the assigned linguistic terms in Phase 3. The assumption for these hierarchical structures is based on no dependency or feedback between the requirements. In Phase 4, TCs are evaluated by the decision-makers with respect to customer requirements. Finally, by aggregating the outputs of these phases, final weights and the importance of the TCs are obtained in Phase 5. For demonstrating robustness, a one-at-a-time sensitivity analysis based on different cases is conducted. Moreover, for the validation of the results and verification of the given decisions, comparative analyses are applied. Through the results of the application and analyses, theoretical and managerial implications have been discussed.

The rest of the study is organized as follows: Section 2 provides a literature analysis both for neutrosophic studies and emerging trends of the QFD method. Section 3 presents the proposed approach together with its preliminaries. Section 4 illustrates the application consisting of problem definitions, calculation and results, sensitivity, and comparative analyses for the design of automobile seat. Section 5 introduces the discussion about theoretical and managerial implications. Finally, in Section 6, concluding remarks and suggestions for further studies are given.

2. Literature Analysis

In this section, the MCDM studies extended with neutrosophic concept, and QFD methods integrated with other techniques and the research gap have been presented. In the following sub-section, analyses for the mentioned ones are presented, respectively.

2.1. Neutrosophic MCDM Studies

In this sub-section, neutrosophic MCDM methods, neutrosophic AHP, and neutrosophic DEMATEL, have been investigated based on their way of involving neutrosophic space into the applied methodologies. For the neutrosophic AHP method, there are three different application concepts in the literature: Neutrosophic calculations during all steps, deneutrosophication after constructing pairwise comparison matrices, and parameter-based calculations during all steps. The analyzed studies are given in Table 1 as follows:

Table 1: Neutrosophic AHP studies and their concept of involving neutrosophic space

ID	[30]	[31]	[32]	[33]	[32]	[34]	[35]	[36]	[37]	[38]	[39]	[40]
1		✓		✓				✓				
2			✓		✓	✓	✓		✓	✓		
3	✓										✓	✓

1: Neutrosophic Calculations during all steps

2: Deneutrosophication after constructing pairwise comparison matrix

3: Parameter Based Calculations during all steps

For the neutrosophic calculations during all steps concept, the steps of the neutrosophic AHP method have been carried out with neutrosophic operations, and the concept has the ability to produce neutrosophic weights. For the deneutrosophication after constructing the pairwise comparison matrix, pairwise comparison matrices are constructed with respect to available data based on a neutrosophic scale consisting of linguistic terms and their corresponding neutrosophic numbers, the neutrosophic numbers are deneutrosophicated, and the crisp values are obtained. After this process, steps of the classical AHP method are conducted to obtain the weights. This concept only produces the crisp weights of the criteria. For the parameter-based calculations during all steps concept, each sub-set of the neutrosophic sets have been subjected into operations in themselves. The concept has the ability to produce neutrosophic weights. When these three concept-based studies are analyzed, their validity and applicability are mostly proved by the comparative analyses in the investigated papers. Based on this, it can be said that there is no absolute superiority one to another, and there can be some advantages of these concepts based on the application area. But, simulating them in the same application will produce more meaningful results for the applicability. In our methodology, the first concept, neutrosophic calculations during all steps, is applied for the interval-valued neutrosophic AHP method. Moreover, a comparative analysis consisting of the second and third concepts is carried out to show the verification and validation of the produced results. For the neutrosophic DEMATEL method, there are two different application concepts in the literature: Deneutrosophication after constructing initial relationship matrices, and parameter-based calculations during all steps. The analyzed studies are given in Table 2 as follows:

Table 2: Neutrosophic DEMATEL studies and their concept of involving neutrosophic space

ID	[41]	[42]	[43]	[44]	[45]	[46]	[47]	[48]	[49]	[50]	[51]
1	✓		✓	✓	✓	✓	✓	✓	✓	✓	
2		✓									✓

1: Deneutrosophication after constructing pairwise comparison matrix

2: Parameter Based Calculations during all steps

As in Table 2, only two studies belonging to the same researchers used extended DEMATEL with parameter-based calculations during all steps. The majority of the studies used extended DEMATEL with deneutrosophication after constructing the initial relationship matrix. This difference may produce similar solutions as in extended neutrosophic AHP versions since the models can incorporate both types of uncertainties into the calculations. Based on the majority of the studies and practicability of the first concept, we use deneutrosophication after constructing the initial relationship matrix for the application.

2.2. QFD and Integrated Methodologies

In the literature, the QFD method has been integrated with other methods to improve its performance since the last decade. For instance, Altuntas and Kansu [7] proposed an integrated approach based on service quality measurement, QFD and failure modes and effects analysis (FMEA) to improve the service quality of the healthcare systems. It was revealed that the introduced approach can be employed to evaluate service quality in an effective manner. Zhang [52] integrated data envelopment analysis (DEA) with QFD for mobile phone development process. In the study, uncertainty is considered by using triangular fuzzy numbers and it was found that the proposed approach is effective to deal with such problems although there are large number of people participating this development process. In some of the studies, the Theory of Creative Problem Solving (TRIZ) method is integrated with QFD [6, 53–56]. Frizziero et al. [6] used TRIZ to eliminate critical problems in the design while utilized the QFD method to improve the design quality of open molds design. Wang [53] utilized TRIZ to handle engineering conflicts among TCs whereas QFD approach is used to match customer expectations with TCs for smartphones. Zhang et al. [54] also used the integration of TRIZ, QFD and fuzzy Delphi method for new stove design. In the study, uncertainty is considered by using trapezoidal fuzzy numbers while evaluating four alternatives and the alternative providing the better ergonomic performance is identified as the best option. Melemez et al. [55] integrated QFD, AHP, and TRIZ for a new trailer design. In the study, TRIZ was used to consider contradiction among TCs whereas QFD was utilized to integrate customer requirements into TCs. Finally, AHP was used to determine the best design concept among four alternatives. Chen and Huang [56] also utilized both QFD and TRIZ for innovative product design. In the study, they employed TRIZ to consider the contradictions among the TCs in the QFD relationship matrix for the design of Notebook PC computer products. Vinodh et al. [57] integrated environmentally conscious quality function deployment (ECQFD), with TRIZ, and AHP for automotive component design. In the paper, CRs were determined by using ECQFD and they were matched with TCs by using QFD. After TRIZ was used to determine innovative design options, AHP was utilized to select the best option with respect to sustainability and innovation.

Kano Model is another method that is commonly integrated with QFD in the literature. Wu et al. [8] proposed an integrated methodology including Kano Model, QFD, and the Function Analysis System Technique (FAST) methodologies to provide a better baby stroller design. In the paper, customer requirements are determined by using Kano model and then QFD is utilized to conduct a quantitative analysis on the user requirements. FAST is employed to identify the key factors affecting the users' purchasing decision and their experience. Gangurde and Patil [3] utilized the QFD and Kano Model method for mobile phone design. In the study, the Kano Model is employed to determine CRs while the QFD method was used to identify relationships between CRs and TCs of mobile phones. Kang et al. [4] integrated Kano Model, Evaluation Grid Method (EGM), fuzzy AHP, and QFD for mini car design. In the paper, both fuzzy Kano model and fuzzy AHP was used to identify the importance degrees of customer requirements whereas fuzzy QFD was used to associate CRs into TCs. In their study, the EGM method was exploited to analyze qualitative relations among CRs and TCs. He et al. [58] integrated QFD with Kano model and importance-frequency (IF) method for an elevator design. After Kano Model and importance frequency methods were utilized to classify CRs by considering the interaction and importance between frequencies, the obtained outputs were integrated into the QFD and non-linear programming models. Ji et al. [59] also used Kano Model together with QFD and non-linear programming. In their study, the proposed approach is applied for notebook design to demonstrate its applicability. The multiple criteria decision-making methods (MCDM) are also another group of methods generally integrated with QFD method. Tian et al. [5] integrated fuzzy sets, Multi-Objective Optimization On The Basis Of Ratio Analysis (MULTIMOORA), best-worst method (BWM) and maximizing deviation method (MDM) with QFD for the design of smart bike-sharing programs. Wu et al. [60] integrated QFD with hesitant fuzzy DEMATEL and VIKOR methods for the design of electric vehicle. In the paper, the interactions among CRs and their importance degrees were considered with the hesitant fuzzy DEMATEL while QFD was used to define TCs. Then, to determine prioritization of TCs, the hesitant fuzzy VIKOR was adopted. Cebi et al. [11] integrated fuzzy sets theory, DEMATEL, AHP and QFD methods for the design of the vessel engine room. In their study, DEMATEL was utilized to identify the weights of TCs by considering the relationships among them whereas fuzzy AHP is integrated to QFD to deal with uncertainty in expert evaluations.

