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Quality function deployment improvement: A bibliometric analysis and literature review

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Abstract
Quality function deployment (QFD) is a customer-driven product development tool used to convert customer requirements into engineering characteristics to maximize customer satisfaction. In real applications, however, the traditional QFD method has been criticized as having lots of deficiencies. Over the past decades, many models and approaches have been suggested for improving QFD, but a paucity of contributions are devoted to review and summarize the related researches on the basis of bibliometric analysis. In this paper, we conduct a comprehensive bibliometric analysis of the journal articles on QFD improvement during the years of 1999–2020. First, the metadata analysis of identified articles was presented to clarify the research progress and development trend in this field. Then, bibliometric analyses of the selected articles are conducted to identify the most prolific and influential researchers, the most productive institutions and their collaborations, and the intellectual structure of studies in QFD development. Via keyword analysis, the research focuses and emerging research trends for QFD improvement are found out. Finally, blind spots and future research directions in the area are summarized to provide valuable reference for the future research of QFD advancement.

Keywords Quality function deployment (QFD) · House of quality (HOQ) · Literature review · Bibliometric analysis · New product development

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1 Introduction

Quality function deployment (QFD) is a customer-driven product design tool widely utilized in a variety of industries. It aims to identify customer requirements (CRs) or known as voice of customer and translate them into corresponding engineering characteristics (ECs) for enhancing the satisfaction level of customers (Prasad 1998; Chan and Wu 2002b). The QFD was first developed in the 1960s in Japan and used at the Kobe Shipyards of Mitsubishi Heavy Industries as a planning technique for product development (Akao 1972; Wasserman 1993). It is defined as how the quality that is expected by customers is understood and how dynamically it is created (Shahin et al. 2018; Haktanır and Kahraman 2019; Avikal et al. 2020). QFD can address the customer requirements and parameters of product or service design, so that these requirements can be satisfied as far as possible. A complete QFD is consisted of four phases: product planning, part deployment, process planning and production planning. In each phase, the relationships between inputs (WHATs) and outputs (HOWs) are established by a relationship matrix called house of quality (HOQ) (Braglia et al. 2007; Carnevalli and Miguel 2008; Wu et al. 2020). The first matrix's inputs (CRs) are being translated into the outputs as ECs.

In QFD, the HOQ is structured by the importance of CRs, the relationships between CRs and ECs, and the interrelations between ECs (Chan and Wu 2002a, 2005). For the classical QFD, many shortcomings have been pointed out when used in real situations, which affect its efficiency and limit its application (Mehrjerdi 2010; Wang 2012; Song et al. 2014; Wu et al. 2016; Ping et al. 2020). For example, the weights of CRs are determined directly without considering their internal relations; the relationships between CRs and ECs are described by a score system such as 1–3-9 or 1–5-9, which is not rational for human's intuitionistic cognition; the importance ratings of ECs are computed by a simple weighted arithmetic aggregation; no feedback system from customer complaints is established. Therefore, a great many modified QFD models and methods have been put forward in previous studies to enhance the performance of QFD in the past decades (Xu et al. 2010; Dat et al. 2015; Franceschini and Maisano 2015; Sivasamy et al. 2016; Huang et al. 2019; Liu et al. 2021).

In prior studies, some literature reviews related to QFD have been accomplished from different aspects. For instance, Chan and Wu (2002a) reviewed the definition and concepts of QFD, provided a comprehensive description of QFD four-phase model, and pointed out the difficulties in executing QFD. Chan and Wu (2002b) performed a qualitative QFD review based on 650 publications, in which the QFD functional fields, applied industries, and methodological development were elaborated by categorical analysis. Carnevalli and Miguel (2008) presented a review, analysis, classification of the QFD articles published between 2002 and 2006 and classified them into conceptual research and empirical research. Xu et al. (2010) reported a literature review on the development of QFD methods, technical improvement, and integration of QFD with other tools. Ayoola Oke (2013) reviewed the QFD methods and applications, and classified them into general studies, analytical approaches, and QFD in manufacturing industries. Zare Mehrjerdi (2010) conducted a review about the fundamental concepts and applications of QFD, and classified the extended QFD researches into five categories: analytic hierarchy process (AHP) and QFD, fuzzy QFD, statistically extended QFD, dynamic QFD, and other extensions. Sivasamy et al. (2016) performed a literature review on the advanced QFD models and divided them into fuzzy QFD, Kano based QFD, AHP integrated QFD, analytic network process (ANP) integrated QFD, Project QFD, and total QFD.

The current QFD review studies mainly adopted subjective categorization and qualitative analysis to summarize previous researches. This, however, is apt to leading inaccurate interpretation and unreliable results (Ganbat et al. 2018; Huang et al. 2020). Differing from standard literature reviews, bibliometric review can reveal internal structure and the development trend of a specific research direction by a replicable and intelligible structured process (Fahimnia et al. 2015). In recent years, the bibliometric analysis has been adopted in many fields to visualize their research status, features, evolution, and emerging trends (Hou et al. 2021; Tandon et al. 2021; Wang et al. 2021). Hence, this paper aims to undertake a systematic literature review on the topic of QFD improvement based on the bibliometric analysis method. This research is designed to facilitate interested scholars and practitioners to get a comprehensive understanding of QFD improvement research, seek cooperation opportunities with other scholars and research institutions, and point out new directions for future research. To do this, the following questions will be answered:

Q1: What is the publication distribution across time? The answer would be helpful for readers to probe the overall development trend and status quo about QFD improvement.
Q2: Which journals contribute the most research articles? The answer would facilitate scholars to select suitable journals for publishing relevant papers.
In this study, a metadata analysis is performed to throw light on the publication trend and the most prolific journals in the research area.
Q3: Which authors and organizations are the most active and influential in this field? The answer would not only help researchers to recognize productive authors and institutions, but also benefit seeking for potential collaborators.
In this paper, author analysis and affiliation analysis are undertaken to recognize the most active and productive authors and institutions, respectively. Meanwhile, cooperative relationships among authors or institutions are clarified by visualizing their collaborative networks.
Q4: What are the highly cited references in this area? The answer can identify critical articles and disclose the inherent connection of knowledge. Then, co-citation analysis is adopted to locate the most influential literatures and grasp the research emphasis in this field.
Q5: What are the evolutionary process and emerging trends of QFD improvement? The answer would help scholars to keep abreast of the current development and ascertain future research directions. Herein, keyword analysis is applied to sort out the research mainstream and evolutionary trends within the given field.

