

# The soft side of QFD: a comparative study on customer requirements' prioritization in the food sector

Mario Fagnoli\*, Nicolas Haber\*\*, Davide Platti\*\*\* and Massimo Tronci\*\*\*\*

Department of Mechanical and Aerospace Engineering

Sapienza - University of Rome

Via Eudossiana 18, 00184 Rome, Italy

\*mario.fagnoli@uniroma1.it, \*\*njhaber@gmail.com, \*\*\*davide.platti.13@gmail.com,

\*\*\*\*[massimo.tronci@uniroma1.it](mailto:massimo.tronci@uniroma1.it)

## Abstract

Despite its large popularity, the Quality Function Deployment (QFD) method has been the object of numerous studies addressing the problem of the assessment and prioritization of customer requirements. Nevertheless, a comparative analysis of these approaches to investigate their practical usability is scarcely discussed. This paper aims at filling this gap by means of a practical case study at a manufacturer in the food sector, where five of the most common approaches used to augment the House of Quality (HoQ) were analyzed and the results were compared. To achieve such a goal, semi-structured questionnaires were developed to capture consumers' preferences and expectations. The outputs of this study contribute to a better understanding of the potential and limitations of the examined approaches in order to address practitioners and companies in decision-making processes and resources allocation. Moreover, the article can serve as a reference for further investigations in the development of food products, where both intrinsic and extrinsic qualities need to be addressed.

## Keywords

Quality Function Deployment (QFD), Kano Model, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Decision Making

## 1. Introduction

Nowadays the globalized market, as well as the ever-increasing speed of companies in putting new products on the market, are making profitability and competitiveness more difficult for companies. Improving the quality of their products is a challenging task for engineers who have to balance the need to satisfy the customers' expectations with the company's bottom line (Haber et al. 2018). This is particularly true for Small and Medium-sized Enterprises (SMEs), which have difficulties in dealing with such issues, in addition to taking into account laws and regulations, e.g. health, safety and environmental requirements (Taticchi et al. 2010; Dror et al. 2012; Munir et al. 2014; Lombardi and Fagnoli 2017). The capability of a product to satisfy certain requisites in an appropriate way before its market-launch represents a key factor in product development activities. As noted by Burke et al. (2002), if decision-makers articulate what a customer requirement means ineffectively, an incorrect assessment of the importance of that demand occurs. In such a context, the Quality Function Deployment (QFD) method (Akao 1990) plays a primary role in assessing and improving the quality of a product or service before it is put on the market. In details, it facilitates the decision-making process allowing manufacturers a better understanding of the needs and expectations of the customers as to translate them into technical characteristics. The traditional QFD method is based on a four-phase approach (Figure 1) able to satisfy customers by translating their demands into design targets and quality assurance points.

The core of the method is the set of matrices called the "House of Quality" (HoQ), that is based on a cause-effect mechanism, which relates the Customer Requirements (CRs) (the so-called "whats") with Engineering Characteristics (ECs) (the so-called "hows") by means of a relationship matrix (Fagnoli and Sakao 2017). Additionally, the assessment of the "hows" is provided (obtaining the so-called "how-much"), while mutual comparisons can be carried out by a correlation matrix ("the roof of the house"), as well as a benchmarking analysis (Figure 2). Despite its large diffusion, the QFD has been criticized for some weaknesses mainly due to the assessment criteria used in the HoQ, that can lead both to an erroneous evaluation of the qualitative characteristics and attributes, as well as to their incorrect prioritization (Chen et al. 2013; Vinayak and Kodali 2013; Zhang et al. 2015). As remarked by Kannan (2008), the inherent vagueness and impreciseness of the traditional HoQ is mainly due to: the type of inputs, which are often provided in the form of linguistic data; the impreciseness in translating qualitative CRs into ECs; and the resulting vagueness in defining the correlation measures among ECs.