Table 3: The methods integrated with QFD and application areas of the proposed methodologies in the literature

Authors	Year	Kano model	TRIZ	AHP	DEMATEL	Fuzzy sets	Other methods integrated with QFD	Application
Wu et al.	2020	✓					FAST	Baby Stroller
Altuntas and Kansu	2019						SERVQUAL, FMEA	Public Hospital
Zhang	2019					✓	DEA	Mobile Phone
Frizziero et al.	2018		✓					Direct Open Molds
Gangurde and Patil	2018	✓						Mobile Phone
Kang et al.	2018	✓		✓		✓	EGM	Minicars
Tian et al.	2018					✓	BWM, MULTIMOORA, MDM	Bike-Sharing Programs
Wang	2017		✓					Smart Phones
He et al.	2017	✓					IF, non-linear programming	Home Elevator
Wu et al.	2017				✓	✓	VIKOR	Electric Vehicle
Akbas and Bilgen	2017			✓		✓	TOPSIS, ANP	Gas Fuel
Chen and Huang	2015		✓					Notebook
Zhang et al.	2014		✓			✓	Delphi method	Rage Hood And Gas Hob
Vinodh et al.	2014		✓	✓				Automotive Component
Ji et al.	2014	✓					non-linear programming	Notebook
Cebi et al.	2014			✓	✓	✓		Vessel Engine Room
Melemez et al.	2013		✓	✓				Forestry Trailer
Nixon et al.	2013			✓			Pugh selection matrix	Solar Thermal Collector
Wang and Chen	2012				✓	✓	Delphi method, linear programming	Sport And Water Digital Cameras

Besides these integrations, the QFD method has been generally used with the fuzzy set theory to consider vagueness in linguistic evaluation this period. For instance, Gundogdu and Kahraman[10] extended the QFD method by using spherical fuzzy sets to handle impreciseness and vagueness in linguistic evaluations in the QFD method. In the paper, evaluations for the CRs, TCs, and relationships between CRs&TCs are considered by using spherical fuzzy sets. Pandey [61] utilized fuzzy QFD to evaluate the strategic TCs for an airport located in Thailand. Zhang et al. [62] proposed a two-phase QFD model including traditional QFD frame, failure modes feedback from end-of-life product, and fuzzy set theory. For the fuzzy and imprecise information, the fuzzy comprehensive evaluation method is used to determine translated. In the paper, the weights of customer requirements obtained from failure modes are taken from the fuzzy comprehensive evaluation to overcome the vagueness and imprecision in linguistic variables. Huang et al. [63] used QFD with a proportional hesitant fuzzy linguistic term set for product development. Liu et al. [64] integrated interval-valued Pythagorean fuzzy sets into QFD for the design of robots. Van et al. [65] integrated interval valued neutrosophic sets into QFD for the green supplier evaluation and selection. Li et al. [66] integrated QFD and interval linguistic information for the design of a turbine engine. Vinodh et al. [67] integrated fuzzy sets theory into QFD to provide sustainable electronics products. Wu and Ho [68] integrated fuzzy sets into QFD for the design of the green mobile phone. Table 3 demonstrates the methods which are integrated with QFD and application areas of the proposed methodologies in the literature. It can be seen that although QFD method has been integrated with DEMATEL, AHP or fuzzy sets, yet, to the best of our knowledge, neutrosophic QFD utilized with neutrosophic AHP, and neutrosophic DEMATEL has not been introduced.

2.3. Research Gap

Based on the literature review conducted on the past studies, it has come to the attention that the cause-and-effect relationships among the TCs that play a role towards the customer-oriented product design should be highlighted under the neutrosophic environment with a quantitative method. The dearth of such consideration leads to impairing the improvement actions to be focused upon by the design professionals later on. Moreover, by conducting neutrosophic AHP in both obtaining the importance of customer requirements and determining the customer competitive assessment, it enables to involve types of uncertainty into mathematical operations to obtain more precise results than the ordinary QFD methods. In light of this, the current study aims to bridge the mentioned research gap using the following objectives:

- What are the essential TCs playing a role in the customer-oriented driver seat design?
- How could we determine the relationship among the TCs and calculate the magnitudes of these relations by considering their possible influences on one another?

- What are the most critical customer requirements for a customer-oriented driver seat design by involving the customers' voice in the solution process?
- What is our position between our own company and the competitors in the market based on the customer requirements?
- Which TCs are most important for a customer-oriented driver seat design based on a compromise solution?

In our proposed methodology, both the weighting between customer needs and the relationships between TCs can be better modeled. Integrating AHP and DEMATEL methods into the QFD process with neutrosophic sets aims to obtain more precise and efficient results than the classical QFD process. Thus, customer needs will be more effectively reflected in TCs.

3. Methodology

In this study, a decision-making approach consists of neutrosophic DEMATEL and neutrosophic AHP is used to construct a novel QFD methodology by considering multi-expert judgments. Before presenting the phases of the proposed methodology, the essentials of the conducted techniques are presented with all their details.

3.1. Preliminaries: Neutrosophic Sets

Definition 1. Let X be a universe of discourse with a generic element in X denoted by x. A single-valued neutrosophic set A in X is presented in

Eq. (1):

$$A = \{x, T_A(x), I_A(x), F_A(x) \mid x \in X\} \tag{1}$$

where $T_A(x)$, $I_A(x)$, and $F_A(x)$ are the truth , indeterminacy , and falsity functions, respectively. For each point x in X, we have $T_A(x)$, $I_A(x)$, $F_A(x)$ $x \in [0,1]$ which are independent subsets. Through that, $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$ [69].

Definition 2. Let X be a universe of discourse. An interval-valued neutrosophic set (IVNS) N in X is independently characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$, and a falsity-membership function $F_A(x)$ for each $x \in X$, where $T_N(x) = [T_N^L(x), T_N^U(x) \subseteq [0,1]]$, $I_N(x) = \left[I_N^L(x), I_N^U(x) \subseteq [0,1]\right]$, and $F_N(x) = [F_N^L(x), F_N^U(x) \subseteq [0,1]]$. As in the Definition 1 conditions, $0 \leq T_N^U(x) + I_N^U(x) + F_N^U(x) \leq 3$. Thus, the IVNS N can be denoted as in Eq. (2) [69]:

$$N = \left\{\left\langle x, \left[T_N^L(x), T_N^U(x)\right], \left[I_N^L(x), I_N^U(x)\right], \left[F_N^L(x), F_N^U(x)\right]\right\rangle \mid x \in X\right\} \tag{2}$$

We will denote $N = \left\langle\left[T_N^L, T_N^U\right], \left[I_N^L, I_N^U\right], \left[F_N^L, F_N^U\right]\right\rangle$ for the simplicity.

Definition 3. Let $A = \langle\, [T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U]\rangle$ and $B = \langle\, [T_b^L, T_b^U], [I_b^L, I_b^U], [F_b^L, F_b^U]\rangle$ be two interval-valued neutrosophic numbers (IVNNs) and k is a crisp value, then the arithmetical operations between them are presented between Eq. (3) to Eq. (6) as follows [70]:

$$kA = \left\langle [(1-(1-T_A^L)^k),(1-(1-T_A^U)^k)],[(I_A^L)^k,(I_A^U)^k],[(F_A^L)^k,(F_A^U)^k] \right\rangle \quad (3)$$

$$\begin{aligned} A^k = \langle\ & [(T_A^L)^k,(T_A^U)^k],[(1-(1-I_A^L)^k),(1-(1-I_A^U)^k)], \\ & [(1-(1-F_A^L)^k),(1-(1-F_A^U)^k)]\rangle \end{aligned} \quad (4)$$

$$\begin{aligned} A \oplus B = \langle\ & [(T_A^L+T_B^L-T_A^LT_B^L),(T_A^U+T_B^U-T_A^UT_B^U)], \\ & [I_A^LI_B^L,I_A^UI_B^U],[F_A^LF_B^L,F_A^UF_B^U]\rangle \end{aligned} \quad (5)$$

$$\begin{aligned} A \otimes B = \langle\ & [T_A^LT_B^L,T_A^UT_B^U],[(I_A^L+I_B^L-I_A^LI_B^L),(I_A^U+I_B^U-I_A^UI_B^U)], \\ & [(F_A^L+F_B^L-F_A^LF_B^L),(F_A^U+F_B^U-F_A^UF_B^U)]\rangle \end{aligned} \quad (6)$$

Definition 4. Let $A = \langle\ [T_a^L,T_a^U],[I_a^L,I_a^U],[F_a^L,F_a^U]\rangle$ and $B = \langle\ [T_b^L,T_b^U],$ $[I_b^L,I_b^U],[F_b^L,F_b^U]\rangle$ be two interval-valued neutrosophic numbers (IVNNs). The division of these two numbers can be applied as in Eq. (7) [36].

$$\begin{aligned} & A \div B = \left\langle \frac{t_{\bar{a}}}{t_{\bar{b}}}, \frac{i_{\bar{a}}-i_{\bar{b}}}{1-i_{\bar{b}}}, \frac{f_{\bar{a}}-f_{\bar{b}}}{1-f_{\bar{b}}} \right\rangle \\ & \text{valid if } t_{\bar{a}} \le t_{\bar{b}}, i_{\bar{a}} \ge i_{\bar{b}}, f_{\bar{a}} \ge f_{\bar{b}}, t_{\bar{b}} \ne 0, \quad i_{\bar{b}}, f_{\bar{b}} \ne 1 \end{aligned} \quad (7)$$

Definition 5. Let $A = \langle\ [T^L_{a_j}, T^U_{a_j}], [I^L_{a_j}, I^U_{a_j}], [F^L_{a_j}, F^U_{a_j}]\rangle\ ,\ j = 1, 2, \cdots, n$ be a collection of IVNNs. The interval-valued neutrosophic number weighted average operator ($\bigoplus$) for that collection is given as in Eq. (8) [71]:

$$\begin{aligned}\bigoplus = \langle\ [1-\prod_{j=1}^{n}(1-T^L_{A_j})^{w_j}, 1-\prod_{j=1}^{n}(1-T^U_{A_j})^{w_j}],\\ [\prod_{j=1}^{n}(I^L_{A_j})^{w_j}, \prod_{j=1}^{n}(I^U_{A_j})^{w_j}], [\prod_{j=1}^{n}(F^L_{A_j})^{w_j}, \prod_{j=1}^{n}(F^U_{A_j})^{w_j}]\rangle\end{aligned} \tag{8}$$

where w_j is the weight vector of A_j $(j = 1, 2, \cdots, n)$ and $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$.