The rest part of this paper is structured as follows: In Sect. 2, the research methodology applied in this study for literature review is introduced. In Sect. 3, results of metadata statistical analysis and bibliometric analysis of the identified articles are provided. Section 4 points out the current challenges and future avenues of research on QFD advancement. Finally, Sect. 5 presents some concluding remarks of this paper.

2 Research methodology

In this paper, a four-step methodology (Huang et al. 2020) is employed to undertake the literature review of the studies regarding QFD improvement. It includes retrieval keyword definition, data collection and identification, metadata analysis, and bibliometric analysis. First, a search string was constructed by analyzing the keywords in QFD articles. To ensure that QFD improvement articles are fully captured, the keywords ("QFD" AND "quality function deployment") and ("HOQ" AND "house of quality") are used for the literature search. Second, the Web of Science (WOS) database was used to obtain the scientific output information for bibliographic review. In this study, only peer-reviewed journal articles published from 1999 to 2020 and in English were considered. The initial retrieval result was 1131 items. By removing duplicate entries, 1031 articles were identified. Next, we reviewed titles, abstracts, and whole text of the remaining articles to exclude unrelated ones. The following selection criteria were applied in the literature screening process: (1) The article that aimed at proposing a method to overcome the shortcomings of the traditional QFD was retained; (2) The article which reported an application of QFD was excluded; (3) The article that focused on automating QFD implementation was considered as irrelevant. Finally, 396 documents were acknowledged to be relevant with the given topic. Figure 1 illustrates the detailed review procedure of this literature review research.

To ensure the reliability and consistency of article selection results, two authors of this study executed the article screening procedure independently. Then, they compared their results for agreement and any discrepancies were resolved in this stage. In addition, metadata analysis and bibliometric analysis of the included literature are performed by the use of CiteSpace software (Chen 2006), and the detailed results are presented in the forthcoming section.

3 Results and discussions

3.1 Metadata analysis results

First, the quantity of annual published papers from 1999 to 2020 is exhibited in Fig. 2. It can be observed that the publication number in the research field increases from 5 in 1999 to 45 in 2019. Specifically, the trend of publications slowly increases during the years of 1999–2007. From 2008 onwards, the number of documents increased rapidly until 2015 with about 20 articles per year during the period. After that, there is an obvious drop in 2016 with a recovery in 2018. Our analysis reveals that there was a strong interest for this research topic in recent three years. It is expected that the attention from researchers to QFD improvement will continually increase over the next decade.

On the other hand, there are 126 different journals in total contributing to the collected QFD articles. Table 1 shows the productive journals with more than 10 documents. As can be seen, *International Journal of Production Research* is the predominant journal in this field with 38 articles, followed by *Expert Systems with Applications* with 28 articles and *Computers & Industrial Engineering* with 26 ones. These journals accounted for 40.66% of the total publications in relation to the topic of study.

3.2 Bibliometric analysis results

In this section, the results of author analysis, affiliation analysis, co-citation analysis, and keyword analysis are provided in detail.