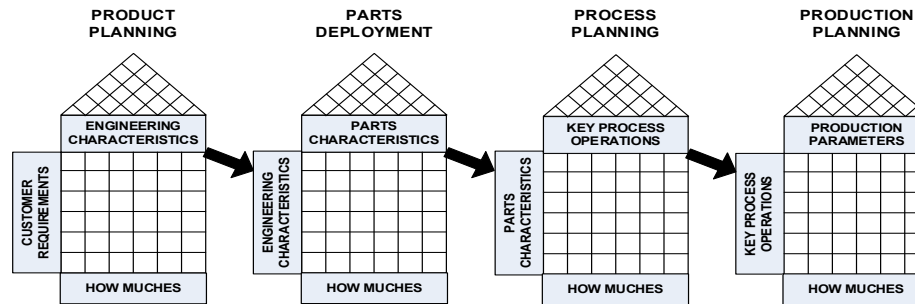


Figure 1. Scheme of the four-phase QFD (adapted from (Akao, 1990)).

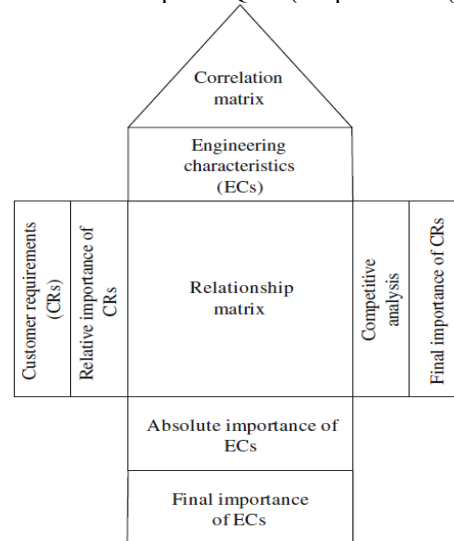


Figure 2. Scheme of the traditional House of Quality (adapted from (Akao, 1990)).

Accordingly, a considerable number of studies proposing possible improvement solutions to reduce this “softness” of the HoQ can be found in the literature (Shen et al. 2001; Xie et al. 2003; Zaim et al. 2014; Zhang et al. 2015; Zheng et al. 2016; Haber et al. 2020). For instance, Nahm et al. (2013) while discussing the limitations of the existing approaches to properly gain the final importance ratings of CRs, focused on capturing the customers’ incomplete or uncertain perceptions on the relative importance of the CRs. Franceschini et al. (2015) reviewed the most diffused techniques for the prioritization of the CRs, underlining the difficulties that can arise when the formulation of the customers’ preference ordering is provided. To solve this problem, they proposed a novel approach based on Yager’s Algorithm (Yager 2001). In addition, Sivasamy et al. (2016) proposed a review of the literature on the development and application of advanced models of QFD. They analysed several well-known HoQ supporting tools, providing a qualitative assessment mainly based on their procedural and computational complexity and pointing out that despite enhancing the precision and accuracy of the results, most advanced models of QFD require excessive efforts that limit their practical usability. On one hand, these studies provided accurate analyses concerning the HoQ’s limitations and its possible augmentations. On the other hand, it can be noted that different studies adopted different approaches, while a comparative and practical evaluation of the effectiveness of these supporting tools is scarcely discussed. Consequently, practitioners have difficulties when selecting the proper tools to improve the HoQ for their specific goal. Hence, the present study is an attempt to fill this gap by investigating the customer requirements’ prioritization problem by means of a case study approach. To do so, the paper addresses the following research question:

RQ. Which approach is more fitting to prioritize the CRs depending on the goal of the analysis and what are the benefits and limitations of each?

With this goal in mind, and based on the studies mentioned earlier, we analyzed and compared some of the most diffused approaches to augment the HoQ’s performances through a case study at the same food manufacturer.

The remainder of the paper is structured as follows: Section 2 briefly exposes our research approach, which is based on a comparative analysis in the food sector. Then Section 3 describes these analyses, and the results are shown and discussed in Section 4. Lastly, Section 5 concludes the article and reflects on future research work.

## 2. Research approach

As mentioned above, numerous studies have investigated the possibility of augmenting the HoQ to reduce its limitations when assessing CRs, and most of them highlighted among others the following types of QFD supporting tools:

1. Methods to categorize CRs, such as the Kano model (Kano et al. 1984). This method is widely recognized as one of the most effective tools for identifying the value perceived by customers concerning the various CRs. It allocates them to five fundamental quality categories: Must-be (M), One-dimensional (O), Attractive (A), Indifferent (I) and Reverse (R). The categorization derives from functional and dysfunctional inquiries where the customer's reactions are identified through specific questionnaires (Matzler and Hinterhuber 1998).
2. Methods to prioritize CRs using pairwise comparisons, e.g. the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) approaches (Saaty 1980; Saaty and Sodenkamp 2008). Both AHP and ANP allow engineers to select the most appropriate solution to a complex problem by decomposing it in a systematically and hierarchically (Ho 2008; Fargnoli et al. 2020; Fargnoli and Haber 2019).
3. The fuzzy set theory to overcome uncertainty problems due to the use of linguistic variables (Büyüközkan and Feyzioğlu 2005; Bevilacqua et al. 2006; Liu 2009). The Fuzzy Logic approach deals with the uncertainty deriving from the imprecision and vagueness of the qualitative and subjective definitions of CRs (Abdolshah and Moradi 2013). Such an approach is usually applied to augment the AHP or ANP methods.
4. Tools aimed at the prioritization of preference orderings of CRs (Nahm et al. 2013; Franceschini et al. 2015). An ordering-based approach based on Yager's theory of aggregation allows engineers to address the problem of aggregating importance orderings of multiple decision-makers with respect to a set of possible alternatives (Yager, 1993; Wang and Tseng 2011; Chen et al. 2013; Zheng et al. 2016). In particular, we focused on Thurstone's Law of Comparative Judgement (LCJ) (Thurstone 1927), introduced by Franceschini and Maisano (2015), to aggregate the CRs' judgments into a continuous interval scale (Haber and Fargnoli 2019).

Needless to say, the above list cannot be considered exhaustive, since a plethora of studies have dealt with the analysis and application of QFD supporting tools in different sectors. Based on the previous analysis, we selected five different approaches that correspond to the main followed solutions to augment the HoQ: in Table 1, the list of the method is proposed, as well as the criteria adopted for the prioritization of CRs and study we used as a reference for the method's application.

Table 1. List of the tools used in the case study

| Tools           | CRs prioritization criteria                                    | References                    |
|-----------------|----------------------------------------------------------------|-------------------------------|
| ANP             | Assessment of the correlation relationships                    | Lam 2015                      |
| Fuzzy Logic     | Translation of linguistic preferences into quantitative values | Liu 2009                      |
| Kano            | CRs importance based on Customer Satisfaction                  | Matzler and Hinterhuber 1998  |
| Thurstone's LCJ | Preference ordering through an ordinal scale                   | Franceschini and Maisano 2015 |
| Fuzzy AHP       | Hierarchization based on multiple sets of values               | Abdolshah and Moradi 2013     |

It has to be noted that these tools do not represent all the solutions that have been proposed in the scientific literature. We limited our selection to some of the most studied ones, as examples of different ways of improving the HoQ's weaknesses concerning the assessment and prioritization of the CRs. Similarly, the analysis of advanced mathematical models, such as the fuzzy goal programming (FGP) approach (Chen et al. 2017) or the evidential reasoning (ER) based QFD method (Chin et al. 2009), are beyond this paper.

The comparative analysis of these tools was carried out through their application in a case study at a food manufacturer. The choice of the case study is due to two main reasons: the size of the manufacturer, as our study is aimed at providing easy-to-handle hints for SMEs; and the complexities that reside in properly interpreting the consumer's requirements given the sensory characteristics of the food product (Vatthanakul et al. 2010; De Pelsmaecker et al. 2015), which make the description of CRs vaguer and imprecise (Dolgun and Koksall 2017).

More in detail, the study was performed in collaboration with a small-sized sugar confectionery manufacturer seeking to improve the quality of its chocolate bars. Six types of bars are produced: the basis can be made by milk chocolate or dark chocolate, and they can include pieces of almonds or nougats. In particular, the concerned product in this study is a milk chocolate bar mainly consumed as a snack, which is sold in pieces of 100 grams at company shops and through retailers. The company was interested in understanding its customers' preferences for this type of product to address its future production. The study was carried out involving a focus group of experts, including a

company technician, an expert in food engineering, and an expert in food science. As per the customers' interviews, a group of 120 university students, who are chocolate bar consumers, was involved. They were divided into 3 groups and interviewed separately to avoid any bias: group A (20 people); group B (50 people), and group C (50 people).

### 3. Case study

The first step of the study consisted of determining the Customer Requirements (CRs) and Engineering Characteristics (ECs). In details, the CRs' definition was obtained by means of semi-structured individual interviews to group A. As for the Engineering Characteristics (ECs), they were established in cooperation with a group of experts (Table 2).