Definition 6. Let $N = \left\langle \left[T^L_N, T^U_N\right], \left[I^L_N, I^U_N\right], \left[F^L_N, F^U_N\right] \right\rangle$ be an interval-valued neutrosophic number. Deneutrosophication ($\mathfrak{S}$) of it is calculated by using the Eq. (9):

$$\begin{aligned}\mathfrak{H} = \frac{\left(T^L + T^U + \left(1-F^L\right) + \left(1-F^U\right) + \left(T^L \times T^U\right) + \sqrt{(1-F^L)\times(1-F^U)}\right)}{6}\\ \times \frac{\left(\left(1-\frac{I^L+I^U}{2}\right) \times \sqrt{(1-I^L)\times(1-I^U)}\right)}{2}\end{aligned} \tag{9}$$

3.2. Interval-Valued Neutrosophic DEMATEL Method

DEcision MAking Trial and Evaluation Laboratory (DEMATEL) method was introduced by Gabus & Fontela in 1974 [18]. The aim of the method is to demonstrate the dependencies of the evaluated factors among themselves.

Through the years, it is mostly applied to the integrated decision making approaches to determine whether there is a dependency or not [72–76].

In our study, since the evaluations consist of uncertainty types, preciseness and indeterminacy, DEMATEL is extended with neutrosophic sets to increase ability to reflect the data set in the calculations. Moreover, in the QFD framework, there would be interactions among TCs. Based on the above statements, these interactions are demonstrated by applying neutrosophic DEMATEL technique for further calculations.

Table 4: Linguistic scale for interactions

Linguistic Term	Abbreviation	Corresponded IVN Number
No Influence	NI	<[0, 0], [0, 0], [1, 1]>
Very Low Influence	VL	<[0, 0.25], [0, 0.1], [0.7, 0.95]>
Low Influence	L	<[0.2, 0.5], [0.1, 0.2], [0.5, 0.75]>
Medium Influence	M	<[0.5, 0.5], [0.2, 0.3], [0.5, 0.5]>
High Influence	H	<[0.5, 0.75], [0.1, 0.2], [0.2, 0.5]>
Very High Influence	VH	<[0.7, 0.95], [0, 0.1], [0, 0.25]>

The pseudo code of the technique is presented as in Algorithm 1:

Algorithm 1: Pseudo Representation of IVN-DEMATEL

Input : n: number of evaluation criteria, $(n = 1, \cdots, i)$

Output: t_{ij}: relation and its magnitudes

Step 1: Construct linguistic influence matrix $\left(\tilde{A} = (\tilde{a}_{ij})_{n\times n}\right)$ ⇒ Based on Table 4

Step 2: Convert linguistic terms into corresponded IVNNs where

$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \left\langle \left[T_{ij}^L, T_{ij}^U\right], \left[I_{ij}^L, I_{ij}^U\right], \left[F_{ij}^L, F_{ij}^U\right] \right\rangle_{n\times n}$ ⇒ Based on Table 4

Step 3: Defuzzification Process by using Eq. (9)

Step 4: Normalization Process | Normalize the matrix $(A)_{(n\times n)}$ to obtain normalized matrix $(C)_{(n\times n)}$ by using following normalization function

$$C = k \cdot A$$
$$k = \min\left(\frac{1}{\max \sum_{1\leq i\leq n}^{n} |a_{ij}|}, \frac{1}{\max \sum_{1\leq j\leq n}^{n} |a_{ij}|}\right)$$

where k is the normalization coefficient, and a_{ij} is the crisp value of defuzzified IVN number.

Step 5: Conduct the Identity Matrix to derive Total Relation Matrix (R) by using the following formula:

$$R = C + C^2 + C^3 + \cdots + C^{\infty} = \sum_{i=1}^{\infty} C^i$$
$$R = C \cdot (I - M)^{-1}$$

Step 6: Calculate the D and R values

Step 7: Calculate the D+R values

Step 8: Normalize the D+R values to obtain relation magnitudes

Based on the D+R values, the magnitudes of the relation for TCs are calculated. These values are conducted for further calculations to obtained final results. Therefore, the aim of this process is to involve the effects of the relations to the calculations quantitatively.

3.3. Interval-Valued Neutrosophic AHP Method

AHP method was introduced by Saaty [17] which has ability to make pairwise comparisons. In this paper, a new interval-valued neutrosophic (IVN) AHP method is proposed. The constructed scale for the IVN AHP method is given as in Table 5.

Table 5: Linguistic scale for pairwise comparisons

Linguistic Term	Corresponded IVNNs
Certainly low importance-CL	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
Very low importance-VL	<[0.2, 0.35], [0.15, 0.2], [0.8, 0.95]>
Low importance-L	<[0.3, 0.4], [0.2, 0.25], [0.7, 0.9]>
Below average importance-BA	<[0.4, 0.45], [0.25, 0.3], [0.6, 0.85]>
Average importance-A	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>
Above average importance-AA	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
High importance-H	<[0.7, 0.9], [0.2, 0.25], [0.3, 0.4]>
Very high importance-VH	<[0.8, 0.95], [0.15, 0.2], [0.2, 0.35]>
Certainly high importance-CH	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>

The pseudo code of the method is presented as in Algorithm 2:

Algorithm 2: Pseudo Representation of IVN-AHP

Input : n: number of evaluation criteria, $(n = 1, \cdots, i)$,
  o: number of pairwise comparison matrices, $(o = 1, \cdots, k)$
Output: w_i: neutrosophic weights of the criteria
Begin
for $o \leftarrow 1$ **to** k **do**
  Step 1: Construct linguistic pairwise comparison matrix $\left(\tilde{R} = (\tilde{r}_{ij})_{n \times n}\right) \Rightarrow$ Based on Table 5
  Step 2: Consistency Check Procedure.
  Convert corresponded neutrosophic numbers to consistency index numerators to obtain the consistency ratio*
  for $o \leftarrow 1$ **to** k **do**
    consistency analysis $CR = \frac{CI}{RI}$ where $CI = \frac{\lambda_{\max}}{n-1}$
    if $CR > 0.1$ **then**
      return Step 1;
    else
      go Step 3;
    end
  end
  Step 3: Convert linguistic terms into corresponded IVNNs where
  $\tilde{R} = (\tilde{r}_{ij})_{n \times n} = \left\langle \left[T_{ij}^L, T_{ij}^U\right], \left[I_{ij}^L, I_{ij}^U\right], \left[F_{ij}^L, F_{ij}^U\right] \right\rangle_{n \times n} \Rightarrow$ Based on Table 5
  Step 4: Carry out normalization by using Eq. (7)
  Step 5: Calculate the aggregated weights by using Eq. (8)
  where $w_j = 1/n$.
end
End

*For the consistency analyses, Saaty used consistency ratios using the principal eigenvector of a positive pairwise comparison matrix [17]. We convert linguistic terms into consistency index numerators as in crisp values in the Saaty's AHP scale to perform consistency analysis. Therefore, linguistic values in Table 5 are converted into crisp values as A=1, AA=3, H=5, VH=7, CH=9.

3.4. Proposed QFD Methodology

In this paper, a novel QFD method consisting of neutrosophic DEMATEL and neutrosophic AHP method with their interval-valued forms is proposed. Neutrosophic weights of customer requirements (NWofCRs) are obtained by using neutrosophic AHP on customer requirements. Relative dependency weights of technical characteristics (RDWofTCs) are calculated by neutrosophic DEMATEL. Relative weights of competitiors (RWofCs) are also calculated with the help of neutrosophic AHP. Neutrosophic assessment of technical characteristics (NAofTCs) are combined with NWofCRs, RDWofTCs and RWofCs by neutrosophic operations to calculate the weights of TCs in customer-oriented product design.The framework of the proposed method is presented in Figure 2.

