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QUALITY PAPER

Integration of multi-criteria decision-making approaches adapted for quality function deployment: an analytical literature review and future research agenda

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Abstract

Purpose – This paper aims to classify journal papers in the context of hybrid quality function deployment QFD and multi-criteria decision-making (MCDM) methods published during 2004–2021.

Design/methodology/approach – A conceptual classification scheme is presented to analyze the hybrid QFD-MCDM methods. Then some recommendations are given to introduce directions for future research.

Findings – The results show that among all related areas, the manufacturing application has the most frequency of published papers regarding hybrid QFD-MCDM methods. Moreover, using uncertainty to establish a hybrid QFD-MCDM the relevant papers have been considered during the time interval 2004–2021.

Originality/value – There are various shortcomings in conventional QFD which limit its efficiency and potential applications. Since 2004, when MCDM methods were frequently adopted in the quality management context, increasing attention has been drawn from both practical and academic perspectives. Recently, the integration of MCDM techniques into the QFD model has played an important role in designing new products and services, supplier selection, green manufacturing systems and sustainability topics. Hence, this survey reviewed hybrid QFD-MCDM methods during 2004–2021.

Keywords Customer requirements (CRs), Engineering characteristics (ECs), Quality function deployment (QFD), Multi-criteria decision-making (MCDM)

Paper type Literature review

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List of acronyms

Acronym	Description
AHP	Analytic hierarchy process
ANP	Analytic network process
BOCR	Benefits, opportunities, costs and risks analysis
BWM	Best-worst method
COPRAS	Complex proportional assessment
CR	Customer requirement
CRM	Customer relationship management
CSF	Critical success factors
DEA	Data envelopment analysis
DEMATEL	Decision-making trial and evaluation laboratory
DM	Delphi method
DMs	Decision-makers
DR	Design requirement
EC	Engineering Characteristic
EDAS	Evaluation based on distance from average solution
EGM	Evaluation grid method
GP	Goal programming
GRA	Grey relational analysis
HFLTS	Hesitant fuzzy linguistic term sets
HOQ	House of quality
ISM	Interpretive structural modelling
IT2FS	Interval type-2 fuzzy sets
IVIF	Interval-valued intuitionistic fuzzy
LINMAP	Linear programming model for multidimensional analysis of preference
MADM	Multiple-attribute decision-making
MCDM	Multi-criteria decision-making
MDM	Maximizing deviation method
MODM	Multi-objective decision making
MOORA	Multi-objective optimization based on ratio analysis
NN	Neural network
FR	Functional requirement
NPD	New product development
OA	Organization agility
OEM	Original equipment manufacturing
PR	Product requirement
QC	Quality characteristic
QFD	Quality function deployment
QUALIFLEX	Qualitative flexible multiple criteria method
RSPs	Receiver State Parameters
RST	Rough set theory
RUC-APS	Risk and uncertain condition for agriculture production system
SFS	Spherical fuzzy sets
SI	Sustainable indicators
SME	Small and medium enterprise
SPI	Sustainable production indicator
SPR	Sustainable passenger requirements

SWARA	Stepwise weight assessment ratio analysis
TA	Technical attribute
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TRIZ	Theory of Inventive Problem Solving
VIKOR	Visekriterijumska Optimizacija i Kompromisno Resenje
WASPAS	Weighted aggregated sum product assessment
ZOGP	Zero-one goal programming

1. Introduction

The fast-growing and rapidly changing markets in today's competitive environment have made the product/service quality a key determinant for business success. In general, effective capturing of customer requirements (CRs) is a major advantage for product-oriented firms. In this regard, quality function deployment (QFD) is an efficient customer-oriented design tool that aims to meet customer expectations in a better way and enhance organizational capabilities while maximizing company goals. In 1972 in Japan, in order to develop a product, QFD emerged as a sufficient systematic tool in Mitsubishi heavy industry to translate CRs throughout the design, planning and implementation phases of the product (Li *et al.*, 2014). Basic concept of QFD is to translate the customers' expectations into design requirements. QFD helps a company to make a trade-off between what the customer wants and what the company can afford to produce. The fulfilment of customer needs depends on features of the product/service which can be considered as engineering characteristics (ECs). It is important to determine the requirements that bring more satisfaction to the customer than others. Many industries have employed the QFD technique in various areas including transportation and communication, electronics and electrical utilities, software systems, manufacturing services, education and research, aerospace, agriculture, construction, environment protection, packaging and so on (Chan and Wu, 2002). The QFD in product development consists of four phases: product planning, parts design, process planning and process control planning. The relationship matrix in each stage between CRs and ECs is called the house of quality (HOQ) (Wu *et al.*, 2020). The relationship between CRs and ECs reflects the impact of the fulfilment of the ECs on the satisfaction of the CRs. These relationships should be calculated by QFD team members. The relationship between CRs and ECs [and the relationship between the ECs themselves] are usually determined by linguistic variables. In other words, they are usually interpreted as symbols which should be converted into crisp numbers. The degree of these relationships is usually expressed on a scale system such as 0-1-3-9 or 0-1-3-5, representing linguistic expressions such as "no relationship", "weak/possible relationship", "medium/moderate relationship" and "strong relationship". Table 1 shows the symbols and related weights between CRs and ECs in HOQ.

In order to develop the conventional QFD technique for establishing a more precise ranking process, multi-criteria decision-making (MCDM) methods can be employed. Such methods evaluate a set of alternatives taking different criteria into account under a deterministic or uncertain decision environment. If the data are based on human perception rather than accurate numbers, uncertain analytical tools such as fuzzy methods can be

Table 1. Symbols and related weights between CRs and ECs in HOQ

HOQ ranking system		
⊙	Strong	9
○	Medium	3
Δ	Weak	1
	No relationship	0

employed (Gündoğdu and Kahraman, 2020). Since 2004, the hybrid QFD-MCDM methods have received increasing attention from both practical and academic perspectives.

The current review investigates subjective categorization and qualitative analysis of the articles during 2004–2021 in QFD-MCDM combinations to achieve a new direction for future agenda and differentiate the review paper from other similar works. The questions which come up differ from previous studies as below answered in this research as reasons for proposing this bibliographic study.

Q1. What is the geographical scope of studies concerning hybrid QFD-MCDM? The answer can identify the geographical scope and evolutionary trend of applications.

Q2. What is the distribution of studies in terms of application in different areas? The answer would show the widespread application of the pointed topic in various areas and how it is distributed in case of application.

Q3. What is the distribution of studies combined with hybrid QFD-MCDM considering the methodology? The answer can show the development of the use of QFD-MCDM during 2004–2021 in different applied procedures.

This article contributes to quality management and customer requirement investigations and the various application QFD-MCDM models. This paper addresses the combination and frequency of use of MCDM and other models and tools with QFD and classes the application of the hybrid MCDM-QFD into three categories. The findings present a broader and more accurate focus on the evaluation tables of the hybrid QFD-MCDM models than the reviewed models. The research findings also indicate the geographical distribution and frequency of publication of new integrated methods in terms of the time horizon of the pointed-out topic.

This paper presents a conceptual classification scheme and classifies more than 59 relevant papers in this area published during the interval 2004–2021. The relevant papers are categorized and analyzed under different metrics. Based on the analytical results, some directions for future studies are recommended. The main objective of this paper is to fill the gap and to provide a recent state-of-the-art survey taking the hybrid QFD-MCDM methods into account.

The rest of this paper is organized as follows: In Section 2, first, the integrated QFD and MCDM methods are discussed. Then, in subsection 2.2, the incorporation of other concepts such as fuzzy theory into QFD-MCDM models is addressed. Afterward, the application of QFD-MCDM methods is discussed concerning their practical applications. Discussion remarks are presented in Section 3. Finally, Conclusion and directions for future research are given in Section 4.

2. Proposed advanced QFD models

In this paper, based on the search string, research has been done by the QFD and MCDM keywords on the "Publish or Perish" application considering the Web of Science, Scopus and Google Scholar databases to obtain the relevant articles for bibliographical review analysis. The initial result identified 997 items with a total citation of 38,433 considering the articles published from 2004–2021 in Journal and conference publications. After eliminating the duplicates, 881 articles were retrieved, and after excluding the non-English articles and conferences, 315 items were extracted. After screening the abstracts and whole manuscripts to be sure to not eliminate the relevant articles, the relevancy of the given topic focused on the integration of MCDM and QFD and the high H-index. Finally, 59 articles were referenced as literature review research.