Table 2. List of the selected customer requirements (CRs) and engineering characteristics (ECs)

| Customer Requirements             | Engineering Characteristics              |
|-----------------------------------|------------------------------------------|
| CR 1 – Rich and intense taste     | EC 1 – Fat content                       |
| CR 2 – Reduced fats               | EC 2 – Sugar content                     |
| CR 3 – Presence of dried fruits   | EC 3 – Dried fruits content              |
| CR 4 – Easiness to chew           | EC 4 – Quantity of chocolate             |
| CR 5 – Easy to store when opened. | EC 5 – Dough smoothness                  |
| CR 6 – Pleasing appearance        | EC 6 – Size of dried fruits              |
| CR 7 – Adequate size.             | EC 7 – Presence and shape of the notches |
| CR 8 – Affordable price           | EC 8 – Chewiness                         |
|                                   | EC 9 – Format                            |
|                                   | EC 10 – Type of wrapping (packaging)     |
|                                   | EC 11 – Price                            |
|                                   | EC 12 – Surface characteristics          |
|                                   | EC 13 – Gloss                            |
|                                   | EC 14 – Aroma                            |
|                                   | EC 15 – Texture                          |

Then, to complete the collection of data to use as input for the application of the selected tools, a questionnaire was developed in cooperation with the company's experts and submitted to group B. The members of this group were asked to grade the importance of each CR using a Likert scale (Likert 1932), ranging from 1 (not important) to 5 (extremely important). The customers were asked to rate their satisfaction levels according to the company's product as well as to two equivalent products produced by two main competitors: this allowed the company to measure its performance on the market vis-à-vis the CRs. The obtained information was measured against a target value set by the experts to identify the possible improvement margins.

Afterwards, a different questionnaire was used involving group C to assess their satisfaction as per Kano et al. (1984), and to obtain a pairwise comparison of the CRs as to evaluate the importance of each CR compared to the others (Liu 2009; Ho et al. 2012). The latter was performed by means of an importance scale ranging from 1 (CR<sub>i</sub> and CR<sub>j</sub> are of equal importance) to 9 (CR<sub>i</sub> is significantly dominant compared to CR<sub>j</sub>). This allowed us to obtain data for the implementation of the AHP and ANP approaches by means of the criteria defined by (Kamvyssi et al. 2014). For the use of the fuzzy logic, we opted for Triangular Fuzzy Numbers (TFNs) given their easy handling and manipulation (Table 3).

Table 3. Crisp and fuzzy scales

| Linguistic variables      | Rating Scale | Equivalence in Fuzzy numbers |                 |
|---------------------------|--------------|------------------------------|-----------------|
|                           |              | TFNs                         | Reciprocal TFNs |
| Equally important         | 1            | (1, 1, 1)                    | (1, 1, 1)       |
| Intermediate              | 2            | (1, 2, 3)                    | (1/3, 1/2, 1)   |
| Moderately more important | 3            | (2, 3, 4)                    | (1/4, 1/3, 1/2) |
| Intermediate              | 4            | (3, 4, 5)                    | (1/5, 1/4, 1/3) |
| Strongly more important   | 5            | (4, 5, 6)                    | (1/6, 1/5, 1/4) |

|                              |   |            |                  |
|------------------------------|---|------------|------------------|
| Intermediate                 | 6 | (5, 6, 7)  | (1/7, 1/6, 1/5)  |
| Very strongly more important | 7 | (6, 7, 8)  | (1/8, 1/7, 1/6)  |
| Intermediate                 | 8 | (7, 8, 9)  | (1/9, 1/8, 1/7)  |
| Extremely more important     | 9 | (8, 9, 10) | (1/10, 1/9, 1/8) |

### 3.1. Traditional House of Quality

The traditional QFD method was applied, taking into account the abovementioned information and the Absolute Importance (AI) of each EC was deduced using (1).

$$AI_j = \sum_{i=1}^8 RI_i \times S_{ij} \quad (1)$$

Where 'j' indicates the column (EC), 'i' indicates the row (CR), RI is the Raw Importance and  $S_{ij}$  is the relationship score between  $EC_j$  and  $CR_i$ , rated 1, 3 or 9 (ReVelle et al., 1998). Then, the company's product was compared to two competitors producing equivalent chocolate bars. Consequently, the gaps separating the company from its desired performance levels were defined by the Improvement Ratio (IR). This results in an HoQ where the CRs are defined by their Raw Weights (RW) (Figure 3).