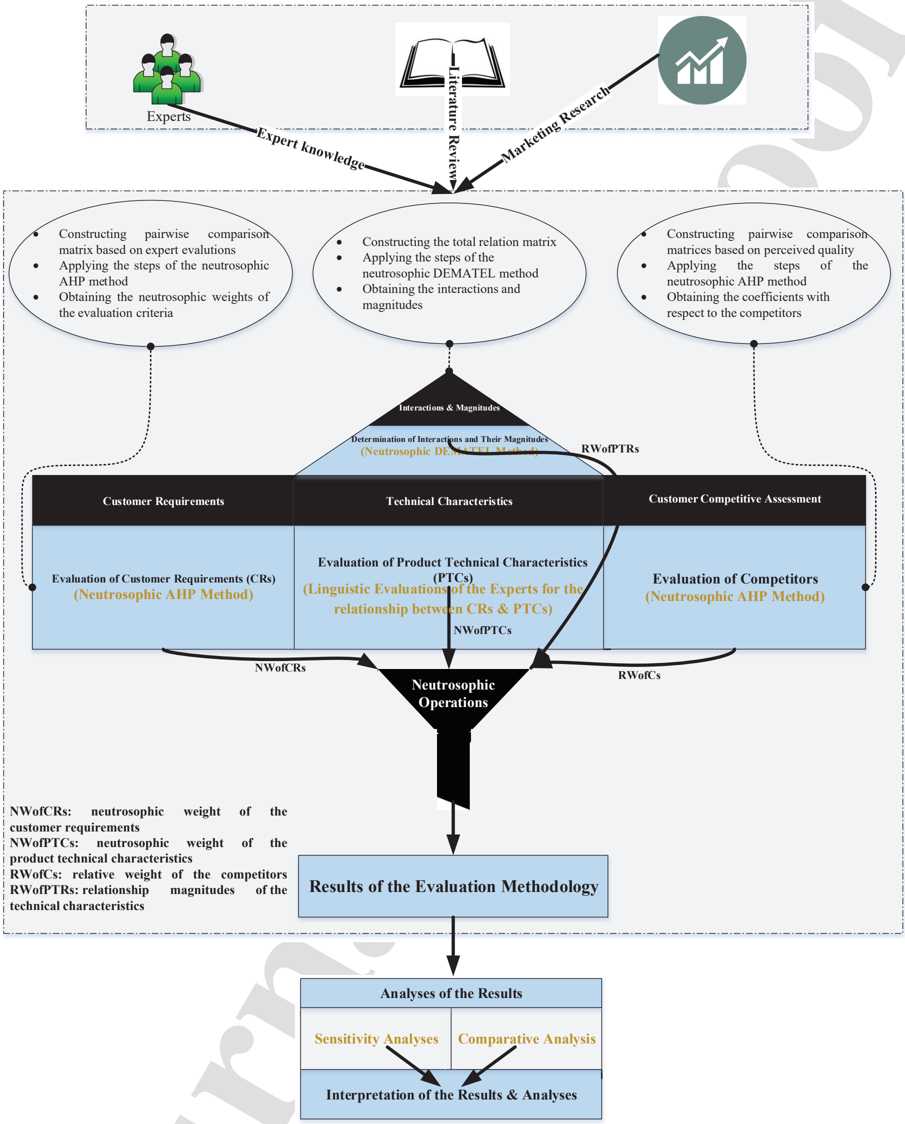

Figure 2: Detailed structure of the proposed QFD method

4. Application

In the following sub-sections, the environment of the problem, steps of the application, sensitivity analysis, and comparative analysis have been introduced, respectively.

4.1. Problem Definition

Automobile manufacturers strive to be better than their competing products with respect to technology, comfort, safety, quality, aesthetic design, and cost. The important component where all of these TCs should be considered at the same time and which has a significant share in purchasing decisions is the driver cabin design. One of the essential parts of the driver cabin design is the driver seat. Drivers' requirements for driver seats consist of four main factors, visibility, reach, adjustments, comfort, and twelve sub-factors. The design characteristics are collected from SAE and ISO standards such as ISO 3958, ISO 4131, SAE J 1100-2009, SAE J 1517-2011, by analyzing characteristics related to driver seats. These customer requirements are given in Table 6.

In the seat design, there are many TCs to satisfy the requirements which are given in the Table 7.

These parameters may affect more than one customer requirement simultaneously. Therefore, to optimize the customer requirements, the importance degree of the TCs and interactions among them should be clarified to develop a successful seat design according to the competing products. For this, the

Table 6: Customer requirements for the driver's seat [77]

Customer Requirements	Sub-Design Requirements
C1-Provide good visibility	C11-Provide good visibility for displays
	C12-Provide good visibility for control panel
	C13-Provide good visibility through the windshield
C2-Provide the easy reach to controls and pedals	C21-Provide reaching to control buttons
	C22-Provide reaching to pedals
C3-Provide the adjustments easily	C31-Provide knee-buttock comfort
	C32-Provide back (buttock-neck) comfort
	C33-Provide neck-head comfort
C4-Provide the drivers' comfort	C41-Provide fore-and-aft adjustment easily
	C42-Provide backrest adjustment easily
	C43-Provide altitude adjustment easily
	C44-Provide headrest adjustment easily

Table 7: TCs for the driver's seat

TC1-The vertical travel range value	TC8-Seat Height
TC2-The horizontal travel range value	TC9-Headrest height
TC3-Angle between backrest and cushion	TC10-Backrest control button
TC4-Cushion length	TC11-Altitude control button
TC5-Cushion width	TC12-Fore-and-aft control button
TC6-Lumbar support	TC13-Headrest control button
TC7-Seat-back width	TC14-Cushion materials to satisfy the requirements

proposed approach is applied to determine the design characteristics of the driver's seat.

4.2. Calculations

Tables A1-A10 show the pairwise comparisons of customer requirements and neutrosophic weight values obtained by using IVN-AHP. An expert team evaluated the pairwise comparisons and relations among the TCs. The expert team consists of mechanical and industrial engineers who have experience in customer-oriented product design and the automotive sector for at least five years, evaluated the pairwise comparison matrices. The pairwise comparison of competitors and the original product and the corresponding weights obtained from IVN-AHP are provided in Tables A11-A34. Moreover, Table 8 demonstrates the final neutrosophic weight values of customer sub-requirements which is obtained by using the neutrosophic multiplication operator given in Eq. 4 to multiply the weights of the main customer requirements and customer sub-requirements. Moreover, weights obtained from the pairwise comparison of the competitors are used to calculate a coefficient based on the targeted value and the original value, and these coefficients are also provided in Table 8.

Table 8: Values obtained from neutrosophic AHP for customer requirement weights and competitor comparison

Customer Requirements	Final neutrosophic weights of customer requirements	Coefficient obtained from competitor comparison
C11	<[0.28, 0.406], [0.457, 0.52], [0.721, 0.812]>	0.138
C12	<[0.28, 0.406], [0.457, 0.52], [0.721, 0.812]>	0.106
C13	<[0.28, 0.406], [0.457, 0.52], [0.721, 0.812]>	0.044
C21	<[0.536, 0.782], [0.343, 0.43], [0.445, 0.446]>	0.156
C22	<[0.439, 0.559], [0.343, 0.43], [0.547, 0.69]>	0.045
C31	<[0.231, 0.371], [0.359, 0.461], [0.761, 0.878]>	0.162
C32	<[0.482, 0.723], [0.35, 0.449], [0.507, 0.586]>	0.053
C33	<[0.325, 0.53], [0.428, 0.495], [0.679, 0.761]>	0.034
C41	<[0.214, 0.351], [0.369, 0.467], [0.78, 0.899]>	0.061
C42	<[0.175, 0.289], [0.369, 0.467], [0.82, 0.928]>	0.109
C43	<[0.253, 0.401], [0.344, 0.445], [0.739, 0.866]>	0.044
C44	<[0.136, 0.214], [0.344, 0.445], [0.86, 0.959]>	0.047

Table 9 shows the evaluation of customer requirements with respect to TCs by using the scale given in Table 5.

Table 9: Assessment of customer requirements with respect to TCs

	TC1	TC2	TC3	TC4
C11	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C12	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C13	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C21	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C22	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C31	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C32	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C33	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C41	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>
C42	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C43	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C44	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>

	TC5	TC6	TC7	TC8
C11	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C12	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C13	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
C21	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
C22	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C31	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
C32	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C33	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C41	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>
C42	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C43	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
C44	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>

	TC9	TC10	TC11	TC12
C11	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C12	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C13	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C21	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C22	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C31	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C32	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C33	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C41	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C42	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C43	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C44	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>

	TC13	TC14
C11	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C12	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C13	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C21	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C22	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C31	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C32	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C33	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C41	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C42	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C43	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>
C44	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>

Table 10 shows interaction coefficients of TCs obtained from neutrosophic DEMATEL, importance values in the form of neutrosophic numbers calculated by using neutrosophic operations given in Eqs. (3,5,6), importance values obtained by using deneutrosophication and relative importance values. These results indicate that *Seat Height* is the most important TC followed by *the vertical travel range value, the horizontal travel range value, Angle between backrest and cushion, Cushion width, Headrest height, Altitude control button, Lumbar support, Cushion materials, Seat-back width, Cushion length, Backrest control button, Fore-and-aft control button* and *Headrest control button.*

Table 10: Importance of the TCs obtained from QFD

	Interaction coefficient from DEMATEL	Importance values in the form of neutrosophic numbers	Importance values after deneutrosophication	Relative importance values
TC1	0.083	<[0.0156, 0.039], [0.931, 0.951], [0.983, 0.99]>	0.00093	0.149
TC2	0.080	<[0.0161, 0.035], [0.936, 0.954], [0.983, 0.991]>	0.00082	0.132
TC3	0.078	<[0.013, 0.031], [0.941, 0.957], [0.986, 0.992]>	0.00065	0.105
TC4	0.058	<[0.0044, 0.0154], [0.949, 0.964], [0.994, 0.999]>	0.00021	0.034
TC5	0.069	<[0.0114, 0.026], [0.946, 0.962], [0.988, 0.993]>	0.00050	0.080
TC6	0.070	<[0.0055, 0.019], [0.941, 0.958], [0.993, 0.998]>	0.00031	0.050
TC7	0.063	<[0.0046, 0.017], [0.946, 0.961], [0.994, 0.998]>	0.00024	0.039
TC8	0.085	<[0.018, 0.044], [0.933, 0.952], [0.98, 0.988]>	0.00104	0.167
TC9	0.071	<[0.007, 0.0208], [0.943, 0.959], [0.992, 0.997]>	0.00036	0.058
TC10	0.063	<[0.003, 0.0146], [0.944, 0.96], [0.995, 0.999]>	0.00019	0.032
TC11	0.083	<[0.004, 0.0183], [0.927, 0.948], [0.994, 0.999]>	0.00031	0.051
TC12	0.064	<[0.003, 0.0142], [0.944, 0.96], [0.995, 1]>	0.00018	0.030
TC13	0.064	<[0.003, 0.0137], [0.943, 0.96], [0.996, 1]>	0.00017	0.028
TC14	0.069	<[0.005, 0.0177], [0.939, 0.957], [0.994, 0.999]>	0.00028	0.045

To illustrate the calculation procedure, let us initially examine the calculation of neutrosophic weights of main customer requirements. After the pairwise comparison matrix of main customer requirements is provided with linguistic terms as in Table A1, they are converted to interval-valued neutrosophic numbers by using the scale presented in Table 5. The interval-valued neutrosophic numbers corresponding to the linguistic terms are given in Table 11.