As noted, this paper classifies the relevant literature into the following three categories.

(1) QFD-MCDM Models.

(2) Hybrid QFD-MCDM models. QFD-MCDM and combination of other approaches such as Fuzzy theory, Kano model and other tools.

(3) Hybrid QFD-MCDM in various areas:

- Healthcare, education, market segment and financial services.
- Supplier selection.
- Industries including aerospace, agriculture, construction, automotive, electrical and computer utilities.

Conventional QFD is more qualitative in terms of the parameters' importance to develop the QFD for establishing a more precise ranking process the MCDM methods can be employed. Kim *et al.* (2000) applied MCDM tools to optimize CRs with target value ranking the ECs in the QFD matrices. Since 2004, the hybrid QFD-MCDM methods have received increasing attention from both practical and academic perspectives because of QFD itself as a more qualitative tool and to improve the importance weight which is significant in QFD process matrices for evaluating the criteria and improving the output of the matrices as a quantitative result of the QFD. Alinezhad and Seif (2020) used MCDM to develop the imprecise CRs' ranking and proposed the decision-making tool to improve supplier selection by prioritizing and comparing them in the QFD technique.

Cui *et al.* (2021) applied the novel MCDM method namely SWARA (stepwise weight assessment ratio analysis) to the QFD in the manufacturing sector in terms of the large number of criteria which facilitated the data computation rather than traditional MCDM tools and decreased the time-consumption of calculations which if not based on the pairwise comparison doesn't need to have high consistency rate between the CRs or ECs.

It can be discussed that MCDM techniques are the most applied tools in the QFD because of the importance of evaluating the CRs and ECs. In the HOQ, to improve the ranking precision and decrease the computing and quantifying of the model, MCDM tools became strong combination of QFD. Then, it is important to provide a comprehensive literature review of hybrid QFD-MCDM methods. In previous reviews, various types of QFD and Fuzzy-QFD combinations used uncertainty instead of crisp numbers in the HOQ discussed. In the proposed taxonomy, first, we discussed the QFD-MCDM models which are the combination of QFD and MCDM tools. Then, in the second part, the hybrid models consist of QFD-MCDM and sustainability, uncertainty and other supplemental models with hybrid QFD-MCDM in terms of the applied methodology discussed. In the third classification, the hybrid QFD-MCDM methods are described according to how to apply and application area of the methods.

The objective of the three sections was to separate the method adopted in each study and the area of application in section 2.3. For instance, we mean the approach discussed in section 2.2 and the case study explained in section 2.3. Then, some studies discussed in sections 2.1 and 2.2 overlapping in section 2.3 (proposed method in the corresponding case study).

2.1 QFD-MCDM models

As an initial stage of the QFD, it is crucial to convert CRs into engineering characteristics (ECs) and determine the technical importance of each EC. However, as indicated by many researchers, there are various shortcomings in conventional QFD, which limit its efficiency and potential applications. As the main concern, it can be referred to determination of the CRs' weights based on customers' evaluations without having a structured pair-wise comparison among CRs. This issue may lead to an inaccurate ranking of ECs. Moreover, ignoring the decision-maker's preferences by using a linear aggregation method in the traditional QFD

can be considered as the second concern. Since 2004, when MCDM methods were frequently adopted in quality management context, an increasing attention has been drawn from both practical and academic perspectives. In this subsection, the QFD-MCDM methods proposed during the time interval 2004–2021 are discussed as below.

Concerning manufacturing applications, Ho *et al.* (2011) adapted QFD and analytic hierarchy process (AHP) to design and improve the sourcing and rank the suppliers in an automobile manufacturing company. Under QFD-MCDM models situation, Yadav *et al.* (2017) introduced a hybrid framework based on integration of QFD technique with MCDM tools including AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and PROMETHEE to calculate the importance weights of CNs. The authors compared the proposed methods to find the best combination in selection of the proper product (Bike). In order to find the most related criteria and obtain an optimized solution, Sobhanallahi *et al.* (2019) introduced a QFD-TOPSIS approach to address supplier selection problems in the IT department of a private financial institution. To accomplish that, first the main criteria to fulfill the QFD phases were determined, and then a four-round Delphi technique was performed to find the most appropriate sub-criteria. Finally, they prioritized the high-rank suppliers. Moreover, they carried out a sensitivity analysis to obtain the most significant sub-criteria sensitivity rate which is the cause of change in alternatives' rank.

To eliminate the major production wastes, Devnath *et al.* (2020) presented a QFD-TOPSIS model to find and prioritize the lean tools. To achieve that, first, the authors discussed the major wastes signs and used the QFD technique to transform them to seven basic wastes and prioritized them according to their relative weights. Afterwards using the TOPSIS technique, the seven wastes were converted into the main cause of wastes (lean tools). It was found that the inventory waste, overproduction and motion are the crucial wastes on the shop floor. Moreover, it was confirmed that the Kanban, cellular manufacturing and Kaizen are the most efficient tools for waste elimination.

2.2 Hybrid models

Recently, incorporating some other topics such as fuzzy theory, Kano model, DEA, risk optimization and so on to establish hybrid QFD-MCDM methods has been considerably applied by the relevant papers during the time frame 2004–2021. In the following subsection, the integration of such topics into hybrid QFD-MCDM models is presented. At the end of this subsection, the geographical scope undertaken with the physical locations of the proposed research is presented.

To calculate the level of fulfilment of design requirements, Karsak (2004) presented a fuzzy multiple objective programming model that employs imprecise and subjective information inherent in the QFD technique. They utilized linguistic variables to represent the imprecise design information and the relative importance of each design objective. The authors evaluated the efficiency of their proposed fuzzy multiple objective decision analysis by a real-world application. A hybrid two-phase framework by integration of fuzzy analytic network process (FANP), QFD and multi-choice goal programming was proposed by Lee *et al.* (2010) to select the engineering characteristics (ECs) for product design. To accomplish that, first they considered the interrelationship among factors as well as vagueness in human judgments and incorporated the QFD with the super matrix approach of ANP and the fuzzy set theory to calculate the priorities of ECs. In the second phase, to select the most suitable ECs, they established a multi-choice goal programming model by taking the outcome from the first phase and other additional goals into account. Ultimately, they used a real data example of the product design process of backlight unit in thin film transistor liquid crystal display industry in Taiwan to illustrate the practicality of their proposed method.

Thakkar *et al.* (2011) proposed a methodology for supply chain planning in small and medium enterprises (SMEs) by integrating QFD, interpretive structural modelling (ISM), ANP and zero-one goal programming (ZOGP) approaches. They confirmed that their proposed decision framework can effectively help the SME managers to improve the supply chain decisions. They elaborated the application of their proposed methodology by a case study of short blasting equipment manufacturer SMEs. Wang (2014) integrated the fuzzy QFD (FQFD) approach into the FMCDM problems. They obtained adjusted criteria weights through relative preference relation instead of multiplying two fuzzy numbers to derive criteria weights in FQFD. Zaim *et al.* (2014) employed a hybrid ANP-weighted fuzzy methodology to analyse the multifarious relationships between the CRs and technical attributes (TAs) and the relative weights among CRs. For this purpose, they synthesized the renowned capabilities of ANP and fuzzy logic for an effective ranking of the product/service attributes while implementing the QFD approach. Li *et al.* (2014) proposed a novel integrated MCDM method by combining QFD and TOPSIS technique in fuzzy environment. To accomplish that, they used the intuitionistic fuzzy sets to deal with the linguistic opinions. They provided an example to illustrate the applicability of their proposed method. To improve the effectiveness of the QFD in handling the vague, subjective and limited information, Song *et al.* (2014) proposed a novel group decision approach for effective prioritizing of the TAs. They took the advantages of the rough set theory (RST) approach for handling the vagueness with less prior information and the grey relational analysis (GRA) technique for structuring the analytical framework and discovering necessary information about the data interactions. They also used the compressor rotor industrial data to express the merit of their proposed approach.