|      | RW    | Relative RW | CR Ranking |
|------|-------|-------------|------------|
| CR 1 | 5.61  | 11.88%      | 3          |
| CR 2 | 5.01  | 10.59%      | 4          |
| CR 3 | 3.92  | 8.30%       | 5          |
| CR 4 | 3.87  | 8.20%       | 6          |
| CR 5 | 3.51  | 7.43%       | 8          |
| CR 6 | 5.97  | 12.62%      | 2          |
| CR 7 | 3.84  | 8.13%       | 7          |
| CR 8 | 15.53 | 32.85%      | 1          |

| EC 1 | EC 2 | EC 3 | EC 4 | EC 5 | EC 6 | EC 7 | EC 8 | EC 9 | EC 10 | EC 11 | EC 12 | EC 13 | EC 14 | EC 15 |
|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
| 9    | 9    | 9    | 9    | 3    | 3    |      |      |      |       | 9     |       | 3     | 1     | 9     |
| 9    | 9    | 9    | 9    |      | 3    |      |      |      |       | 3     | 1     | 1     | 3     | 9     |
| 3    | 1    | 9    | 3    | 3    | 9    | 3    | 9    |      |       |       | 3     |       | 1     | 9     |
| 3    | 3    | 9    | 9    | 9    | 9    |      | 9    |      |       |       |       |       |       | 9     |
| 3    | 3    | 9    | 9    |      | 9    | 9    |      | 9    | 9     |       |       |       |       |       |
| 3    | 1    | 9    | 9    | 3    | 9    | 9    |      | 9    | 9     |       | 9     | 9     |       |       |
|      |      |      |      |      |      |      |      | 9    | 9     | 9     |       |       |       |       |
| 9    | 9    | 9    | 9    |      | 9    |      |      | 9    | 9     | 9     |       |       | 3     | 3     |

| Absolute Importance (AI)     | 287.12 | 267.34 | 390.74 | 367.20 | 81.36 | 327.02 | 97.04 | 70.16 | 259.57 | 259.57 | 239.83 | 70.47 | 75.54 | 71.13 | 212.32 |
|------------------------------|--------|--------|--------|--------|-------|--------|-------|-------|--------|--------|--------|-------|-------|-------|--------|
| Relative Absolute Importance | 9.33%  | 8.69%  | 12.70% | 11.94% | 2.64% | 10.63% | 3.15% | 2.28% | 8.44%  | 8.44%  | 7.80%  | 2.29% | 2.46% | 2.31% | 6.90%  |
| EC Ranking                   | 4      | 5      | 1      | 2      | 11    | 3      | 10    | 15    | 6      | 6      | 8      | 14    | 12    | 13    | 9      |

### 3.2. Kano model implementation

As mentioned above, Kano's quality categories were deduced from the questionnaires. Thus, the Customer Satisfaction Coefficient for satisfaction ( $CSC_{SI}$ ) and dissatisfaction ( $CSC_{DI}$ ) were calculated using (2) and (3). Then the Improvement Ratio was defined by means of (4), where "k" represents a correction coefficient related to the Kano categories (Matzler and Hinterhuber 1998) as shown in (5).

$$CSCSI = \frac{A+O}{A+O+M+I} \quad (2)$$

$$CSCDI = -\frac{O+M}{A+O+M+I} \quad (3)$$

$$IR_{adj} = (IR_0)^{\frac{1}{k}} \quad (4)$$

$$k = \begin{cases} 0.5, & \text{Must - be quality} \\ 1, & \text{One - dimensional quality} \\ 2, & \text{Attractive quality} \\ 3, & \text{Indifferent quality} \end{cases} \quad (5)$$

The adjusted IR is utilized in (3), leading to the adjusted RWs of each CR, which are then used to complete the HoQ (the results are shown and discussed in Section 4).

### 3.3. Fuzzy Logic implementation

As mentioned before, we adopted the Fuzzy Logic approach based on the criteria proposed in Table 3 and the TFN scale was used to estimate the results of the CRs comparisons. This allows us to construct a fuzzy pairwise-comparison matrix for each customer, and finally, an average fuzzy value is obtained to construct a CR comparison matrix (Table 4). The resulting TFNs are then normalized.