Table 11: Corresponding interval-valued neutrosophic numbers to Table A1

	C1	C2	C3	C4
C1	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.3, 0.4], [0.2, 0.25], [0.7, 0.9]>	<[0.4, 0.45], [0.25, 0.3], [0.6, 0.85]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>
C2	<[0.7, 0.9], [0.2, 0.25], [0.3, 0.4]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.85, 0.99], [0.05, 0.15], [0.1, 0.3]>
C3	<[0.6, 0.85], [0.25, 0.3], [0.4, 0.45]>	<[0.4, 0.45], [0.25, 0.3], [0.6, 0.85]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>	<[0.7, 0.9], [0.2, 0.25], [0.3, 0.4]>
C4	<[0.4, 0.45], [0.25, 0.3], [0.6, 0.85]>	<[0.1, 0.3], [0.05, 0.15], [0.85, 0.99]>	<[0.3, 0.4], [0.2, 0.25], [0.7, 0.9]>	<[0.5, 0.6], [0.3, 0.35], [0.5, 0.6]>

Table 12: Neutrosophic addition operation

	C1	C2	C3	C4
(C1+C2)	<[0.85, 0.96], [0.06, 0.0875], [0.15, 0.24]>	<[0.65, 0.76], [0.06, 0.0875], [0.35, 0.54]>	<[0.76, 0.9175], [0.0625, 0.09], [0.24, 0.3825]>	<[0.94, 0.9985], [0.0125, 0.045], [0.04, 0.135]>
(C1+C2+C3)	<[0.94, 0.994], [0.015, 0.02625], [0.06, 0.108]>	<[0.79, 0.868], [0.015, 0.02625], [0.21, 0.459]>	<[0.88, 0.967], [0.01875, 0.0315], [0.12, 0.2295]>	<[0.982, 0.99985], [0.0025, 0.01125], [0.012, 0.054]>
(C1+C2+C3+C4)	<[0.964, 0.9967], [0.00375, 0.007875], [0.036, 0.0918]>	<[0.811, 0.9076], [0.00075, 0.0039375], [0.1785, 0.45441]>	<[0.916, 0.9802], [0.00375, 0.007875], [0.084, 0.20655]>	<[0.991, 0.99994], [0.00075, 0.0039375], [0.006, 0.0324]>

Calculation of sum of each column in Table 11 is performed by using neutrosophic addition operation given in Eq. 5 and the results are provided in Table 12. Let us examine the calculations in the first column of Table 12. The sum of $C1 + C2$ is calculated as $< [0.5 + 0.7 - 0.5 * 0.7, 0.6 + 0.9 - 0.6 * 0.9], [0.3 * 0.2, 0.35 * 0.25], [0.5 * 0.3, 0.6 * 0.4] >=< [0.85, 0.96], [0.06, 0.0875], [0.15, 0.24] >$. The sum of $C1 + C2 + C3$ is calculated as $< [0.85+0.6-0.85*0.6, 0.96+0.85-0.96*0.85], [0.06*0.25, 0.0875*0.3], [0.15*0.4, 0.24*0.45] >=< [0.94, 0.994], [0.015, 0.02625], [0.06, 0.108] >$.

After the calculation of $C1 + C2 + C3 + C4$, the neutrosophic division operation is used to divide the neutrosophic numbers in Table 11 to $C1 + C2 + C3 + C4$. Table 13 showed the normalized versions of the values in Table 11 by using neutrosophic divison operation given in Eq. 7

Table 13: Normalized values

	C1	C2	C3	C4
C1	<[0.519, 0.602], [0.297, 0.345], [0.481, 0.56]>	<[0.37, 0.441], [0.199, 0.247], [0.635, 0.817]>	<[0.437, 0.459], [0.247, 0.294], [0.563, 0.811]>	<[0.605, 0.85], [0.249, 0.297], [0.396, 0.432]>
C2	<[0.726, 0.903], [0.197, 0.244], [0.274, 0.339]>	<[0.617, 0.661], [0.299, 0.347], [0.391, 0.267]>	<[0.655, 0.867], [0.247, 0.294], [0.345, 0.307]>	<[0.858, 0.99], [0.049, 0.147], [0.095, 0.277]>
C3	<[0.622, 0.853], [0.247, 0.294], [0.378, 0.394]>	<[0.493, 0.496], [0.249, 0.297], [0.513, 0.725]>	<[0.546, 0.612], [0.297, 0.345], [0.454, 0.496]>	<[0.706, 0.9], [0.199, 0.247], [0.296, 0.38]>
C4	<[0.415, 0.451], [0.247, 0.294], [0.585, 0.835]>	<[0.123, 0.331], [0.049, 0.147], [0.817, 0.982]>	<[0.328, 0.408], [0.197, 0.244], [0.672, 0.874]>	<[0.505, 0.6], [0.299, 0.347], [0.497, 0.587]>

Let us examine the calculations in the first cell of Table 13. The first cell is calculated as $< [0.5/0.964, 0.6/0.9967], [(0.3-0.00375)/(1-0.00375), (0.35-0.007875)/(1-0.007875)], [(0.5-0.036)/(1-0.036), (0.6-0.0918)/(1-0.0918)] >=< [0.519, 0.602], [0.297, 0.345], [0.481, 0.56] >$. Then, the final neutrosophic weights of Table 14 is obtained by using the neutrosophic number weighted average operator given in Eq. 8.

Table 14: Neutrosophic weights of main customer requirements

	Neutrosophic weights
C1	<[0.49, 0.633], [0.246, 0.294], [0.511, 0.632]>
C2	<[0.732, 0.919], [0.164, 0.246], [0.243, 0.296]>
C3	<[0.6, 0.768], [0.246, 0.294], [0.402, 0.482]>
C4	<[0.357, 0.457], [0.164, 0.246], [0.632, 0.805]>

Since there is a hierarchy, the same procedure is applied to the pairwise comparison of customer requirements related to visibility as well. The neutrosophic weights obtained for sub-requirements, given in Table A4, A6, A8, A10, are multiplied with the neutrosophic weights obtained in Table 14 by using neutrosophic multiplication operation provided in Eq. 6. The neutrosophic weight given in Table 8 is calculated as $< [0.49 * 0.571, 0.633 * 0.641], [0.246 + 0.281 - 0.246 * 0.281, 0.294 + 0.321 - 0.294 * 0.321], [0.511 + 0.429 - 0.511 * 0.429, 0.632 + 0.49 - 0.632 * 0.49] >=< [0.280, 0.406], [0.457, 0.520], [0.721, 0.812] >$.

As neutrosophic AHP is also used to compare the original product and its competitors with respect to customer requirements, the calculation procedure to find neutrosophic weights are same. After deneutrosophication on these weights is performed by using Eq. 9, the maximum of their competitors' deneutrophicated weights is divided by the deneutrophicated weight of original product. It can be illustrated for C11 as $max(0.597, 0.421, 0.359)/0.229 = 0.597/0.229 = 2.602$. Then, these values are divided by the sum of these values which is 18.8 to obtain the coefficient of competitor comparison. In this way, the coefficient for C11 is found as $2.602/18.8 = 0.138$.

4.3. Comparative and Sensitivity Analysis

A sensitivity analysis is conducted to present the robustness of the given decisions of the proposed method. Moreover, to prove the proposed method's applicability, a comparative analysis with the classical QFD and method is also illustrated. Figure 3 shows the change in the ranking of the TCs when the dependency weight of only one of the characteristics is increased up to 0.1 each time while decreasing the other weights proportionally. In Figure

3, Y-Axis represents the ranking of 14 TCs while the 14 cases in the X-Axis represents the changes made one by one in these TCs. The changes of weights in these different cases are provided in Table 15. It can be seen that TC8 is generally the most important TC, followed by TC1. Moreover, the third and fourth place belongs to TC2 and TC3, respectively. Since more sharp changes in ranking occurred only if the initial weight of a TC is quite low, it is possible to say that the results are not sensitive to such changes.

Table 15: The changes made on the dependency weights for different cases

	Base Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13	Case 14
TC1	0.083	0.100	0.081	0.081	0.079	0.080	0.080	0.080	0.082	0.080	0.080	0.081	0.080	0.080	0.080
TC2	0.080	0.079	0.100	0.078	0.077	0.078	0.078	0.077	0.079	0.078	0.077	0.079	0.077	0.077	0.078
TC3	0.078	0.077	0.077	0.100	0.075	0.076	0.076	0.075	0.077	0.076	0.075	0.077	0.075	0.075	0.076
TC4	0.058	0.057	0.057	0.057	0.100	0.056	0.056	0.056	0.057	0.056	0.056	0.057	0.056	0.056	0.056
TC5	0.069	0.068	0.067	0.067	0.066	0.100	0.067	0.066	0.068	0.067	0.066	0.068	0.066	0.066	0.067
TC6	0.070	0.068	0.068	0.068	0.067	0.067	0.100	0.067	0.068	0.067	0.067	0.068	0.067	0.067	0.067
TC7	0.063	0.062	0.062	0.062	0.060	0.061	0.061	0.100	0.062	0.061	0.061	0.062	0.061	0.061	0.061
TC8	0.085	0.083	0.083	0.083	0.081	0.082	0.082	0.081	0.100	0.082	0.082	0.083	0.082	0.082	0.082
TC9	0.071	0.069	0.069	0.069	0.068	0.068	0.068	0.068	0.070	0.100	0.068	0.069	0.068	0.068	0.068
TC10	0.063	0.062	0.062	0.062	0.060	0.061	0.061	0.061	0.062	0.061	0.100	0.062	0.061	0.061	0.061
TC11	0.083	0.082	0.081	0.081	0.079	0.080	0.080	0.080	0.082	0.080	0.080	0.100	0.080	0.080	0.080
TC12	0.064	0.062	0.062	0.062	0.061	0.061	0.062	0.061	0.063	0.062	0.061	0.062	0.100	0.061	0.061
TC13	0.064	0.063	0.063	0.063	0.061	0.062	0.062	0.062	0.063	0.062	0.062	0.063	0.062	0.100	0.062
TC14	0.069	0.068	0.068	0.067	0.066	0.067	0.067	0.066	0.068	0.067	0.066	0.068	0.066	0.066	0.100