In order to select important elements among a wide range of sustainability indicators and launch performance factors for improving the sustainability of manufacturing SMEs, Hsu *et al.* (2017) utilized a hybrid methodology based on the QFD approach as the basic structure, fuzzy Delphi method (FDM), modified fuzzy extent analytic hierarchy process (FEAHP) and TOPSIS technique to prioritize the performance factors. Their integrated model helps managers to identify key performance factors and deploy the company's resources to develop the sustainability of the company. Wu *et al.* (2017) proposed a hybrid analytical model based on the integration of decision-making trial and evaluation laboratory (DEMATEL) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) techniques under hesitant fuzzy environment to obtain the importance ratings of ECs in QFD. The hesitant fuzzy DEMATEL has been used to analyse the interrelationships among CRs and determine their weights and the hesitant fuzzy VIKOR to prioritize ECs. Then, it illustrated the feasibility and practicality of their proposed hybrid framework using industrial data borrowed from the product development of the electric vehicle.

Lee *et al.* (2017) first discussed the limitations of the conventional QFD such as generalizing the opinions of multiple decision-makers, dealing with a huge amount of subjective data, performing a large dimensional comparison and taking the uncertainty into account. Then, to tackle the mentioned issues, they developed a comprehensive model by integrating QFD with fuzzy set theory and decision-making methodologies, including the Delphi method, DEMATEL and ANP for implementing new product development (NPD) project. The authors validated the performance of their proposed model using a case study of solar cell manufacturer. Fiorenzo *et al.* (2017) first defined the relationships among CRs and ECs and then employed a consolidated ME-MCDM (multi-expert/multiple criteria decisions making) technique to prioritize the ECs. To accomplish that, it has considered: (1) the relationships among ECs and CRs and (2) the importance of the related CRs. Under uncertain linguistic variables, Peng *et al.* (2018) proposed a systematic decision-making approach for the QFD approach. In this regard, first, they determined CRs based on the hesitant fuzzy linguistic term sets (HFLTSs) to address doubt in human cognition and thought processes.

Second, they defined the tolerance deviation to measure the deviation range of fuzzy linguistic terms for quantitative analysis of CR deviation. Afterwards, to deal with uncertainties, they formulated an information entropy to determine the final importance of design requirements.

Galetto *et al.* (2018) introduced a multi-expert/multiple criteria decision-making based method that does not require any debatable ordinal to cardinal conversion. They assessed theoretical principles and the robustness of their proposed method by some application examples. To overcome the insufficiencies of the traditional QFD, Huang *et al.* (2019) proposed a novel QFD approach based on proportional hesitant fuzzy linguistic term sets (PHFLTSs) and prospect theory. Moreover, using the best-worst method (BWM), the relative importance of the CRs is determined. Moreover, an extended prospect theory is utilized to prioritize the identified ECs. Finally, the two practical examples are provided to evaluate the applicability and advantages of the proposed QFD approach by the authors. To solve complex decision problems in supply chain management, Yazdani *et al.* (2019) proposed a multiple-attribute decision-making (MADM)-based fuzzy QFD methodology. To increase the preciseness and decrease vagueness, they employed the interval valued fuzzy sets and grey relational analysis (GRA) to improve the efficiency of the classical QFD. Moreover, they utilized the grey relational coefficient in their proposed fuzzy QFD to measure the similarity to the ideal solution. To improve new product design process, Kang *et al.* (2018) developed a hybrid method using the evaluation grid method (EGM) and fuzzy Kano model combined with the FAHP-QFD by evaluating the voice of customers (attractive factors) and translate them to DRs. They employed EGM which uses a design philosophy to create attractive product design based on customer's privileges. To accomplish that, they transmitted the hierarchical customer preferences obtained from EGM to the QFD matrix. Besides, they used the fuzzy-Kano model to classify the crucial attractive factors.

Yazdani *et al.* (2020) developed an interval type-2 fuzzy sets (IT2FS) DEMATEL-QFD model to evaluate and rank sustainable supply chain drivers in a group decision-making environment. The authors provided a real research project for eliminating risks in the supply chain related to agricultural production systems to illustrate the application of their proposed fuzzy decision model. Through sensitivity analysis, they confirmed the stability of their proposed model and discussed the advantages of their developed model over the existing ones. Ping *et al.* (2020) introduced a novel QFD approach by integrating the picture fuzzy linguistic sets (PFLSs) and the evaluation based on distance from average solution (EDAS) methods to rank the ECs. In addition, they utilized a combined weighting method based on the TOPSIS method and maximum entropy theory to obtain the weights of the experts objectively. Finally, they elaborated the application of the proposed model by a real-life example from a product-service system design.

Liu and Cheng (2016) introduced a grey quality function deployment (GQFD) method based on the integration of interval grey numbers, QFD and theory of inventive problem solving (TRIZ) techniques. In addition, they developed a new ranking method to determine the ranking order of interval grey numbers. Finally, they highlighted the advantages of their proposed GQFD method using a real industrial data from a computer peripheral product. Babazadeh (2017) used data envelopment analysis (DEA) method to address the uncertainty caused by different behaviour of QFD team members. To achieve that, they considered each member's subjective assessment and constructed a novel DEA method in group situation. Afterwards, they transformed the proposed model into a linear programming problem.

For determining the order of ECs in the QFD, Wu *et al.* (2020) extended a multi-objective optimization model the ratio analysis plus the full multiplicative form (MULTIMOORA) method based on cloud model theory (called C-MULTIMOORA). To accomplish that, first, they converted the linguistic variables obtained by decision-makers into normal clouds and aggregated them using the cloud weighted averaging operator. After that, they calculated the

weights of CRs through a maximizing deviation method with incomplete weight information. Finally, using the C-MULTIMOORA method, they obtained the relative importance of ECs. They provided an empirical case study from an electric vehicle manufacturing organization to validate the advantages of their proposed QFD-MCDM model.

Using a multi-phase QFD approach, Tian *et al.* (2018) introduced a hybrid fuzzy MCDM method to cover the performance evaluation of smart BSPs (bike-sharing programs) considering the customer voices under uncertain conditions. For this purpose, they integrated the fuzzy BWM, fuzzy maximizing deviation method (MDM), and fuzzy multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA). Taking both qualitative and quantitative environmental criteria into account, Babbar and Amin (2018) proposed a model based on QFD and multi-objective mathematical method to select the best suppliers for ranking the orders of a beverage company considering environmental factors. To achieve this, they used a qualitative two-stage QFD method to assess the criteria in supplier selection problem by eliminating the vagueness of human judgments. Afterwards, they adapted a multi-objective mixed-integer linear programming model to determine the beverage order quantity. They considered three methods of weighted-sums, distance and ε-constraint to optimize cost, defect rate, carbon emission, weight of suppliers and on-time delivery objectives. Table 2 summarizes the relevant papers in terms of the practical application and MCDM technique.

To overcome the limitations of the traditional QFD, Liu *et al.* (2019) proposed a novel QFD approach by integrating the extended hesitant fuzzy linguistic term sets (EHFLTSs) and prospect theory. To accomplish that, first, they used the EHFLTSs for the elicitation of hesitant linguistic assessment information of the QFD team members. Then, taking the interrelations between CRs into account, they employed Choquet integral to obtain the aggregated relationship evaluation results. Furthermore, they suggested an extended prospect theory to derive the ranking orders of ECs.

Yazdani *et al.* (2017) presented a new integrated approach based on the DEMATEL and QFD methods. To this end, a multi-objective optimization based on ratio analysis (MOORA) and complex proportional assessment (COPRAS) methods were applied to rank and compare the green suppliers. Initially, the main CRs defined and were used to obtain the TAs for prioritizing the supplier criteria. The authors also utilized the DEMATEL technique to evaluate the establishment of direct and indirect causal relationships between different customer variables. Afterward, the QFD model was applied to establish a relationship matrix to determine the value of each pair of CRs and the supplier selection criteria. Then, the authors identified the supplier rating matrix. The novelty of this model was to use the MOORA and COPRAS methods to indicate whether one alternative is better or worse than another one.