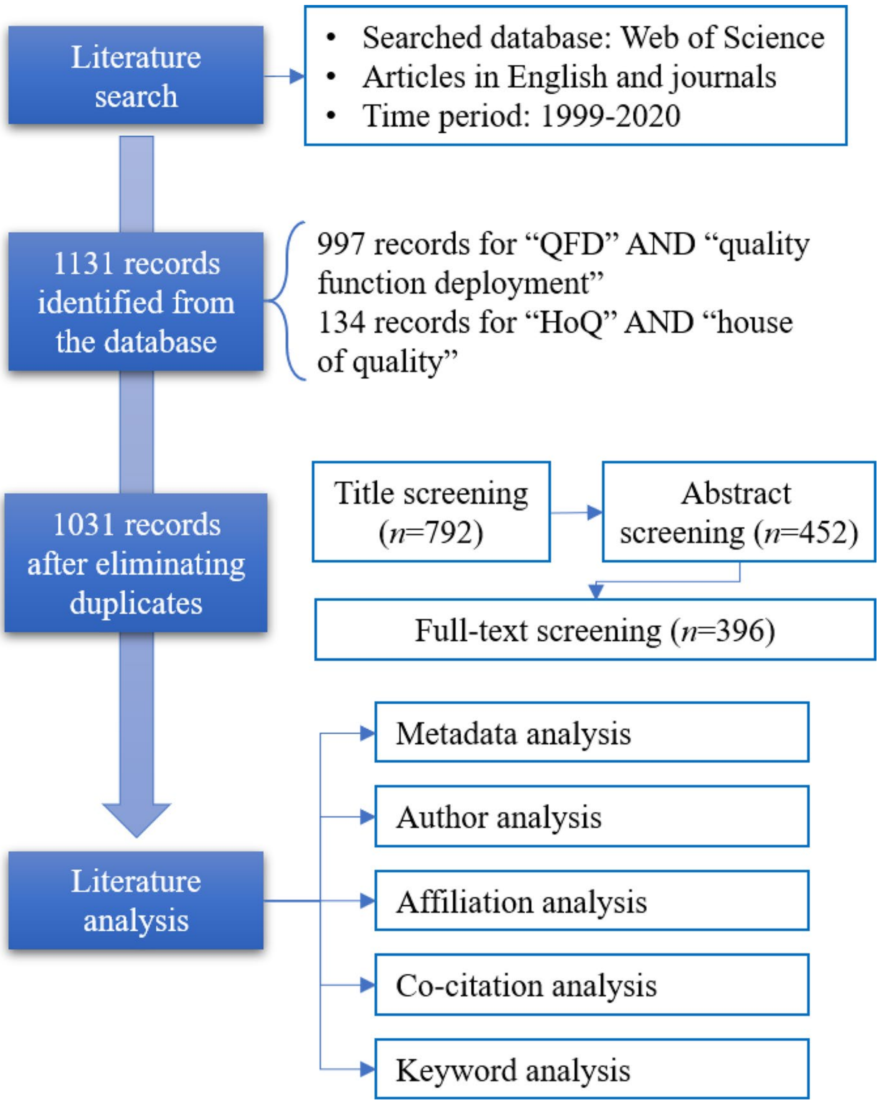

Fig. 1 Article screening process of this study

3.2.1 Author analysis

Researchers play a crucial role to reflect the research capacity and evaluate the development of an academic field (Guo et al. 2021). Therefore, it is important to identify the core authors who not only have good publication abilities but also have greater contributions on promoting the development of the field (Xu et al. 2020a). In this study, both author analysis and co-authorship analysis are conducted to identify the most active and influential authors, and the cooperative relationship among them. The quantity of publications, number of citations and average citation per publication are three critical indexes to measure

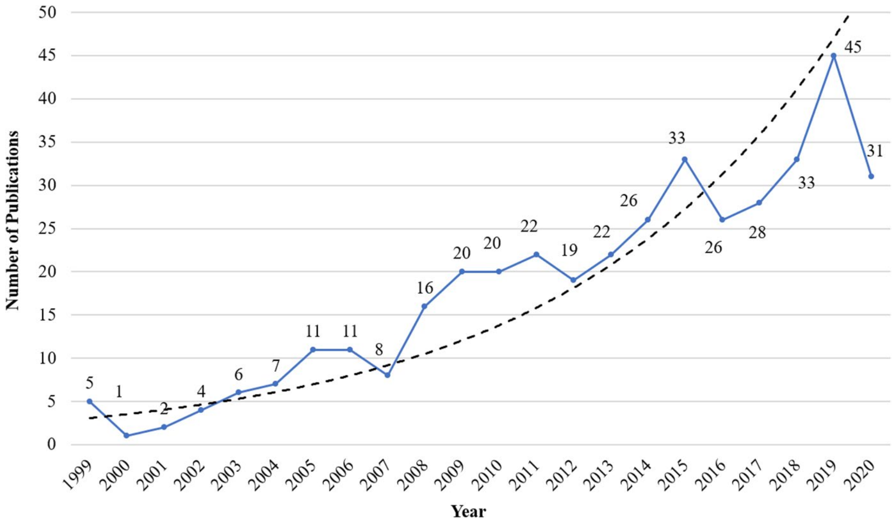

Fig. 2 Publication distribution over the years

Table 1 Most significant journals on QFD improvement

Journal	Impact factor	Number of articles
International Journal of Production Research	4.577	38
Expert Systems with Applications	5.452	28
Computers & Industrial Engineering	4.135	26
Total Quality Management & Business Excellence	2.922	16
Journal of Intelligent & Fuzzy Systems	1.851	15
Mathematical Problems in Engineering	1.009	14
International Journal of Advanced Manufacturing Technology	2.633	13
European Journal of Operational Research	4.213	11

an author's contribution for a certain research topic. Based on the three indexes, the top 10 contributing authors are determined and listed in Table 2. According to the publication quantity, Chen YZ is the most productive author with 20 papers, and there are five authors who published more than 10 papers in this field. In regards to the total citation, Buyukozkan G, Chen YZ, and Kwong CK dominate the list. Nevertheless, Karsak EE, Kwong CK, and Buyukozkan G rank the top three in light of the average citation. It may be mentioned here that the top authors based on total citation are not match those by average citation because sufficient time is usually needed for an influential paper to establish citations.

The key collaborative networks among authors of the selected articles are depicted in Fig. 3. In this figure, a node represents an author, a line describes the cooperative relationship between two authors, the thickness of different lines stands for the frequency of two authors collaborated, and line color denotes the period when they were co-authored. As can be seen, eight cooperative groups are revealed in the QFD advancement area. For example,

Table 2 The top 10 contributing authors

Ranking	Author	Publication quantity	Author	Total citation	Author	Average citation
1	Chen YZ	20	Buyukozkan G	862	Karsak EE	84.4
2	Tang JF	15	Chen YZ	641	Kwong CK	76
3	Buyukozkan G	13	Kwong CK	608	Buyukozkan G	66.3
4	Li YL	13	Karsak EE	591	Fung RYK	65.6
5	Chin KS	11	Fung RYK	590	Chen LH	39.4
6	Chen LH	10	Tang JF	578	Tang JF	38.5
7	Luo XG	10	Chen LH	394	Chen YZ	32.1
8	Fung RYK	9	Ko WC	232	Ko WC	29
9	Ko WC	8	Luo XG	216	Chu XN	27.5
10	Kwong CK	8	Li YL	195	Liu HT	26.6