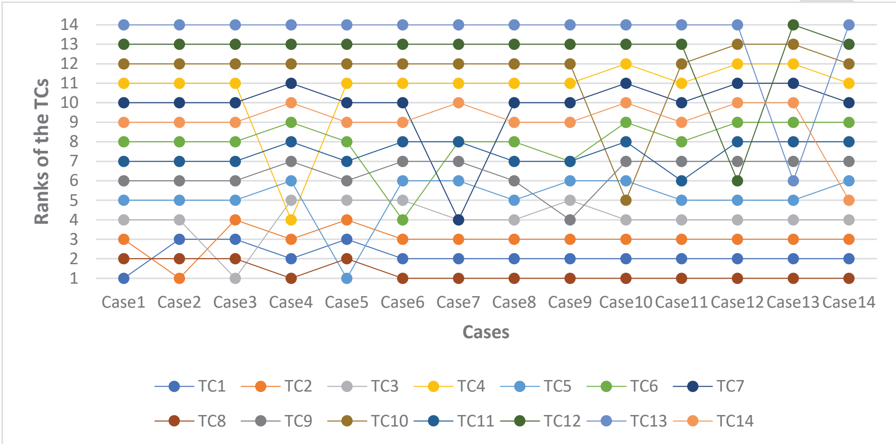

Figure 3: Change in the ranking of the TCs in the case of different weights of dependency

Figure 4 demonstrates the change in the ranking of the TCs when only one of the competitor assessment weights is increased up to 0.15 each time while decreasing the other weights proportionally. In Figure 4, Y-Axis represents the ranking of fourteen TCs while the 12 cases in the X-Axis represent the changes made one by one in customer requirement weights. The changes of weights in these different cases are provided in Table 16. It can be seen that TC8 is always the most important TC, followed by TC1. Moreover, the third and fourth places belong to TC2 and TC3, respectively. Thus, the overall graph indicates that the results are robust. It can be seen that there are less drastic changes in the ranking in Figure 4 than in Figure 3, so it is possible to say that dependency weights between TCs have a greater impact on the final ranking of these characteristics than the weights obtained from competitor comparisons.

Table 16: Changes made on the weights of competitor assessments in different cases

	Base Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
TC1	0.123	0.150	0.132	0.123	0.139	0.123	0.140	0.124	0.122	0.125	0.132	0.123	0.123
TC2	0.094	0.104	0.150	0.094	0.107	0.094	0.107	0.095	0.093	0.096	0.101	0.094	0.094
TC3	0.039	0.044	0.042	0.150	0.045	0.039	0.045	0.040	0.039	0.040	0.042	0.039	0.039
TC4	0.139	0.154	0.149	0.139	0.150	0.139	0.159	0.140	0.138	0.142	0.149	0.139	0.139
TC5	0.040	0.045	0.043	0.040	0.046	0.150	0.046	0.041	0.040	0.041	0.043	0.040	0.040
TC6	0.144	0.159	0.154	0.144	0.163	0.144	0.150	0.145	0.142	0.146	0.154	0.144	0.144
TC7	0.047	0.052	0.051	0.047	0.054	0.047	0.054	0.150	0.047	0.048	0.051	0.047	0.047
TC8	0.030	0.034	0.032	0.030	0.034	0.030	0.035	0.031	0.150	0.031	0.033	0.030	0.030
TC9	0.055	0.060	0.058	0.055	0.062	0.055	0.062	0.055	0.054	0.150	0.058	0.055	0.055
TC10	0.097	0.108	0.104	0.097	0.110	0.097	0.110	0.098	0.096	0.099	0.150	0.097	0.097
TC11	0.039	0.043	0.042	0.039	0.044	0.039	0.045	0.039	0.039	0.040	0.042	0.150	0.039
TC12	0.150	0.046	0.045	0.042	0.047	0.042	0.048	0.042	0.041	0.043	0.045	0.042	0.150

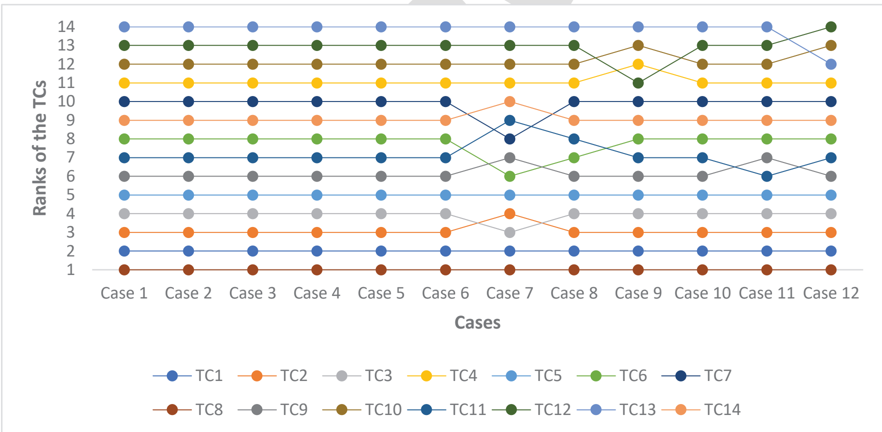

Figure 4: Changes in the ranking of the TCs in the case of different competitor evaluation weights

Furthermore, the results obtained from the proposed approach are compared with the crisp QFD method and QFD with neutrosophic AHP [40]. Table 8 presents the rankings of TCs in a seat design, obtained by these methods. As it can be seen from Table 17, although there were some changes in the results between the methods, similar results are obtained in general. However, the results of the proposed neutrosophic QFD method are more similar to the results coming from QFD with neutrosophic AHP [40] than the results of crisp QFD.

Table 17: Comparison of rankings obtained by different methods

	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9	TC10	TC11	TC12	TC13	TC14
Methods	**Ranks of TCs**													
1	2	3	4	11	5	8	10	1	6	12	7	13	14	9
2	2	3	4	8	5	7	9	1	10	11	12	13	14	6
3	2	3	4	11	5	7	8	1	6	12	9	13	14	10

1: Proposed neutrosophic QFD

2: Crisp QFD

3: QFD with neutrosophic AHP [40]

Moreover, Spearman's rank correlation test is also applied to observe the relation between the obtained results. Table 18 presents the test results.

Table 18: Spearman's rank correlation test results

	Proposed Method	Crisp QFD	neutrosophic AHP [40]-QFD	Average
Proposed Method	-	0.86	0.98	0.92
Crisp QFD	-	-	0.89	0.89
Neutrosophic AHP [40] AHP-QFD	-	-	-	-
			Total Average	**0.90**

As in Table 18, the results of the two of the neutrosophic methods are almost identically the same. Since both methods' effectiveness is proved in the literature, whether fully neutrosophic or parameter-based calculations, the proposed method results are validated. Moreover, to see the effect of indeterminacy on the results, we also used the crisp QFD method. The changes in the results are minimal since their similarity is very high with both of the neutrosophic methods. Its reason is the lower indeterminacy values that are conducted during the application phase. If the indeterminacy of the experts is high, then the difference will also be increased. But, if the indeterminacy of the experts becomes high, then validation of the results will be difficult. Therefore, the neutrosophic concept allows decision makers to distinguish absoluteness and relativity by considering indeterminacy. Through that, decision-makers can set a threshold value for the indeterminacy, which we applied as at most 0.3. For the values that are higher than this threshold value, decision-makers can neglect them to involve the decision-making processes.

5. Discussion

Based on the outputs of the proposed methodology and applied analyses, discussions concerning theoretical and managerial aspects have been carried out in the following sub-sections.