### 3.4. ANP implementation

The ANP method consists of three main stages: developing the network diagram, generating the matrix and determining the system elements' priorities. Hence, in accordance with the model proposed by Liu and Tsai (2012) in a QFD context the network representation can be adapted as follows.

Table 4. Fuzzy CR comparison matrix (excerpt of 3 CRs)

|      | CR 1 |      |      | CR 2 |      |      | CR 3 |      |      |
|------|------|------|------|------|------|------|------|------|------|
| CR 1 | 1.00 | 1.00 | 1.00 | 4.16 | 4.90 | 5.64 | 2.80 | 3.42 | 4.05 |
| CR 2 | 0.18 | 0.20 | 0.24 | 1.00 | 1.00 | 1.00 | 1.45 | 1.80 | 2.16 |
| CR 3 | 0.25 | 0.29 | 0.36 | 0.46 | 0.56 | 0.69 | 1.00 | 1.00 | 1.00 |

The first step is the definition of the degree of importance of the CRs with respect to the goal,  $w_{21}$ , assuming there are no dependencies among them (Lam 2015). The inner-dependencies of the CRs is then determined as well as the inner-dependencies of the ECs. Then, the importance levels are calculated with respect to each of the 8 CRs, which leads to  $w_{32}$ . Using the formula (6), the overall priorities of the ECs are then computed by multiplying the four resulting weight vectors: (the ensuing results are shown and discussed in Section 4).

$$W_{ANP} = W_{21} \times W_{22} \times W_{32} \times W_{33} \quad (6)$$

### 3.5. LCJ implementation

The LCJ implementation is based on the approach proposed by Franceschini and Maisano (2015). Accordingly, each CR is characterized by a normal distribution  $CR_i \sim N(\mu_i, \sigma_i^2)$ , where “ $\mu$ ” is the mean and “ $\sigma$ ” the standard deviation. Per Thurstone (1927), a CR is characterized by a variance which mirrors the CR-to-CR variability (7), where “ $\rho_{ij}$ ” is the correlation between  $CR_i$  and  $CR_j$ .

$$CR_{ij} = CR_i - CR_j \sim N(\mu_{ij} = \mu_i - \mu_j, \sigma_{ij}^2 = \sigma_i^2 + \sigma_j^2 - 2 \rho_{ij} \sigma_i \sigma_j) \quad (7)$$

First, the customers’ importance level attribution is morphed into a linear ordering known as a rank-order data (Figure 4). The CR comparison matrix is derived from the linear ordering previously established by using the practical response mode, where a preferred CR over another is noted “1” (otherwise “0”) and an equal importance level is noted “0.5” (Table 5).

|      | Importance Level |                  |           |                |                     |                                                                |
|------|------------------|------------------|-----------|----------------|---------------------|----------------------------------------------------------------|
|      | Not important    | Little important | Important | Very important | Extremely important |                                                                |
| CR 1 |                  |                  | X         |                |                     | <div>Linear Ordering</div> <div>CR 3 &gt; CR 1 &gt; CR 2</div> |
| CR 2 |                  | X                |           |                |                     |                                                                |
| CR 3 |                  |                  |           |                | X                   |                                                                |

Figure 4. Linear ordering example of the CRs (excerpt from an interviewed customer for 3CRs)

Table 5. CR comparison matrix (excerpt of 3 CRs)

|      | CR 1 | CR 2 | CR 3 |
|------|------|------|------|
| CR 1 | 0.5  | 1    | 0    |
| CR 2 | 0    | 0.5  | 0    |
| CR 3 | 1    | 1    | 0.5  |

Subsequently, the paired comparison matrices are aggregated into a single Frequency matrix (F) which denotes the number of times a row-entry  $CR_i$ , has been preferred over a column-entry  $CR_j$ . Based on this, a Probability matrix (P) is created as per (8), where  $F_{ij}$  is an element of the  $i^{\text{th}}$  row and the  $j^{\text{th}}$  column of F and N is the total number of customers,  $N = 50$ .

$$P_{ij} = \frac{F_{ij}}{N} \quad (8)$$

The Probability matrix (P) can then be interpreted through a standardized variable  $z_{ij}$  (9), which leads to the Standardized matrix (Z).