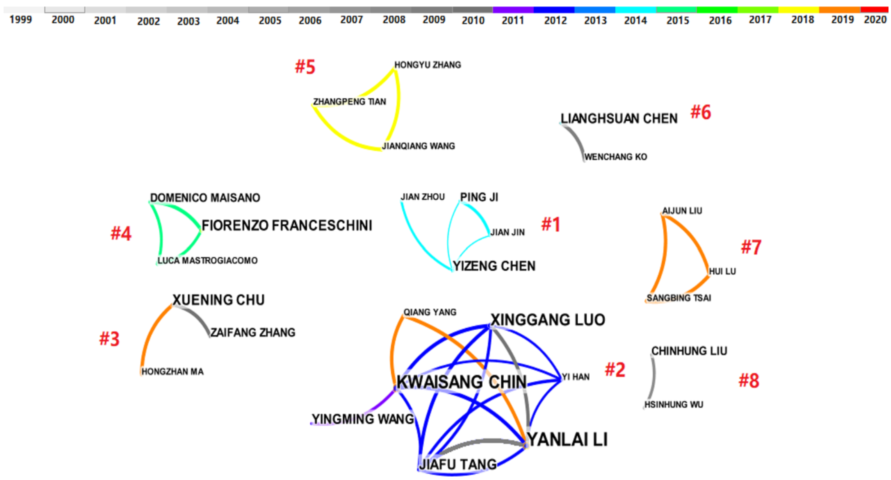

Fig. 3 Main collaborative networks among authors

in the research group #1, Chen YZ authored with Zhou J for 6 times since 2014, with Ji P for twice since 2014, and with Jin J for twice since 2014. The research group #2 consists of seven authors, in which Luo XG authored with Chin KS for 4 times since 2012, with Tang JF for 4 times since 2012, and with Li YL for 7 times since 2009; Li YL authored with Tang JF for 7 times since 2009 and with Chin KS for 7 times since 2012.

Next, a detailed analysis of the representative research groups (#1 and #2) is conducted. The group #1 published seven relevant research articles from 2014 to 2018, and focused on improving the conventional QFD based on mathematical programming model. For example, Liu et al. (2014) designed a fuzzy non-linear regression model using the minimum fuzziness criterion to identify the degree of compensation among CRs. Zhong et al. (2014) developed a fuzzy chance-constrained programming model to determine the target values of ECs considering the importance of ECs and their correlations. Miao et al. (2017) proposed a QFD model based on two uncertain chance-constrained programming models for setting the target levels of ECs. Liu et al. (2016) proposed an expected value-based method to obtain the exact expected values of EC fuzzy importance. Liu et al. (2015) presented a systematic approach using the fuzzy linear regression models with optimized *h* values to establish the relationship matrix between CRs and ECs. Later, Liu et al. (2018b) studied the situation in which relationship coefficients were assumed as asymmetric triangular fuzzy numbers.

The group #2 contributed 11 research articles during the years of 2009–2019, and paid more attention to the importance determination of CRs in QFD. For instance, Li et al. (2009) proposed a hybrid QFD model integrating rough set theory, Kano model, analytical hierarchy process (AHP), and scale method to drive the importance ratings of CRs. Li et al. (2010) applied an improved maximal deviation approach to cope with the corporation performance estimations on CRs, and integrated AHP and scale method for obtaining the importance ratings of CRs. In Li et al. (2012a), a systematic and operational method based on minimal deviation-based method (MDBM), balanced scorecard (BSC), AHP, and scale method was designed to determine the priority ratings of CRs. Li et al. (2012b) integrated the group decision-making, multi-format preference analyses and three types of least square models for acquiring the sale points of CRs. Li et al. (2018) introduced a group decision-making framework based on interval linguistic information, cosine method and entropy approach to determine the importance ratings of CRs. Yang et al. (2019) developed a group decision-making model using ordinal scale value to prioritize CRs in new product planning.

3.2.2 Affiliation analysis

Affiliation analysis helps us to acquire a better understanding of the most productive institutions and their collaborations in a certain research filed. Table 3 lists the top 10 contributing organizations based on the number of published papers on QFD improvement. These institutions contributed 97 articles accounting for 23% of the total publications. As shown in Table 3, City University of Hong Kong (17 articles) is the most productive institution, followed by Galatasaray University (14 articles), Northeastern University (13 articles), and National Cheng Kung University (13 articles).

Figure 4 portrays the institution cooperation network of the selected QFD publications. In this figure, a node represents an affiliation, a line describes the cooperative relationship between two affiliations, the thickness of lines stands for the frequency of two affiliations

Table 3 Top 10 contributing organizations

No	Organization	Location	Publication
1	City University of Hong Kong	Hong Kong	17
2	Galatasaray University	Turkey	14
3	Northeastern University	China	13
4	National Cheng Kung University	Taiwan	13
5	Shanghai University	China	10
6	Hong Kong Polytechnic University	Hong Kong	9
7	Islamic Azad University	Iran	6
8	Shanghai Jiao Tong University	China	5
9	Natl Chin Yi University Technology	Taiwan	5
10	Politecnico Torino	Italy	5

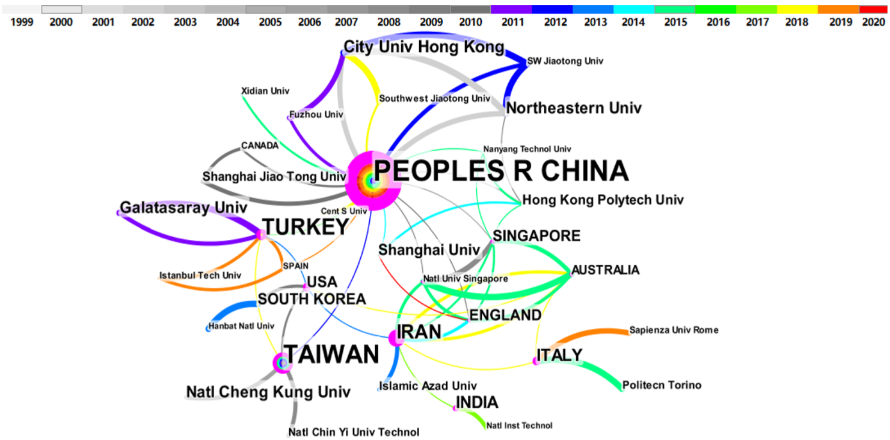

Fig. 4 Collaborative networks among institutions

collaborated, and line color denotes the year they were firstly cooperated. Besides, the nodes with a red–purple ring indicate the countries or areas having a high betweenness centrality. It can be seen that City University of Hong Kong and Northeastern University have a collaborative relationship in this field (they cooperated for six times since 2004); City University of Hong Kong cooperated with Southwest Jiaotong University for four times since 2018; Hong Kong Polytechnic University cooperated with Shanghai University for three times since 2014. Besides, China is the centrality with the most publications; England, Taiwan, Singapore, and Canada keep a close cooperation with China.