Gündoğdu and Kahraman (2020) introduced a hybrid spherical fuzzy set (SFS)-QFD technique to address the linguistic evaluations of the criteria importance. They used the SFS to prioritize the CRs and improve the ECs values, and, due to this objective, they aggregated judgments in the HOQ matrix, correlation matrix and customer evaluation matrix by spherical fuzzy aggregation operators. They employed a competitive analysis using the SF-TOPSIS to obtain the final weights of competitors. Haber *et al.* (2020) developed a hybrid method considering the QFD technique and Kano model integrated with the fuzzy-AHP for the improvement of product-service systems. The Kano model has been applied to transform the CRs and commute them into Receiver State Parameters (RSPs). Then, the authors used the FAHP for reducing the ambiguity regarding the proper understanding of the PSS receivers. To determine the importance weights for engineering characteristics of the product design, Mistarihi *et al.* (2020) focused on presenting a hybrid FANP-QFD method. To accomplish that, they obtained the relative importance weights of the CRs from fuzzy pairwise comparison matrix by using fuzzy-AHP technique.

Authors	MCDM approach	Practical context
Karsak (2004)	Fuzzy multiple objective programming method	Textile industry (Turkey)
Bayraktaroğlu and Özgen (2008)	AHP, KANO	Library service improvement (Turkey)
Lee *et al.* (2010)	ANP, multi-choice goal programming model	Thin film transistor liquid crystal display industry (Taiwan)
Ho *et al.* (2011)	AHP, Supply chain	Supplier selection in automobile company (UK)
Raharjo *et al.* (2011)	AHP, dynamic QFD, Uncertainty	Education quality in a university (Singapore)
Alinezad *et al.* (2013)	Fuzzy, AHP	Supplier selection in a pharmaceutical company (Iran)
Wang (2014)	Fuzzy, Relative preference relation on MCDM	Bank credit card (Taiwan)
Zaim *et al.* (2014)	Fuzzy, Analytic network process (ANP)	Polyethylene pipes (Turkey)
Li *et al.* (2014)	TOPSIS, Fuzzy	Aviation design (China)
Song *et al.* (2014)	Rough set theory (RST) and grey relational analysis (GRA)	Industrial service design for compressor rotor (China)
Wang *et al.* (2016)	Hybrid group decision-making model based on hesitant 2-tuple linguistic term sets and an extended QUALIFLEX	Market segment selection problem (Vietnam)
Liu and Cheng (2016)	Interval grey number, GQFD, TRIZ	Computer peripheral product (Taiwan)
Ocampo *et al.* (2016)	ANP, AHP, DEMATEL, sustainability	Agriculture manufacturing product (Philippines)
Wu *et al.* (2017)	Hesitant fuzzy DEMATEL, Hesitant fuzzy VIKOR	Product development of electric vehicle (China)
Hsu *et al.* (2017)	Fuzzy Delphi method (FDM), modified fuzzy extent analytic hierarchy process (FEAHP), TOPSIS, Sustainability	Manufacturing SMEs (Taiwan)
Lee *et al.* (2017)	Fuzzy, Delphi method, decision-making trial and evaluation laboratory and analytic network process	Solar cell manufacturing (Taiwan)
Akbaş and Bilgen (2017)	FAHP, FANP, TOPSIS	Wastewater treatment plants (Turkey)
Fiorenzo *et al.* (2017)	multi expert/multiple criteria decisions making	Design of a new model of a climbing safety harness (Italy)
Tavana *et al.* (2017)	ANP, Ratio analysis, Weighted aggregated sum product assessment, Sustainability	Supply selection in a dairy company (Iran)
Yazdani *et al.* (2017)	DEMATEL, MOORA, COPRAS, Green supplier	Supplier selection in a dairy company (Iran)
Babazadeh (2017)	DEA, MODM	-(Iran)
Kang *et al.* (2018)	FAHP, Fuzzy Kano, EGM	New design of Minicars (China)
Van *et al.* (2018)	INS, TOPSIS, Sustainability	Green supply chain (Vietnam)
Abdel-Basset *et al.* (2018)	AHP, Neutrosophic set	Supplier selection in pharmaceutical manufacturing company (Egypt)
Peng *et al.* (2018)	Group decision-making approach	Vortex recoil hydraulic retarder (China)
Galetto *et al.* (2018)	Multi expert/multiple criteria decision-making technique	Design of a new model of a climbing safety harness (Italy)
Bottani *et al.* (2018)	ANP, Benefits, Opportunities, Costs and Risks (BOCR) analysis	Supplier selection for components of machinery in a food company (Italy)
Tian *et al.* (2018)	Fuzzy BWM, fuzzy MDM, fuzzy MULTIMOORA	Bike sharing project, Two-oriented society (China)

(*continued*)

Table 2. Classifications of publications concerning hybrid QFD-MCDM procedure

Authors	MCDM approach	Practical context
Babbar and Amin (2018)	Multi-objective mixed -integer linear programming and trapezoidal fuzzy numbers, environmental factors	Supplier selection in a beverage company (Canada–USA)
Huang *et al.* (2019)	PHFLTS, Best-worst method (BWM)	Design of a flexible manufacturing system/Product development of electric vehicles (China)
Yazdani *et al.* (2019)	Internal valued fuzzy set, Multi attribute decision support model, GRA	Agriculture Production Systems (France)
Liu *et al.* (2019)	EHFLTSs, Choquet integral, Prospect theory	Electric vehicle manufacturing (China)
Yazdani *et al.* (2020)	IT2FS, Decision-making trial and evaluation laboratory (DEMATEL), Sustainability	Agricultural supply chain (Spain)
Ocampo *et al.* (2020)	Fuzzy, AHP, DEMATEL, ANP, MADM, Sustainability	Meat processing industry (Philippines)
Ping *et al.* (2020)	PFLS, TOPSIS/maximum entropy theory, EDAS	Product-service system design (China)
Wu *et al.* (2020)	Uncertainty, MULTIMOORA	Electric vehicle manufacturing (China)
Mistarihi *et al.* (2020)	Fuzzy Analytic Network Process (FANP), fuzzy-AHP	Design of a wheelchair (Jordan)
Gündoğdu and Kahraman (2020)	SFS, Spherical fuzzy TOPSIS	Linear delta robot technology development (Brazil)
Ahmadzadeh *et al.* (2021)	DEMATEL, ERP, OA	Banking sector (Iran)
Haber *et al.* (2020)	FAHP, KANO, PSS	Medical devices (Sweden)
Kaya and Erginel (2020)	HF-SQFD, HF-SWARA, Sustainability	Airport sustainable design/ improvement (Turkey)
Neira-Rodado *et al.* (2020)	Fuzzy Kano, AHP, DEMATEL	Medical surgery aid devices (Italy)
Wang *et al.* (2020a)	Cloud model MCDM, interval-valued fuzzy-rough sets	Air compressor company (China)
Wang *et al.* (2020b)	Multi-attribute grey target decision-making method, Fuzzy, Supply chain management	Supplier selection in Launch vehicle design (China)
Haiyun *et al.* (2021)	IVIF DEMATEL, IVIF MOORA, Green	Green supply chain (China)
Wu and Liao (2021)	BWM, interval-valued linguistic	Aviation service development (China)
Chen *et al.* (2021)	HFLTS, DEMATEL, MULTIMOORA, entropy weight method	CNC machine tool (China)
Fetanat and Tayebi (2021)	Fuzzy, linear programming technique for multidimensional analysis of preference	Water treatment system (Iran)
Ocampo *et al.* (2021)	Fuzzy, DEMATEL, AHP, ANP, Sustainability, Means-end chain	Vegetable cooking oil (Philippines)

Table 2.