5.1. Theoretical Implications

Since the customer-oriented product design process consists of both qualitative and quantitative data, the most reasonable way of handling the assessments is to involve uncertainty concepts in the mathematical operations of the applied methodology to produce meaningful outcomes. For an effective representation, fuzzy logic is one of the most sensible concepts that can be conducted to the solution process. In the proposed methodology, an integrated decision-making methodology is extended with neutrosophic sets, which offers a domain area that is able to model the impreciseness of the data and indeterminacy of the experts with three independent subsets of uncertainty. In the integrated methodology, DEMATEL and AHP methods are used to understand customer demands better, to realize the gap between customer demands and TCs of the developed product, and to observe the gap between the competitors and developed product. In this sub-section, the advantages and possible limitations of the proposed methodology have been discussed for the researchers or managers who will apply our approach for their systems. The important phases of the methodology can be summarized as construction of the scales, DEMATEL technique, and AHP method. Therefore, in the following, the advantages and limitations of these phases will be discussed. For constructing the scales (both used in extended DEMATEL and AHP methods), computing with words concept is used. Computing with Words (CWW), a concept that is used to operate the data defined with natural language to represent the uncertainty of human-based knowledge, is introduced by Zadeh [78]. In this concept, the linguistic terms are used to label the natural language in a dataset, which may contain imprecise, indeterminant, incomplete information with hesitant thoughts [79]. In our proposed neutrosophic QFD methodology, experts are both imprecise and indeterminant to some degree while evaluating the system. Moreover, since some part of the QFD methodology is fully dependable on subjective information gathering impeccable data, which is precise and complete with no indeterminacy, is not possible. Thus, linguistic scales for each applied method are constructed, which aims to deal with the mentioned situations during the evaluations. There are three main components during the scale construction: the lowest linguistic term, mid-one, and highest linguistic term with corresponding interval-valued neutrosophic numbers. Based on the discussions, intermediate linguistic terms are also determined. In the determination of the neutrosophic numbers, it is observed that experts have difficulty while assigning the intermediate linguistic terms. Its reason can be explained as follows: Consider a chart that belongs to a population with normal distribution. Most of the values are spread around the average value, and as it gets closer to the smallest and largest values, the existing values that can be assigned are decreased. Therefore, for an expert who wants to assign a value that is close to the average one, many values can be picked from the poll. Similar to that, for an evaluation, which is the highest rate, there are only a few possible choices. Therefore, in our scale, the indeterminacy value is increased when the linguistic terms are close to the average value. The second important part of the constructing scales with the neutrosophic concept is to enable observation of the level of indeterminacies of the experts during the evaluations. Apart from the other extension of the fuzzy sets and fuzzy sets themselves, the most advantageous characteristic of the concept of neutrosophic sets is to distinguish between relativity and absoluteness. Through that, the type of uncertainty, indeterminacy, can be conducted to mathematical operations to consider experts' hesitancy. Moreover, decision-makers can be able to see the level of indeterminacy for an expert that can be used for the decision or not where the evaluations can be used for the problem or can be neglected. If the level of indeterminacy for an expert is considerably high for the decision-makers, then the expert's evaluations can be neglected. Therefore, the indeterminacy subset can be observed by the level of indeterminacy and more verified results can be produced in the neutrosophic set concept.

For such a system that decision-making structure components are highly dependable to each other, one of the most crucial steps is to decide involving these relations in the problem or not. Again, for such a decision-making structure that we used, considering the criteria have no dependency between each other is unrealistic and does not reflect the system characteristics well. In our application, the neutrosophic DEMATEL approach has been conducted to determine the relationships and their magnitudes among TCs. To reveal the relations among TCs, applying a systematic and quantitative approach promises meaningful outcomes, which improve the application results. Neutrosophic DEMATEL is a technique that is able to consider the uncertainty of the system (both impreciseness of the data and indeterminacy of the expert) and produces outcomes that show the magnitudes of the relations based on an initial relationship matrix. For the steps of the neutrosophic DEMATEL, we firstly designed a scale for the linguistic evaluations, which has corresponded to interval-valued neutrosophic numbers, and then based on the evaluations, constructed the initial relationship matrix. For the applicability of the matrix calculations, a deneutrosophication process is carried out. By deneutrosophication, we incorporate both types of uncertainties into the calculations. Since neutrosophic matrix operations are not practical and cumbersome for this process, we preferred to include neutrosophic numbers in this process by letting experts to express their judgments in the form of linguistic terms.

Another essential step for an assessment problem is to determine the weights of the customer requirements and customer competitive assessment. Since the considered structure is hierarchy-based, the AHP method extended with neutrosophic sets has been used for the calculations. The most challenging phase of the method is collecting the data, which is gathered by the experts' evaluations of the pairwise comparison matrices. The difficulty for this phase is ensuring consistency, which is proof of the validation of the evaluations. Moreover, when the dimension of the comparison matrix is increased, the consistency condition becomes difficult to maintain. Since the most advantageous side of AHP is dividing the whole problem into sub-problems, we offer the researcher/managers to divide the considered problem into sub-problems as much as possible. Moreover, the proposed interval-valued neutrosophic AHP method offers a fully neutrosophic environment during all of its steps with neutrosophic operations. Through the results of the applications and further analyses, the proposed methodology for the customer-oriented product design can be an efficient decision-making tool to generate solutions and meaningful inferences and decisions for the systems that have uncertain data.

5.2. Managerial Implications

It is expected that the targeted customer segment will prefer the products designed by the enterprises that adopt the proposed approach, as a better understanding of customer requirements, better matching of these requirements with TCs, and in addition to these, taking into account other products in the market will provide a superior product design. Moreover, when customers see that their wishes and needs are better reflected in the products, customer loyalty will also be positively affected. Since this will return to the enterprises as an increase in sales volume and profits, it enables these enterprises to gain an advantage over their competitors. In addition, as the quality of a product or service is defined as conformity to specifications, requirements, meeting customer expectations [80–84]; designing products/services that better incorporate customer voice to design process while considering relations among TCs ensures that the quality of the products is at a desired level. In other words, the use of the proposed approach will positively affect the quality management studies of the enterprises.

6. Conclusions

The rapid developments in technology and industry have increased the speed of product release to the market. Increasing product variety required companies to produce more successful products than competitors' products in order to maintain their success. In order to achieve this goal, companies should not only understand customer expectations and their position among their competitors but also integrate their findings into design process. Therefore, in this study, a new approach based on QFD, AHP, DEMATEL, and neutrosophic sets are proposed to prioritize TCs with respect to their weights. Although TCs, customer requirements, and competitor assessments are taken into account in classical QFD as well, these components are obtained by neutrosophic AHP and neutrosophic DEMATEL in the proposed approach. Since the representation of relations between customer requirements and TCs is made with neutrosophic numbers as well, the integration of all these components are also carried out with neutrosophic operations. In this way, uncertainty in the weighting of customer requirements, the relationships among TCs and the assessment of the relations between TCs and customer requirements might be better represented. As the customers requirements are better associated with the TCs by considering uncertainty, the voice of customer is better incorpotated into the design process. Even though the utilization of AHP and DEMATEL provides an analytical base to identify the weights of customer requirements and the relationships between TCs, there might be a disadvantage of incorporating them into the proposed approach. The disadvantage of using AHP is that as the number of factors considered increases, ensuring the consistency of AHP matrices might be quite challenging. Moreover, the number of sub-factors under the main factors should be similar to each other while using AHP. Otherwise, AHP might yield unreliable results. In addition, since these techniques have a certain level of complexity, it is better to make the related assessments by informing the participants or carrying out them in the presence of an expert which will increase the cost of design phase.

Thanks to this method, managers can convey customer expectations to TCs more effectively, as well as have the opportunity to market a better designed product by considering similar products of competitors. In this way, the level of meeting customer expectations and therefore customer satisfaction will increase. In addition, being able to reveal how important a feature is for customers and giving less importance to features that have a low impact on customer satisfaction during product design make this approach cost effective. Therefore, the proposed approach is an effective method that can be used in customer-oriented product designs as a decision support system that ensures a more efficient and more profitable production process.

The proposed approach is adopted to seat design of passenger cars with a customer–oriented perspective. These results indicate that *Seat Height* is the most important TC followed by *The vertical travel range value* and *The horizontal travel range value*. Moreover, the comparative and sensitivity analyses indicated that the proposed method is robust and produces reliable outputs.

In future studies, this approach can be used by public or private firms from different sectors as well since this method can be used not only in car seat design but also in all customer-oriented product development. Moreover, other types of fuzzy sets such as intuitionistic, hesitant and Pythagorean fuzzy sets which represent uncertainty in different ways can be incorporated to such a methodology. Furthermore, other multi-criteria decision making techniques can be utilized for competitor assessment and weighting of customer expectation depending on their structure.

Appendix

Table A1: Pairwise comparison of main customer requirements

Goal	C1	C2	C3	C4
C1	A	L	BA	AA
C2	H	A	AA	CH
C3	AA	BA	A	H
C4	BA	CL	L	A

Table A2: Corresponding neutrosophic weights obtained from neutrosophic AHP

C1	<[0.055, 0.136], [0.222, 0.266], [0.205, 0.271]>
C2	<[0.294, 0.55], [0.177, 0.234], [0.034, 0.06]>
C3	<[0.126, 0.264], [0.222, 0.266], [0.101, 0.148]>
C4	<[0.012, 0.05], [0.177, 0.234], [0.403, 0.521]>

Table A3: Pairwise comparison of customer requirements related to visibility

	C11	C12	C13
C11	A	A	A
C12	A	A	A
C13	A	A	A

Table A4: Corresponding neutrosophic weights obtained from neutrosophic AHP

C11	<[0.083, 0.333], [0.286, 0.333], [0.222, 0.333]>
C12	<[0.083, 0.333], [0.286, 0.333], [0.222, 0.333]>
C13	<[0.083, 0.333], [0.286, 0.333], [0.222, 0.333]>

Table A5: Pairwise comparison of customer requirements related to easy reach to controls and pedals

	C21	C22
C21	A	AA
C22	BA	A

Table A6: Corresponding neutrosophic weights obtained from neutrosophic AHP

C21	<[0.314, 0.757], [0.423, 0.5], [0.153, 0.245]>
C22	<[0.076, 0.243], [0.423, 0.5], [0.549, 0.755]>

Table A7: Pairwise comparison of customer requirements related to easy adjustments

	C31	C32	C33
C31	A	CL	BA
C32	CH	A	H
C33	AA	L	A

Table A8: Corresponding neutrosophic weights obtained from neutrosophic AHP

C31	<[0.017, 0.07], [0.24, 0.324], [0.472, 0.627]>
C32	<[0.374, 0.708], [0.228, 0.311], [0.056, 0.094]>
C33	<[0.09, 0.222], [0.304, 0.366], [0.206, 0.279]>

Table A9: Pairwise comparison of customer requirements related to drivers' comfort