3.2.3 Co-citation analysis

Co-citation is the frequency with which two or more earlier articles are cited together by the later literature (Khaldi and Prado-Gascó 2021). It denotes the degree of relationship between documents. Normally, co-citation analysis can be used to identify key authors and studies and visualize the intellectual structure of a research topic (Hou et al. 2021). Co-citation analysis includes author co-citation analysis and reference co-citation analysis. Based on the citation information of the selected articles, author co-citation analysis for the researches on QFD improvement is shown in Fig. 5. In the figure, each node represents an author, a link signifies the co-citation relationship between authors, the thicknesses of lines stand for the frequency of two authors co-cited, and line color denotes the year they were firstly co-cited. According to citation number, the top five cited authors are Akao Y with 194, Chan LK with 191, Hauser JR with 159, Karsak EE with 133, and Zadeh LA with 110. While in terms of centrality, the five authors with a higher betweenness centrality are Chan LK, Karsak EE, Hauser JR, Buyukozkan G and Akao Y. By an in-deep analysis, we find that the HOQ was originally developed by Hauser (1988), which aimed to vividly portray the connections between CRs and ECs. Chan and Wu (2002a) performed the first literature review about the concepts and methods of QFD. Akao and Mazur (2003) described the QFD evolution, provided its current best practice, and suggested some proposals for future direction. Karsak (2004) proposed a fuzzy multiple objective programming approach for determining the ranking orders of ECs, and Buyukozkan et al. (2007)

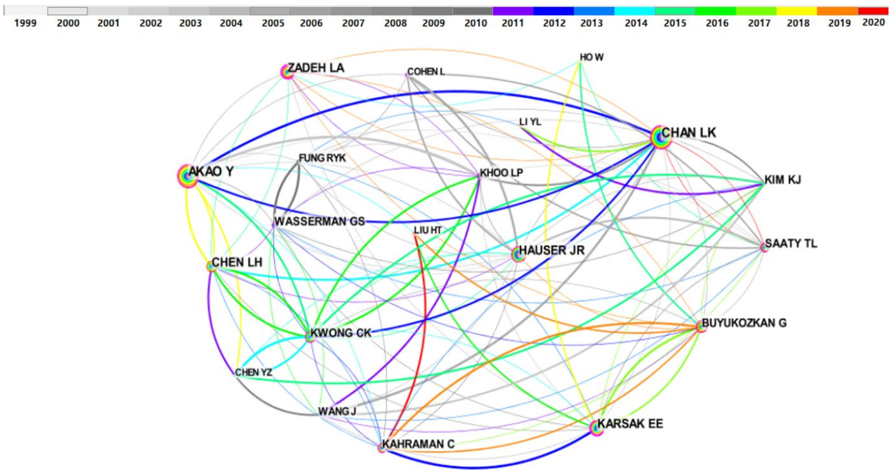

Fig. 5 Author co-citation result

put forward a fuzzy group decision-making approach to incorporate multiple preference styles to express customer needs in QFD.

The reference co-citation analysis for the selected researches is depicted in Fig. 6. In this figure, each node represents a reference, a link indicates the co-citation between two articles, and the colors of different lines correspond to the years they were firstly co-cited. As can be seen, the top five co-citated references are Kahraman et al. (2006), Chan and Wu (2005), Chan and Wu (2002b), Karsak et al. (2003), and Chen and Weng (2006). Figure 7 shows a timeline visualization of co-citation references from 1999 to 2020, and the references are clustered into the following nine clusters:

Cluster #0: To effectively compute the relative importance of CRs, combined weighting methods were used by many researchers in QFD. For instance, Tian et al. (2019) established an improved QFD model for prioritizing service designs, in which a combined weighting method integrating maximizing deviation with best worst method was employed