Ahmadzadeh *et al.* (2021) ranked the critical success factors (CSF) of enterprise resources planning (ERP). Firstly, they used the DEMATEL technique to identify the CSFs of ERP and the enablers of organization agility (OA). After that, they established a multi-phase QFD to rank both the influencing and influenced criteria. They showed that the organizational structure, IT technology infrastructure and commitment and support by top managers includes indicators with top priority. Kaya and Erginel (2020) developed a new hybrid method based on the hesitant fuzzy (HS)-QFD using sustainable passenger requirements (SPRs) to design or improve an airport based on sustainable criteria including environmental, social and economic. During the decision-making process, to reflect the hesitancy in human nature, they implemented the HF-SQFD method to rank the design requirements for a sustainable airport. Afterwards, they determined the importance weight of SPRs by

employing the hesitant fuzzy stepwise weight assessment ratio analysis (HF-SWARA) method which has the privilege of a less pairwise comparison matrix rather than other MCDM tools. Wang *et al.* (2020b) used an improved QFD methodology by integration of cloud model and GRA. They implemented the comparative analysis of different approaches as well as the sensitivity analysis on criteria weights to demonstrate the stability of their proposed method.

The research scheme of the selected studies is presented through a geographical scope in Figure 1. In this study, the geographical scope shows that China (15 studies), Iran (6 studies), Turkey and Taiwan (5 studies), Italy (4 studies) and the Philippines (3 studies) are the six countries with the highest number of studies on hybrid QFD-MCDM topics, respectively.

2.3 Applications of advanced hybrid QFD-MCDM in different industries

The QFD method has been extensively utilized in different industries and services such as healthcare, research and development, education, supplier selection and so on. The purpose of this subsection is to discuss the different applications of hybrid QFD-MCDM methods.

2.3.1 Healthcare, education, market segment and financial services. Since high-quality urgent services can lead to protection of human life, and healthcare organizations are one of the most important domains, it is vital to develop an integrated model to identify the patient's needs and select the best solution to optimize the quality of healthcare systems. Recently, some studies taking both conventional and hybrid models into account have been presented on this domain. Below we discuss the most important application of hybrid QFD-MCDM techniques in service systems.

Regarding education application, Bayraktaroğlu and Özgen (2008) presented an integrated method using the AHP, Kano model and planning matrix of HOQ to evaluate the requirements of library users. The authors considered the central library services of Dokuz Eylul University (DEU) and evaluated and categorized the student requirements. Raharjo *et al.* (2011) proposed a systematic methodology to deal with customer needs' dynamics in terms of the relative weights in the QFD approach. Thus, the existing studies in three directions are extended. First, the authors proposed a short-term forecasting method to model the dynamics of the AHP-based importance rating. After that, it estimated the

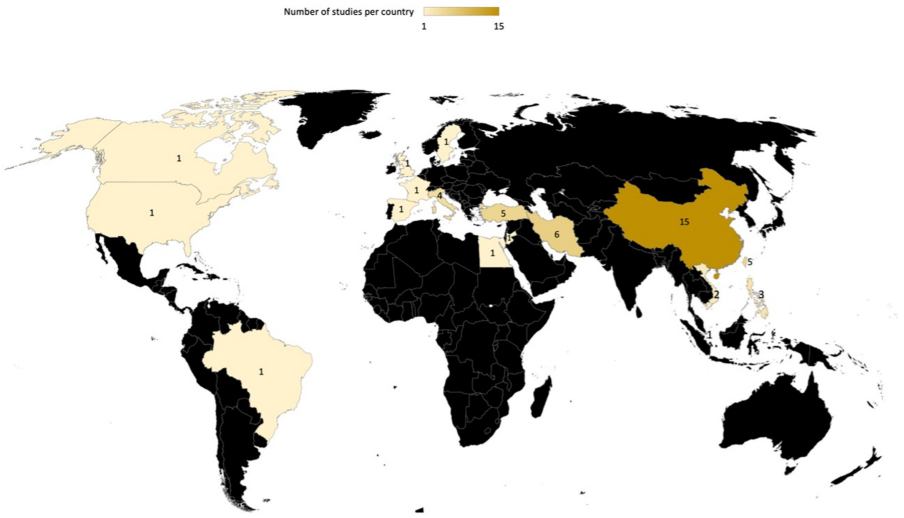

Figure 1. The geographical scope of studies concerning hybrid QFD-MCDM procedure

uncertainty degree of customer needs. Then, a quantitative approach that considers the decision maker's attitude towards risk to optimize the QFD decision-making analysis is employed. Finally, the proposed method is adopted for improving education quality in a university in Singapore.

Wang *et al.* (2016) presented a new hybrid group decision-making model based on hesitant 2-tuple linguistic term sets and an extended QUALIFLEX (qualitative flexible multiple criteria method) approach to handle the QFD problems under incomplete weight values. For this purpose, at the first stage, they integrated hesitant linguistic term sets into interval 2-tuple linguistic variables to express various uncertainties available in the assessment information of QFD team members. Using GRA, they formulated a multi-objective optimization model to determine the relative weights of CRs. Afterward, they extended the QUALIFLEX approach with an inclusion comparison method to rank the DRs identified in the QFD. Finally, they validated their proposed methodology through the market segment selection data. To reduce the likelihood of poor and awkward body postures, Mistarihi *et al.* (2020) used a hybrid QFD-FANP method to assess the modified wheelchair design. A hybrid multiphase fuzzy QFD-MADM framework by integrating the QFD, AHP, DEMATEL and ANP along with fuzzy set theory has been developed by Ocampo *et al.* (2020) for sustainable product design. They implemented the case study of meat processing industry in Philippines to indicate the application of their proposed approach.

Haber *et al.* (2020) developed an integrated method of Kano model, QFD and FAHP to improve medical hemodialysis devices. To accomplish that, they converted the CRs into RSPs by the Kano model and employed the QFDforPSS which can satisfy market expectations rather than traditional QFD by translating the CRs to PSS functionalities. Moreover, FAHP was adapted for reducing the vagueness regarding understanding the CRs. Considering the example of a hip replacement surgery aid device for elderly people, interdependence and vagueness, Neira-Rodado *et al.* (2020) proposed an integrated DEMATEL-AHP-QFD framework to translate the CRs to product features and rank the design alternatives. They employed the fuzzy Kano model to obtain how each CR affects the customer satisfaction.

2.3.2 Supplier selection. Supplier selection plays a crucial role in establishing an effective supply chain by reducing purchase risk, maximizing overall value to the purchaser and developing closeness and long-term relationships among network components. The Supplier selection is defined as the process by which companies identify, assess and contract with suppliers. During the past decades increasing attention has been paid to address hybrid MCDM-QFD methods in the context of supplier selection. Alinezad *et al.* (2013) used fuzzy theory and AHP technique to assess the alternative suppliers in a pharmaceutical company and obtain the CRs weights in QFD model. Yazdani *et al.* (2017) considered the example of a dairy product company and developed a hybrid model using DEMATEL, COPRAS and MOORA techniques integrated with QFD model for evaluating alternative green suppliers and choosing the best candidate by taking conventional and green criteria into account, simultaneously. The authors employed MOORA to optimize two or more conflict criteria simultaneously subjecting to specified constraints and COPRAS to prioritize suppliers based on their significant degrees. They identified two suppliers as the worst suppliers because of their weak capability in terms of energy and natural resource consumption, delivery speed, green design, re-use and recycle rate and production planning. On the other hand, they selected two suppliers as the best ones because of their high re-use and recycle rate as well as quality adaptation values.

Tavana *et al.* (2017) introduced a novel integrated multi-criteria decision-making framework based on the combination of the ANP and QFD approaches for sustainable supplier selection problems. The authors identified a clear hierarchical structure for all relevant sustainable factors and sub-factors and determined the weights of decision criteria

based on the importance given to each CR. Afterward, the suppliers are prioritized using a multi-objective optimization procedure based on ratio analysis and the weighted aggregated sum product assessment (WASPAS) method. Then, the application of the proposed methodology is validated using a real-life example from a dairy company. Aiming at evaluating suppliers, Bottani *et al.* (2018) proposed a structured method based on the QFD, ANP and benefits, opportunities, costs and risks (BOCR) analysis. It is noted that their proposed approach can help companies to derive useful information to guide their partner selection process. It presents a real industrial example from an Italian company to represent the applicability of their model in identifying the most suitable supplier. Abdel-Basset *et al.* (2018) extended a framework for supplier selection problem based on the combination of neutrosophic sets and AHP-QFD. They justified the efficiency of their hybrid method by a real-life application. Taking environmental factors into account, Babbar and Amin (2018) proposed a model based on QFD and a multi-objective mathematical method to select the best suppliers to allocate the orders of a beverage company. To do so, a qualitative two stages QFD method was used to assess the criteria in supplier selection problem while the vagueness of human judgments was eliminated using trapezoidal fuzzy numbers. Also, the authors adapted a multi-objective mixed-integer linear programming in order to determine the beverage order quantity considering three methods of weighted-sums, distance and ε-constraint considering objective functions of cost, defect rate, carbon emission, weight of suppliers and on-time delivery.