	C41	C42	C43	C44
C41	A	AA	BA	H
C42	BA	A	L	AA
C43	AA	H	A	VH
C44	L	BA	VL	A

Table A10: Corresponding neutrosophic weights obtained from neutrosophic AHP

C41	<[0.126, 0.264], [0.217, 0.26], [0.101, 0.149]>
C42	<[0.055, 0.136], [0.217, 0.26], [0.206, 0.272]>
C43	<[0.279, 0.541], [0.196, 0.24], [0.036, 0.064]>
C44	<[0.016, 0.059], [0.196, 0.24], [0.406, 0.515]>

Table A11: Pairwise comparison of competitors on good visibility for displays

C11	OP	CP1	CP2	CP3
OP	A	CL	VL	BA
CP1	CH	A	H	AA
CP2	VH	L	A	A
CP3	AA	BA	A	A

Table A12: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.012, 0.045], [0.168, 0.224], [0.397, 0.505]>	0.23
CP1	<[0.29, 0.549], [0.175, 0.233], [0.034, 0.059]>	0.51
CP2	<[0.099, 0.22], [0.208, 0.253], [0.155, 0.214]>	0.36
CP3	<[0.069, 0.186], [0.245, 0.29], [0.153, 0.222]>	0.33

Table A13: Pairwise comparison of competitors on good visibility for control panel

C12	OP	CP1	CP2	CP3
OP	A	CL	CL	BA
CP1	CH	A	VL	H
CP2	CH	VH	A	CH
CP3	AA	L	CL	A

Table A14: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.008, 0.037], [0.166, 0.247], [0.41, 0.535]>	0.21
CP1	<[0.146, 0.245], [0.184, 0.25], [0.105, 0.137]>	0.4
CP2	<[0.386, 0.627], [0.153, 0.231], [0.029, 0.05]>	0.56
CP3	<[0.037, 0.091], [0.205, 0.272], [0.213, 0.278]>	0.3

Table A15: Pairwise comparison of competitors on good visibility through the windshield

C13	OP	CP1	CP2	CP3
OP	A	VH	CH	H
CP1	VL	A	A	BA
CP2	CL	A	A	CL
CP3	L	AA	CH	A

Table A16: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.334, 0.6], [0.17, 0.231], [0.031, 0.053]>	0.53
CP1	<[0.022, 0.079], [0.236, 0.284], [0.296, 0.395]>	0.25
CP2	<[0.013, 0.06], [0.163, 0.236], [0.308, 0.414]>	0.27
CP3	<[0.151, 0.261], [0.189, 0.249], [0.102, 0.137]>	0.4

Table A17: Pairwise comparison of competitors on easy reach to control buttons

C21	OP	CP1	CP2	CP3
OP	A	CL	CL	BA
CP1	CH	A	AA	CH
CP2	CH	BA	A	A
CP3	AA	CL	A	A

Table A18: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.009, 0.039], [0.157, 0.229], [0.39, 0.511]>	0.23
CP1	<[0.354, 0.588], [0.157, 0.229], [0.031, 0.054]>	0.54
CP2	<[0.12, 0.228], [0.209, 0.271], [0.144, 0.205]>	0.36
CP3	<[0.051, 0.145], [0.209, 0.271], [0.162, 0.231]>	0.33

Table A19: Pairwise comparison of competitors on easy reach to pedals

C22	OP	CP1	CP2	CP3
OP	A	VH	A	AA
CP1	VL	A	L	L
CP2	A	H	A	A
CP3	BA	H	A	A

Table A20: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.195, 0.411], [0.206, 0.248], [0.074, 0.119]>	0.44
CP1	<[0.014, 0.057], [0.181, 0.223], [0.385, 0.481]>	0.24
CP2	<[0.099, 0.306], [0.228, 0.27], [0.12, 0.19]>	0.37
CP3	<[0.083, 0.227], [0.217, 0.259], [0.145, 0.21]>	0.35

Table A21: Pairwise comparison of competitors on easy adjustment for knee-buttock comfort

C31	OP	CP1	CP2	CP3
OP	A	CL	CL	L
CP1	CH	A	A	H
CP2	CH	A	A	CH
CP3	H	L	CL	A

Table A22: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.006, 0.034], [0.157, 0.231], [0.416, 0.531]>	0.22
CP1	<[0.182, 0.407], [0.207, 0.271], [0.065, 0.106]>	0.43
CP2	<[0.24, 0.445], [0.17, 0.246], [0.064, 0.101]>	0.47
CP3	<[0.047, 0.114], [0.189, 0.251], [0.199, 0.263]>	0.32

Table A23: Pairwise comparison of competitors on easy adjustment for back comfort

C32	OP	CP1	CP2	CP3
OP	A	CH	A	CH
CP1	CL	A	CL	VL
CP2	A	CH	A	CH
CP3	CL	VH	CL	A

Table A24: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.223, 0.43], [0.179, 0.263], [0.063, 0.099]>	0.45
CP1	<[0.005, 0.03], [0.157, 0.237], [0.432, 0.542]>	0.21
CP2	<[0.223, 0.43], [0.179, 0.263], [0.063, 0.099]>	0.45
CP3	<[0.062, 0.11], [0.157, 0.237], [0.198, 0.26]>	0.33

Table A25: Pairwise comparison of competitors on easy adjustment for neck-head comfort

C33	OP	CP1	CP2	CP3
OP	A	CH	H	CH
CP1	CL	A	VL	VL
CP2	L	VH	A	A
CP3	CL	VH	A	A

Table A26: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.356, 0.605], [0.153, 0.229], [0.03, 0.052]>	0.55
CP1	<[0.007, 0.034], [0.166, 0.23], [0.421, 0.521]>	0.22
CP2	<[0.086, 0.195], [0.234, 0.284], [0.151, 0.21]>	0.34
CP3	<[0.077, 0.166], [0.192, 0.257], [0.155, 0.217]>	0.35

Table A27: Pairwise comparison of competitors on easy fore-and-aft adjustment

C41	OP	CP1	CP2	CP3
OP	A	H	BA	CH
CP1	L	A	CL	A
CP2	AA	CH	A	VH
CP3	CL	A	VL	A

Table A28: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.173, 0.301], [0.191, 0.251], [0.093, 0.131]>	0.41
CP1	<[0.015, 0.067], [0.2, 0.26], [0.302, 0.404]>	0.26
CP2	<[0.32, 0.565], [0.182, 0.241], [0.032, 0.055]>	0.52
CP3	<[0.016, 0.066], [0.189, 0.249], [0.311, 0.41]>	0.26

Table A29: Pairwise comparison of competitors on easy backrest adjustment

C42	OP	CP1	CP2	CP3
OP	A	AA	CL	A
CP1	BA	A	VL	BA
CP2	CH	VH	A	CH
CP3	A	AA	CL	A

Table A30: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.053, 0.138], [0.199, 0.262], [0.164, 0.233]>	0.33
CP1	<[0.018, 0.061], [0.218, 0.265], [0.372, 0.482]>	0.23
CP2	<[0.427, 0.664], [0.143, 0.212], [0.03, 0.052]>	0.58
CP3	<[0.053, 0.138], [0.199, 0.262], [0.164, 0.233]>	0.33

Table A31: Pairwise comparison of competitors on easy altitude adjustment

C43	OP	CP1	CP2	CP3
OP	A	VH	A	VH
CP1	VL	A	BA	A
CP2	A	AA	A	H
CP3	VL	A	L	A

Table A32: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.234, 0.46], [0.192, 0.235], [0.068, 0.107]>	0.46
CP1	<[0.026, 0.088], [0.212, 0.254], [0.29, 0.386]>	0.27
CP2	<[0.143, 0.369], [0.224, 0.266], [0.072, 0.117]>	0.41
CP3	<[0.021, 0.083], [0.202, 0.244], [0.298, 0.39]>	0.27

Table A33: Pairwise comparison of competitors on easy headrest adjustment

C44	OP	CP1	CP2	CP3
OP	A	H	A	H
CP1	L	A	BA	A
CP2	A	AA	A	AA
CP3	L	A	BA	A

Table A34: Corresponding neutrosophic weights and defuzzified values

	Neutrosophic values	Values obtained after deneutrosophication
OP	<[0.176, 0.423], [0.2, 0.24], [0.072, 0.117]>	0.44
CP1	<[0.031, 0.108], [0.21, 0.25], [0.282, 0.381]>	0.28
CP2	<[0.145, 0.36], [0.22, 0.26], [0.076, 0.121]>	0.41
CP3	<[0.031, 0.108], [0.21, 0.25], [0.282, 0.381]>	0.28

Table A35: Abbreviation List

QFD	Quality Function Deployment
DEMATEL	Decision Making Trial and Evaluation Laboratory
HoQ	House of Quality
CR	Customer Requirement
TC	TC
AHP	Analytic Hierarchy Process
FMEA	Failure Modes and Effects Analysis
TRIZ	Theory of Creative Problem Solving
ECQFD	Environmentally Conscious Quality Function Deployment
FAST	Function Analysis System Technique
EGM	Evaluation Grid Method
IF	Importance Frequency
MULTIMOORA	Multi-Objective Optimization on The Basis Of Ratio Analysis
VIKOR	Viekriterijumsko Kompromisno Rangiranje
TOPSIS	Technique for Order of Preference By Similarity To Ideal Solution
ANP	Analytic Network Process
IVN	Interval-Valued Neutrosophic
OP	Original Product
CP	Competing Product

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HIGHLIGHTS

- A customer-oriented product design approach is developed and applied for car seats.
- A new methodology based on QFD, DEMATEL, AHP and neutrosophic sets is proposed.
- The proposed approach can handle uncertainty in customer expectations.

CREDIT AUTHOR STATEMENT

Manuscript title: Customer–oriented Product Design Using an Integrated Neutrosophic AHP & DEMATEL & QFD Methodology

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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