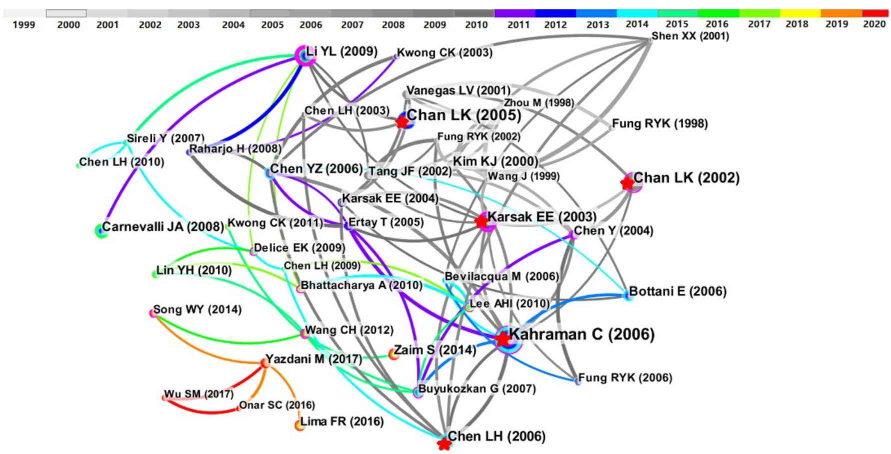

Fig. 6 Reference co-citation result

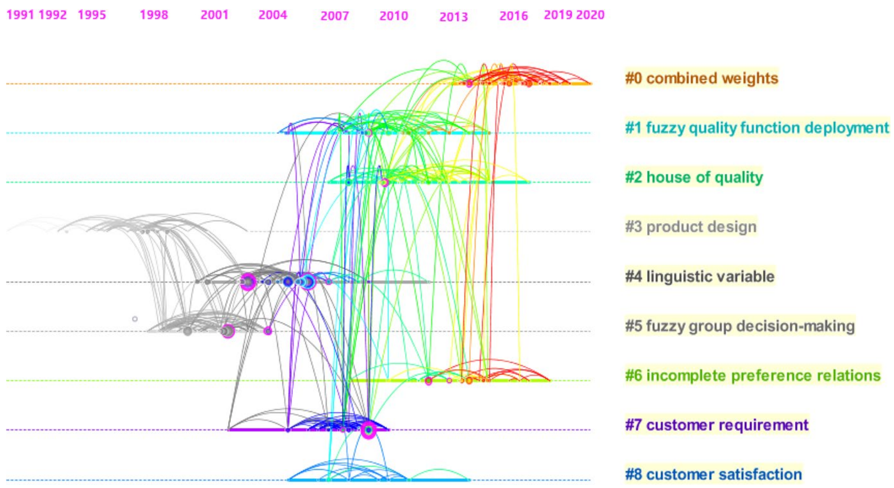

Fig. 7 Reference co-citation clustering result

to obtain the weights of service designs. In (Tian et al. 2018a, b), single-valued neutrosophic numbers and decision-making trial and evaluation laboratory (DEMATEL) were adopted to drive the combined weights of CRs. To acquire more accurate weights of CRs, Liao et al. (2020) utilized a combined weight determining method to integrate former weights to objective weights derived from the evaluation matrix.

Cluster #1: In this cluster, fuzzy set theory was frequently utilized to improve the performance of the traditional QFD. For example, Chen et al. (2006) constructed a fuzzy QFD method by utilizing fuzzy weighted average method in the fuzzy expected value operator to acquire technical importance of ECs. Zhai et al. (2008) designed a rough set enhanced fuzzy approach to determine the importance ratings of CRs. Bevilacqua et al. (2012) introduced fuzzy logic into QFD and developed a fuzzy QFD model for obtaining the customer rating of food products.

Cluster #2: HOQ is the core of QFD, and in this cluster, the QFD improvement process was often achieved via rebuilding it. For instance, Geum et al. (2012) used driver-based approach and interrelationship-based method to modify the HOQ structure for service modularization. Motlagh et al. (2015) suggested a fuzzy preference ranking organization method for enrichment evaluation (PROMETHEE) in a group decision support system to rank ECs in QFD. Fung et al. (2002) proposed a non-linear fuzzy model to quantify the numeric entries of HOQ.

Cluster #3: QFD is a product design tool for transferring customer voice into design requirements. Over the past decades, plenty of methods been have exploited to ameliorate the traditional QFD for better product design. For example, Karsak et al. (2003) carried out a zero–one goal programming model, which considered importance levels of ECs, cost budget, extendibility level, and manufacturability level goals, to obtain the importance ratings of ECs. Kim et al. (2000) developed a fuzzy multi-objective model for QFD to facilitate the design team choosing target levels for ECs under different contexts. Dawson and Askin (1999) introduced a non-linear mathematical program model for determining the most important ECs during new product design.

Cluster #4: Linguistic variable performs well in expressing the subjective and ambiguous information of experts. Hence, a number of researches have incorporated the linguistic variables for QFD improvement. To name a few, Chen and Weng (2006) developed a fuzzy multi-objective QFD method, in which linguistic terms were adopted to depict the relationships between CRs and ECs, and a fuzzy goal programming model was modified to generate the priority orders of ECs. Wang and Xiong (2011) proposed an integrated linguistic approach to cope with the imprecise and vague input information of QFD. Wang (2010) utilized linguistic variables to characterize customer needs and the relationship between customer needs and solution schemes in QFD.

Cluster #5: Normally, the prioritization of ECs in QFD can be viewed as a group decision-making problem and many fuzzy decision-making methods have been used to overcome the shortcomings of the traditional QFD. For instance, Kahraman et al. (2006) employed fuzzy analytic network process (ANP) to analyze the correlations between CRs and ECs, and a fuzzy ranking procedure for the prioritization of ECs. Karsak and Dursun (2014) combined QFD with data evidence analysis (DEA) to construct a fuzzy decision-making framework for supplier selection. Lee et al. (2017) reported a fuzzy QFD method using Delphi method, DEMATEL, and ANP for new product development.

Cluster #6: Recently, incomplete preference relation has been applied to represent the vague and missing information in QFD. In this cluster, Buyukozkan and Cifci (2012) provided a fuzzy logic-based approach with incomplete preference relations to enhance the ability of QFD. Nahm et al. (2013) proposed a customer preference rating method and a customer satisfaction rating method to prioritize CRs in QFD, in which the customers' perceptions were expressed as incomplete preference relations. Buyukozkan and Guleryuz (2015) put forward a fuzzy QFD methodology for collaborative product development project, in which experts' opinions were provided as preference relations with different formats.

Cluster #7 & Cluster #8: QFD is a customer-driven quality management tool to capture CRs and maximize customer satisfaction. Thus, Lee et al. (2008) incorporated Kano model into the matrix of fuzzy QFD to acquire CRs and enhance customer satisfaction and loyalty. Chen et al. (2004) proposed a two-stage method for customer satisfaction maximization, in which natural language processing techniques were adopted to classify CRs, and fuzzy logic inference method was used to determine the revised priority of CRs. To realize maximum customer satisfaction under limited resource, Cherif et al. (2010) suggested an imprecise goal programming model to yield the optimal target levels of ECs, and employed the concept of satisfaction functions to quantify CRs.

3.2.4 Keyword analysis

In this part, keyword co-occurrence analysis is applied to display frequently used keywords in the researches on QFD improvement. Then, keyword burst analysis is utilized to reveal the research hotspots and their emerging trends in a certain period of time. Finally, keyword time line analysis is performed to provide a chronological chart of topic evolution and probe the thematic concentration, respectively. Figure 8 shows the whole intellectual landscapes of co-occurrence keywords in the selected QFD articles. It can be seen that "quality function deployment", "QFD", "fuzzy QFD", "house of quality", and "customer requirement" are important keywords which take over notable positions. Besides, "fuzzy set theory", "fuzzy logic", "rough set", and "fuzzy group decision making" are the methods used for handling the vague evaluation information in HOQ; "analytic hierarchy process", "analytic network process", "TOPSIS", "programming model", and "MCDM" are the techniques utilized for rebuilding the framework of HOQ. The keywords "supplier selection",

Fig. 8 Co-occurrence keywords

"service quality", "product design", "engineering design", and "product development" represent different QFD applications.