Taking sustainability criteria into account, Van *et al.* (2018) used a hybrid QFD approach for green supplier evaluation and selection process. They defined the normalized weighted rating and extended the TOPSIS technique to prioritize the green suppliers. Moreover, they presented a real example to illustrate the efficiency and computational procedure of their proposed framework. Asadabadi (2017) introduced a hybrid method based on the QFD and ANP to address the supplier selection problem in a water-based air cooler company. They utilized a Markov chain to trace the changing priorities of customer needs and identify a pattern for them. Afterward, they adapted the QFD structure to connect CNs to product requirements (PRs) and supplier qualifications. The study showed that the performance of the motor is the most important customer need among performance, reliability, price, serviceability, noise and maintenance cost.

Wang *et al.* (2020a) presented a novel collaborative quality design framework for large complex products' supply chain by integrating the fuzzy QFD and the grey decision-making approach. The authors also used a weighted multi-attribute grey target decision-making method to help decision-makers in identifying the optimal quality scheme under uncertain information and poor data. The authors illustrated the efficiency of their proposed framework by a case study borrowed from a new launch vehicle design in China. Haiyun *et al.* (2021) defined the criteria of green supply chain for each stage of QFD and proposed an integrated framework by integrating IVIF (interval-valued intuitionistic fuzzy), DEMATEL and IVIF MOORA (Multi-Objective Optimization by Ratio Analysis) techniques. It has shown that customer relationship management (CRM) is the most vital innovation strategy for green supply chain management in the energy industry.

2.3.3 Aerospace, agriculture, construction, automotive, electrical and computer applications. QFD emerged in the 1960s in Mitsubishi Heavy Industries as a planning technique for product development (Akao, 1972). Since the QFD is a customer-driven tool, translating the CRs to DRs and implementing the product design and product development based on the conventional QFD is an improvement methodology with four matrixes. A sufficient QFD in product-oriented systems consists of four phases: product planning, part deployment, process planning and production planning. Recently, because of deficiencies in traditional QFD, most of the studies on this domain applied the hybrid QFD-MCDM techniques in this category.

Lin *et al.* (2010) used a fuzzy QFD model by considering interdependent relations of environmental production requirements (EPRs) and sustainable production indicators (SPIs) for an original equipment manufacturing (OEM) firm in Taiwan. Using the XYZ group as a case study has demonstrated the systematic evaluation process for identifying the weighted SPIs. Under fuzzy environment, Ocampo *et al.* (2016) employed an integrated framework based on AHP, DEMATEL, ANP and a four-stages QFD to design an edible oil product by taking sustainability interests of stakeholders into account. Moreover, the authors incorporated comprehensive sustainability requirements to help both design and manufacturing processes. Akbaş and Bilgen (2017) introduced an integrated model of the MCDM technique and fuzzy QFD procedure to maintain sustainable operations in wastewater treatment plants. To avoid inconsistent results of crisp QFD analyses caused by the variability of human judgment, it has utilized the FAHP method for determining the importance weights of attributes in the MCDM model. Also, the authors used the FANP technique for taking both symmetrical and asymmetrical relationships between CRs and ECs into account. Moreover, the comprehensive weight vector of ECs as the weights of the selection criteria is used in the TOPSIS module of the proposed integrated methodology. Kang *et al.* (2018) employed a fuzzy Kano model to identify the quality attributes of minicars properly. To achieve that, experts were asked to fulfil EGM qualitative interviews and quantitative questionnaires to extract attractive factors of customers. Next, the fuzzy QFD was implemented to find the relationship among CRs and minicars design factors. Furthermore, the FAHP method was used to prioritize those factors' weights to identify the most important customers' attractive preferences. In the end, it found "fashionable and tasteful", "appealing and delicate" and "comfortable and ventilated" were the top three factors that should be given priority for designing a minicar.

Ahmadipourroudposht *et al.* (2018) adapted an integrated method using QFD-ANP and multi-objective decision making (MODM) technique considering CRs, technical requirements and budget constraints of designing a dry gas filter product in the Petro-gas company. They ranked the weights of CRs as "Output quality", "Pressure drop", "Cartilage durability", "Cleaning period" and "Appearance dimension", respectively. In addition, they indicated a reduction of around $900 per product in total production cost. For the first time, Gündoğdu and Kahraman (2020) incorporated the SFS in a QFD model for designing linear delta robots. It utilized the spherical fuzzy concept to rate the weights of CRs and showed that the significance of the linear delta robot in industrial products has become more popular in pick-and-place processes, packaging, welding, CNC operations and additive manufacturing. On the other hand, the authors represented that the reduction of the working area is the negative point of linear delta robots. To address this issue the CRs were identified and, to overcome the crisp and vague data and evaluate the company among the competitors, spherical fuzzy-QFD and spherical fuzzy-TOPSIS were adopted to develop the linear delta robots.

Yazdani *et al.* (2019) developed a platform to ease the decision-making process based on the QFD model and GRA under a fuzzy environment. For this purpose, the model is adopted by a "risk and uncertain condition for agriculture production systems" (RUC-APS) project. The environmental, social and economic aspects are considered to provide guidelines for external customers and stakeholders. Besides, the authors employed their proposed model by documents from the RUC-APS project and expert-based decision system to select a supply chain driver and rank the suppliers. Kaya and Erginel (2020) employed a combined method of HF-SQFD and HF-SWARA approaches to improve the quality of the airport design in terms of sustainability criteria. The SPRs which are obtained include "energy efficiency", "green design", "air quality", "water management" and "recycling". Finally, they identified "solar power integrated into the airport building", "production of own electricity with natural gas" and, "heat dissipation roof systems" as the most significant rank of sustainable design requirements. To determine the ranking order of ECs in QFD, Wu and Liao (2021) proposed a

three-stage QFD framework by considering the complex linguistic evaluations of experts. In the first step, it has used the BWM method in determining the importance degrees of CRs and additional requirements. Then, in the second step, the relative importance of design requirements has been determined. Finally, in the third step, the authors calculated the interval weights of alternatives according to the uncertainty degrees of evaluations and the weights of design requirements. A case study is presented of aviation service development for a Chinese airline to illustrate the practicability of their proposed framework. For improving the QFD model, Chen *et al.* (2021) presented a hybrid MCDM method by integrating the hesitant fuzzy linguistic term set (HFLTS), DEMATEL and multi-objective optimization by ratio analysis plus full multiplicative form (MULTIMOORA). To this end, firstly, it used HFLTS to deal with the ambiguity in the evaluation process. Secondly, concerning the interaction relationships among the quality characteristic (QCs), the fuzzy DEMATEL technique is utilized to capture their influence weights. Furthermore, the authors combined MULTIMOORA and entropy weight methods for obtaining the objective weights of CRs and prioritizing the QCs. Finally, the efficiency of their proposed method is highlighted using a real-life example of product design of CNC machine tool. Taking the sustainable design into account, Fetanat and Tayebi (2021) integrated the QFD with a linear programming model for multidimensional analysis of preference (LINMAP) under uncertainty to design the household water treatment system company. They prioritized the most and the least sustainable indicators (SI) in CRs and DRs as the "operation and maintenance costs" and "technical capacity" in CRs, respectively; and "purchasing power" and "liquid waste" in DRs respectively. Ocampo *et al.* (2021) promoted the QFD model using the means-end chain model to transmit the current CRs focused on sustainable requirements of the stakeholder to the next phase of product design parameters (sustainable DRs). The DEMATEL, FANP and FAHP are adopted for the sustainable stakeholders' requirements' prioritization in a vegetable cooking oil product to illustrate these requirements to improve the product design requirements.