Based on the keyword burst analysis, Fig. 9 presents ten keywords with the strongest citation bursts from the year 1999 to 2020. The strength denotes the burst intensity of a keyword and the red line depicts its active time. As we can see, "QFD" and "system" are the two strongest keywords, which burst during 1999–2005 and 2003–2009, respectively. The keywords "customer requirement", "house of quality", and "engineering characteristic" represent three essential parts of a QFD model, which activated in 2002–2006, 2003–2010, and 2014–2019, respectively. It may be explained that researchers paid more attentions to eliciting CRs and framing HOQ at early stage, and determining the priority of ECs has become a popular research theme in recent years. Besides, the keywords "group decision making", "programming model", and "AHP" represent three key approaches for improving QFD during 2010–2015, 2013–2014, and 2014–2017, respectively. Lastly, "product development" and "service quality" are the keywords pertaining to the applications of QFD with the burst time of 2010–2015 and 2014–2016, respectively.

Keywords	Year	Strength	Begin	End	1999-2020
QFD	1999	6.089	**1999**	2005	
Customer requirement	1999	5.323	**2002**	2006	
System	1999	6.465	**2003**	2009	
House of quality	1999	5.891	**2003**	2010	
Group decision making	1999	3.635	**2010**	2015	
Product development	1999	3.587	**2010**	2015	
Programming model	1999	3.226	**2013**	2014	
AHP	1999	4.395	**2014**	2017	
Service quality	1999	3.430	**2014**	2016	
Engineering characteristic	1999	3.487	**2014**	2020	

Fig. 9 Keyword burst analysis result

Figure 10 depicts the time line visualization of keywords network and the nodes with a cross indicate that they have a high betweenness centrality. In terms of this figure, the following results can be obtained: (1) The keywords “quality function deployment”, “QFD”, “fuzzy QFD”, and “house of quality” have the highest betweenness centralities. These keywords are also cited frequently as shown in Fig. 8. This is because they are the basic concepts of QFD. (2) The researches on QFD advancement experienced four stages. The first three years, 1999 to 2001, signal the nascency stage, in which rare co-occurrence keywords emerged. Around the year 2002, more researchers focused on the concepts “design requirement”, “optimization”, “fuzzy set”, and “house of quality”, and the studies of this field began to grow progressively. Between 2008 and 2016, with the rise of “fuzzy QFD”, a variety of theories and methods, such as “fuzzy logic”, “fuzzy preference relation”, “programming model”, “analytic hierarchy process”, “analytic network process”, and “TOPSIS” were used to address the deficiencies of the conventional QFD. In recent years, we can find that some scholars have probed to utilize a new “MCDM approach” for enhancing the performance of the classic QFD method, and some studies have been performed to apply improved QFD methods in new areas, e.g., supply management. (3) All the co-occurrence keywords are classified into seven communities, and the cluster “extended QFD” in the highest position has the most keywords. This reflects “extended QFD” occupies the position of primary category in this research field.

4 Research gaps and opportunities

QFD is an efficient and useful technique for produce development which provides a guide for companies to maximize customer satisfaction in the highly competitive market. Based on the results of literature review and bibliometric analysis, there exists room to further refine the QFD. The possible future research avenues are advocated as follows:

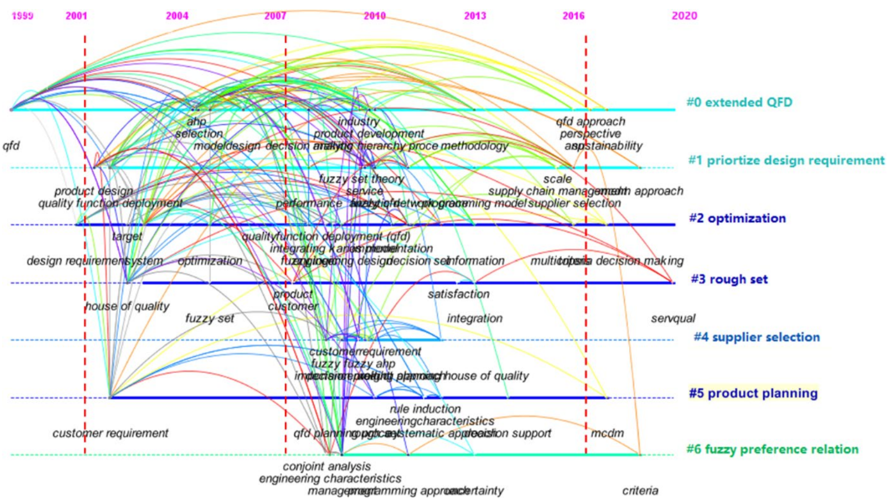

Fig. 10 Keyword time line analysis result

(1) Determining the importance weights of CRs is an essential and crucial process in QFD as they can largely affect the target values set for ECs (Li et al. 2018; Shi and Peng 2020). In the literature, the relative importance of CRs is normally defined subjectively by direct assignment, pairwise comparison, and preference ordering (Kutlu Gündoğdu and Kahraman 2020; Mistarihi et al. 2020), or objectively computed with the entropy method (Wu and Lin 2012). In the QFD process, a single use of subjective or objective weighting methods cannot reflect the inequality status of CRs and consistency of evaluation results simultaneously. Thus, it would be valuable to apply combination weighting techniques to derive the relative weights of CRs (Tian et al. 2019; Wang et al. 2020; Ping et al. 2020). Figure 7 also shows that "combined weighting" is a potent potential research topic in the near future. Besides, most improved QFD methods are based on the hypothesis that CRs are independent. In the real world, various types of relationships may exist among CRs (Wu et al. 2016; Huang et al. 2019). Hence, another orientation for future research is to take the dependency between CRs into account in determining their weights.

(2) Normally, the evaluation information on CR weighting and the relationships between CRs and ECs in QFD is usually vague, uncertain, or even incomplete. As discussed in the reference co-citation clustering and keyword time line analysis, fuzzy set (Akkawuttiwanich and Yenradee 2018; Efe 2019; Haktanır and Kahraman 2019; Kutlu Gündoğdu and Kahraman 2020), rough set (Song et al. 2014), linguistic computing methods (Huang et al. 2019; Liu et al. 2021; Tian et al. 2019), fuzzy preference relations (Yan and Ma 2015), and incomplete preference relations (Buyukozkan and Çifçi 2013; Nahm et al. 2013) were commonly employed to deal with the subjective and ambiguous information of experts in previous studies. In the future, it is suggested to use other powerful uncertainty theories, such as Pythagorean fuzzy sets (Yager 2014), multi-granular fuzzy linguistic model (Morente-Molinera et al. 2020), and *q*-rung orthopair fuzzy sets (Garg and Chen 2020), to effectively manipulate uncertainties from human judgements, manage incomplete relation evaluations and heterogeneous data, and bring an organized method to characterize the experience and knowledge of consumers and experts for QFD.

(3) Prioritizing ECs in QFD is often considered as a complex multi-criteria decision making (MCDM) problem (cf. Cluster #5 in Fig. 7). Thus, a variety of MCDM methods, such as multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA) (Wu et al. 2020), distance from average solution (EDAS) (Ping et al. 2020), technique for order performance by similarity to ideal solution (TOPSIS) (Kutlu Gündoğdu and Kahraman 2020), grey relational analysis (GRA) (Wang et al. 2020), and prospect theory (Huang et al. 2019), have been employed by researchers for determining the priority ranking of ECs in the product planning process. Future research can be targeted towards applying or developing other new MCDM methods (Tian et al. 2021), such as MACBETH (Ferreira and Santos 2021) and three-way decision method (Ye et al. 2020), to rank ECs in the QFD. Besides, the priority rankings of ECs yielded by different MCDM approaches are inconsistent. So, in the future, it is suggested to develop QFD models via combining two or more MCDM methods (Feng et al. 2018; Tian et al. 2018a, b) to generate a robust ranking of ECs.

(4) In the existing QFD studies, a small number of experts are frequently organized to evaluate the relationships between CRs and ECs. Along with more complicacy of products or services, QFD is often performed under a distributed context. That is, it is adopted to coordinate an expert group dispersed across organizations and countries. In such situation, the analysis results by a small QFD team are either hard or impossible

to reflect the real situation of a product (Liu et al. 2018a; Jiang et al. 2020). Therefore, large numbers of experts from distributed departments or institutions should be involved in the future to ensure the effectiveness of QFD in real situations. Also, exploring how to efficiently cope with the individual consistency and group consensus of large-scale experts' evaluation information (Xu et al. 2019, 2020b; Xiao et al. 2020) is much needed.

(5) Another possible direction for future work would be to employ artificial intelligent techniques (Feng et al. 2019) to efficiently deal with QFD problems. For instance, deep learning (Pal et al. 2020; Lazaridis et al. 2021) algorithms can be applied to learn CR weights from the evaluation data of consumers. Also, QFD methods can be empowered by neural networks (Zhu and Liu 2010; Kutschenreiter-Praszkiewicz 2013) to consider fluctuations in the ranking of ECs in the way changes occur in the human brain.

(6) Finally, the application of improved QFD models is a significant issue in this field. Since most of the proposed models and methods involve a complex computational process, it is difficult and cumbrous for practitioners to utilize them in the practice (Liu et al. 2021; Ping et al. 2020; Wu et al. 2020). Therefore, it would be useful to develop a decision support system to assist practitioners in employing improved QFD models in real situations conveniently.

5 Conclusions

The study provides a bibliometric review on the QFD improvement literature from 1999 to 2020, mapping the state of the art in the field and identifying current research trends and gaps. After refining the search results, a total of 396 documents on the topic were identified based on the WOS database. The result of metadata analysis showed that the annual publications on QFD improvement were rising quickly in the past two decades. The author analysis found that Chen YZ, Tang JF, and Buyukozkan G are the most prolific researchers; Buyukozkan G, Chen YZ, and Kwong CK are the most influential authors. From the affiliation analysis, we found that China is the major contributor in the research of QFD advancement. Further, City University of Hong Kong and Galatasaray University are the top two contributing organizations. The author co-citation analysis indicated that Chan LK, Karsak EE, and Buyukozkan G have made significant contributions in promoting the development of QFD. The reference co-citation analysis revealed that the topics of "fuzzy quality function deployment", "house of quality" and "linguistic variable" absorb lots of studies; and the topics of "combined weights" and "incomplete preference relations" are emerging research focuses recently. In addition, the keyword analysis showed that quality function deployment, QFD, fuzzy QFD, house of quality, and customer requirement appeared the most frequently in the QFD improvement literature. Moreover, the hot research topics within QFD improvement field were identified as: "extended QFD", "prioritize design requirement", "optimization", "rough set", "product planning", and "fuzzy preference relation".

In conclusion, the QFD research has been rapidly developing in method improvement and extended fields of application. Our research is possibly the first study that has performed an informative, updated and bibliometric analysis of the literature on QFD improvement. It would be helpful for scholars and practitioners to get a comprehensive understanding of QFD improvement researches and seek cooperation opportunities with other scholars and research institutions. Furthermore, this study has contributed to depicting the intellectual structure of QFD improvement, clarifying the current trend in research, and pointing out the best directions for future research, which would make the QFD a more scientific and practical tool for quality management in various fields.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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