In the studies performed according to Table 3, QFD-MCDM hybrid models have played an important role as a new approach in designing and developing new products and services, supplier selection, green manufacturing systems and sustainability. Many studies have been conducted using new MCDM methods in various areas, such as service industries, bank and finance systems, healthcare, supplier selection and manufacturing systems including electrical utilities, automotive, aerospace and agriculture.

Figure 2 depicts the percentage of the studies in the main areas discussed in subsection 2.3. The "industries and manufacturing the products" with 35 studies has the largest share in this review.

General area	Application in various areas	Number of studies	
Healthcare, education and financial services	Healthcare	3	8
	Education	2	
	Market segment	1	
	Financial	2	
Supplier selection	Supplier selection	10	10
Industries and manufacturing products	Aerospace	3	35
	Agriculture	4	
	Construction	1	
	Automotive	8	
	Electrical and computer utilities	8	
	Products (textile, safety harness, medical)	10	

Table 3. Distribution of studies in terms of application in different areas

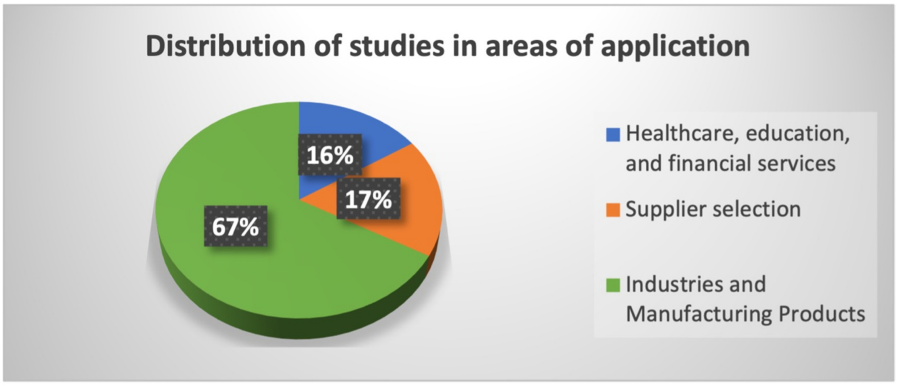

Figure 2.
Distribution of studies in different areas

3. Discussion

Nowadays, the integrated MCDM-QFD methods have been extensively used to solve practical problems using functionalities and properties of MCDM methods. In this regard, it is important for decision-makers (DMs) to combine and extend MCDM techniques for certain objectives and requirements. To improve the QFD-MCDM models to a sufficient model, many recent studies have considered some concepts [including uncertainty, sustainability or supplement quality, manufacturing, optimization and statistical tools] which are represented in this paper as a hybrid QFD-MCDM method in various fields of applications in industries and services.

To prioritize customer needs as an important objective of the QFD method, and to form the relationship matrix between CRs and DRs and interrelationships between the DRs themselves, weighting and prioritization methods in the traditional model are not accurate. Consequently, the use of MCDM methods helps to achieve reliable results. The studies mentioned in this literature review during 2004–2021 show the application of QFD-MCDM methods and hybrid models, which include a combination of several methods using different tools in the final ranking of CRs and DRs. Furthermore, case studies that adapted the DEMATEL method on the roof of HOQ, as well as the application of fuzzy theory to increase accuracy and reduce vagueness and expert judgment, had better results in the final evaluation. In some studies, methods such as Markov and Kano model have been used to classify customer needs before entering the QFD process, which is effective in better identifying and classifying customer needs. This study showed, in recent years, that the decision-making tools used to prioritize, and weighting is much more accurate than the traditional ones. In addition, in combination with fuzzy theory, namely in the healthcare area where customers' demands are more qualitative, is more effective, and more accurate. In this study, we categorized the published articles into three main categories, (1) QFD-MCDM models which consists of models adapted QFD and MCDM. (2) hybrid QFD-MCDM includes the use of QFD and MCDM and other tools. (3) The application of hybrid models in different fields, which includes the use of the mentioned methods in the practical field. Table 4 presents papers were discussed the QFD model in four main classifications. The uncertainty adopted in studies to eliminate the vagueness in the voice-of-customer. Sustainability is a broad policy concept in the global public discourse that consists of environmental, economic and social dimensions. The MCDM tools have been discussed, and the supplement models, including mathematical, logical and other quality models can combine with QFD to improve the output of the hybrid model.

ID		Methodology	Number of studies	
1	Uncertainty	Fuzzy, RST, Hesitant 2-tuple linguistic, Interval grey numbers, Hesitant fuzzy, Fuzzy Delphi, INS, Neutrosophic set, HFLTS, Fuzzy trapezoidal, PHFLTS, Internal valued fuzzy set, EHFLTS, IT2FS, PFLS, TFN, SFS, HF, IVIF	39	39
2	Sustainability	Sustainability, Green, environmental	12	12
3	Decision-making tools	ANP	10	68
		SWARA	1	
		AHP	13	
		MOORA and Multi-MOORA	6	
		BWM	3	
		Entropy	3	
		TOPSIS	6	
		DEMATEL	10	
		COPRAS	1	
		VIKOR	1	
		Choquet integral	1	
		MODM (linear programming)	5	
		Grey target decision making	1	
		Multi choice GP	1	
		ME-MCDM	2	
		GRA	4	
4	Supplement models	Risk optimization	1	20
		BOCR	1	
		TRIZ	1	
		Dynamic QFD	1	
		EGM	1	
		QUALIFLEX	1	
		Prospect theory	1	
		DEA	1	
		EDAS	1	
		ERP	1	
		OA	1	
		Cloud Model	1	
		KANO Model	4	
		PSS	1	
		Delphi	2	
		Means-end chain	1	

Table 4. Distribution of studies combined with QFD considering the methodology

Table 4, the decision-making tools shows the most implemented with 68 times, so it can be concluded that this method is introduced as the sufficient method to obtain the optimum results. Also, applying uncertainty in studies (39 times) shows integrated models for translating CRs to DRs, in terms of eliminating the vagueness element, can increase precision.

Figure 3 shows the distribution of the various methods in the studies.

Figure 4 depicts the distribution of different decision-making tools. As seen the AHP method (19%) is the most adapted tool in the studies.

4. Conclusion and directions for future research

According to the broad search of articles in recent years, many studies have been interested in filling the research gap in the QFD model. To this end, due to the identifying strengths and weaknesses of the QFD method, many articles, particularly in the last 4 years (from 2017),

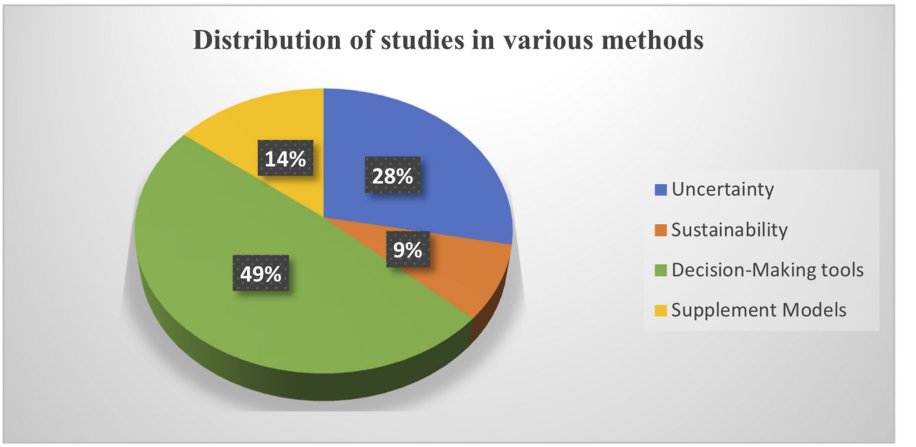

Figure 3.
Distribution of methods in studies

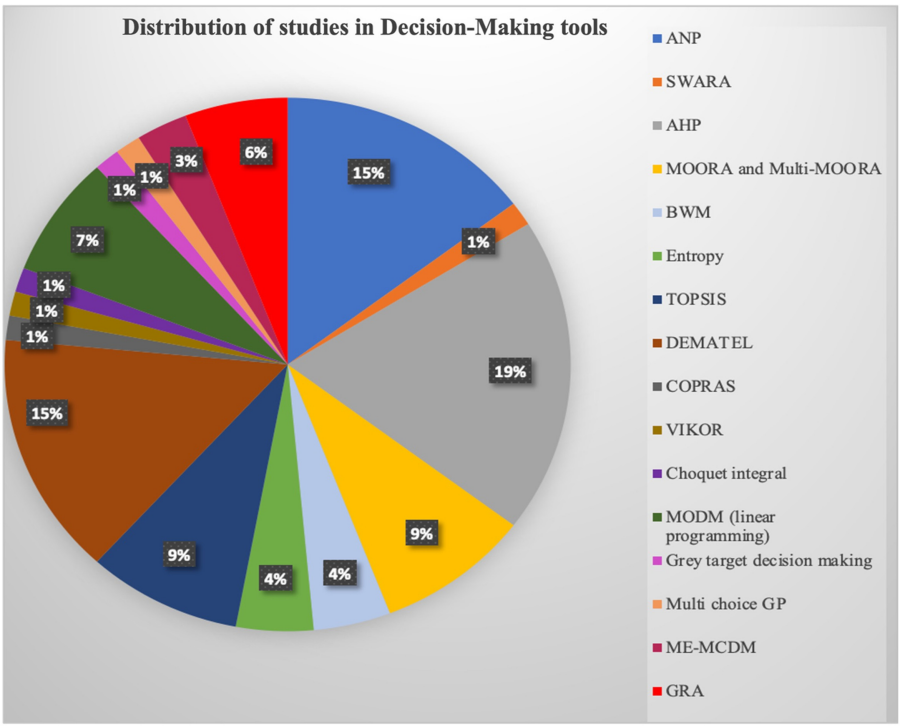

Figure 4.
Distribution of studies in decision-making tools

have applied hybrid models to improve the traditional QFD model. The application of multi-criteria decision making in the QFD model has improved the traditional methods used in QFD, has also increased the precision and accuracy of evaluation, and ranking the CRs and thus DRs and makes the output of the model provide the design requirements for

manufacturing a product or service. In the proposed hybrid models, most of the QFD applications are integrated with fuzzy theory. The entry of customer demands in a fuzzy manner (since the variables are fuzzy-verbal) and qualitative judgments of customers and experts have increased the flexibility and accuracy of the data.

The fuzzy theory has some limitations which two remarkable are the handling of imprecision data and the inherent inference of human thinking. If the data is imprecise in the system a human being cannot infer the knowledge or relation. The application of fuzzy theory requires complex calculations because the combination of fuzzy numbers is used with the decision method, which requires fuzzification and defuzzification. Therefore, creating appropriate software to facilitate the process can be effective in conducting case studies with extensive information. Depending on the type of CRs, the type of fuzzy numbers that may be used differs, but it can make the calculation difficult. For this reason, some research may remain theoretical, or the case study may not be fully implemented.

Investigations in many areas have focused on user-friendliness, sustainability, green manufacturing system and environmental concerns, which are some of the current important needs of customers compared to many years ago. On one hand, these new requirements led to limitations for manufacturers, but with increased customer satisfaction. But, on another hand, enterprises and factories have encountered problems (such as the complexity of the production process and the incompatibility in the interrelationship of DRs), which have led to the use of different machines and increased the final cost of the products or services. Thus, the application of hybrid models by using intelligent multi-criteria decision-making methods can decrease the overlap and conflict in operational processes, especially, in new areas that often seek to reduce fuel consumption and pollution and increase productivity and use new energy sources, such as the use of photovoltaic in automotive process design (Huang *et al.*, 2019).

To implement hybrid models, it is necessary to consider the needs of customers and manufacturers properly. For example, in the health care case, if the target customers are defined as patients, the DRs should be determined differently from the physician and nurse's DRs as the final customers because their needs differ with the patients, but sometimes the experts and physicians can be considered as representative of the patient needs because they have enough knowledge about the tools and treatment process (Neira-Rodado *et al.*, 2020).

In some studies, the Kano model has been used in research that is suitable as a tool to classify customer needs and should be combined with appropriate fuzzy and decision tools to achieve the desired results, which is also very useful in NPD. Kano model is used to show a better understanding of the most important product features from the customers' point of view and divides customers' needs into five main categories: Must-be, Attractive, One-dimensional, Indifferent, or Reverse attribute for a product (Chen *et al.*, 2010). Therefore, this tool can be very useful in riddling CRs to enter the HOQ matrix and make the required classifications on the left wall of the HOQ. Using this tool can also help the manufacturer to avoid wasting extra time and money to meet customer needs.

In many studies, there is no mention of studying the competitors' evaluation section. The creation of this section in the HOQ matrix can be significant and have a difference in the ranking of CRs. The competitor evaluation department can also act as a benchmarking tool in creating business process competition patterns and the best performance from other similar companies, which requires comparing a similar product or service with the desired product and service. The competitive conditions in the market make it necessary to put some factors such as supplier selection, raw materials and transportation preferable to overall customers' preferences, which should provide a model to consider having competitive advantages and faster customer satisfaction. In this case, the Kano model can also integrate into the hybrid model to classify and highlight that customer needs are more basic and show the cause of customer dissatisfaction.

TRIZ can be used as a problem-solving tool to better introduce DRs (Chen *et al.*, 2010). It can aid to engineers in product design, by improving the process to identify technical

characteristics in the HOQ matrix. Studies have rarely shown how to use questionnaires and techniques used to assess customer needs. It is recommended to determine the validity and reliability of the questionnaire and sample size determination tools because this has a great impact on the data collection results. Also, establishing a control verification matrix can be effective in prioritizing methods and process control parameters and can provide good support to the prioritized elements of the QFD process design stage by controlling the critical factors in the final stage. After determining the critical processes and operations in the matrix rows, the requirements for controlling them to prevent errors and failures in the matrix columns of the process control planning are determined.

Due to the correlation matrix between engineering characteristics in the roof of the HOQ, many studies have not paid special attention to this sector, which may not cause attention to the impact of ECs on each other, causing inconsistencies in customer needs and conflict in the performance of some processes in the HOQ. Therefore, the use of multi-criteria decision tools including DEMATEL can greatly improve the calculation of the roof of the HOQ and obtain the weights of interrelationships of roof elements. Particularly, the DEMATEL accurately identifies the effect of elements on each other in the roof, and it helps to eliminate the contradiction effects in ECs.

According to the statistics of the research conducted in this study, the use of the hybrid QFD-MCDM methods including QFD, MCDM, and other applied tools is much more than individual QFD-MCDM. It shows the efficiency of hybrid QFD-MCDM in achieving the desired results which are mostly used in manufacturing products and industries, supplier selection and services, respectively. According to recent studies (after 2018), there are hybrid methods for Integrated product and process development and Integrated decision-support mechanisms for all product-related processes which improve the flexibility of the manufacturing system.

Due to the changing customer demands over time, also the advancement of technology, customers who are initially attracted to the new service characteristics take them for granted over time in most cases. Some customer demands from the design process and even the final product change. Therefore, it recommends using a dynamic QFD or other quality tools such as Kano Dynamic (An online platform to meet the updated needs of customers to update customer requirements) or the production of the product without considering customers' need (which leads to customer dissatisfaction and has an extra cost for the company). It is also possible to predict changes in customer demand or use the time series to update CRs.

(1) Feature selection methods can efficiently reduce the number of functional requirements and decrease the complexity of a new product/service design by reducing the number of FRs at the customer requirement definition phase. In this regard, unsupervised machine learning techniques in selection of functional requirements during customer requirement definition phase of QFD technique can be an attractive future research topic.

(2) An optimal new product design needs high-dimensional information analysis at the early stage of the QFD technique. In this regard, neural network (NN) is a powerful tool for data analysis for product development purposes. Combining NNs with QFD technique for assessing the design alternatives during design phase is suggested as an important direction for future research.

Regarding the limitation, as the current study was a comparative analysis and the frequency of the hybrid QFD-MCDM studies, future study needs to validate empirical research to compare the results obtained from various hybrid models in detail to introduce more efficient models in terms of accuracy and precision of the results. Furthermore, different alternatives in various developed QFD models can be discussed. However, as a limitation in this review has not been addressed, the authors agreed in the future to contribute more by presenting the novel QFD evolution results rather than traditional methods.

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