$$z_{ij} = \frac{CR_{ij} - \mu_{ij}}{\sigma_{ij}} \quad (9)$$

where:

$$\begin{aligned} \mu_{ij} &= \mu_i - \mu_j \\ \sigma_{ij} &= \sqrt{(\sigma_i^2 + \sigma_j^2 - 2 \rho_{ij} \sigma_i \sigma_j)} \end{aligned} \quad (10) \quad (11)$$

Moreover, in a paired judgement scheme where the evaluation of one CR has no effect nor influence on the evaluation of another CR, the correlation factor  $\rho_{ij}$  is very low and even null (Franceschini and Maisano, 2015). Furthermore, each CR represents different requirement concepts and the number of responding customer is adequate. This allows assuming a constant and null correlation factor, as per Thurstone (1927):  $\rho_{ij} = \rho = 0$ , for all row and column entries. Consequently, the Thurstone scale's values, ranging from 1 to 5, of each column element,  $CR_j$ , are determined as the mean of each column's elements of (Z). The resulting scale values represent the weights (importance) of the CRs which lead to the HoQ augmented by Thurstone's LCJ.

### 3.6. Fuzzy AHP implementation

In addition to the application of tools belonging to the four approaches discussed in Section 2, a combination of them is also possible as illustrated in numerous studies. In particular, the fuzzy approach is incorporated to improve the transparency of the CRs and minimize inconsistencies by enhancing the conventional AHP approach (Kwong et al., 2003; Saaty and Sodenkamp, 2008; Kamvysi et al., 2014).

The first step of such an approach is the same as in Section 3.3. This allowed us to define the Fuzzy CR comparison matrix and the normalized CR fuzzy comparison matrix. Then, the average of the row elements of this matrix are calculated using (15) to define the column vector where  $C_{ik}^1$  characterizes the grading of each CR's importance 'i' ( $i=1...n$ ). A consistency check follows by multiplying each element in column 'j' of the normalized CR fuzzy AHP matrix by  $C_{ik}^1$  and then dividing the sum of the elements of row 'i' by  $C_{ik}^1$  to yield another column vector, i.e. the  $\hat{C}_{CR}$  crisp matrix (Ho et al. 2012). The consistency ratio is finally deduced (where RI (n) is the random index value dependent on the number of RSPs, 8 in this context and hence RI (8) = 1.41 (Ho et al. 2012) as:

$$CR = \frac{CI}{RI (n=8)} = 0.0616 \quad (12)$$

Similarly, the CRs were grouped into four categories: alimentary characteristics, practicality, aesthetics, and economical aspect. The same approach as the CRs was applied which led to the  $C_{cat}$  crisp matrix (Table 6).

Table 6.  $C_{CAT}$  crisp matrix.

| Categories                                      | $C_{CAT}$ crisp | $C_{CAT}$ relative |
|-------------------------------------------------|-----------------|--------------------|
| A. Alimentary characteristics (CR 1, CR 2, CR3) | 2,50            | 62,52%             |
| B. Practicality (CR 4, CR 5)                    | 0,54            | 13,44%             |
| C. Esthetics (CR 6, CR 7)                       | 0,37            | 9,23%              |
| D. Economical aspect (CR 8)                     | 0,59            | 14,80%             |

Consequently, the HoQ augmented taking into consideration the importance levels obtained per the Fuzzy AHP method is obtained, where the final weight of each CR is calculated as per (13) and the results are shown and discussed in Section 4.

$$C_{FIN} = C_{CR} \times C_{CAT} \quad (13)$$

## 4. Discussion of results

The different approaches represent different ways to augment the performances of the HoQ in understanding and assessing CRs: the weights and the importance levels for each CR based on each approach are shown in Figure 5. These results bring to light the significant differences that occur depending on the approach used to augment the HoQ. For instance, on the one hand, Thurstone's LCJ and the Kano model provide slight differences among the various CRs: i.e. CRs vary in a small range of values, 15,35% (Thurstone's LCJ) and 14,95% (Kano). On the other hand, the other approaches allow a higher level of differentiation: i.e. 31,83% (Fuzzy), 31,31% (ANP) and 47,60% (fuzzy AHP). Secondly, even though the Thurstone's LCJ approach did not show any significant preference (i.e. a CR much more important than the others), it allows engineers to differentiate the CRs. In other words, CRs with similar weights were not found, while some strong resemblances can be observed for the other methods.

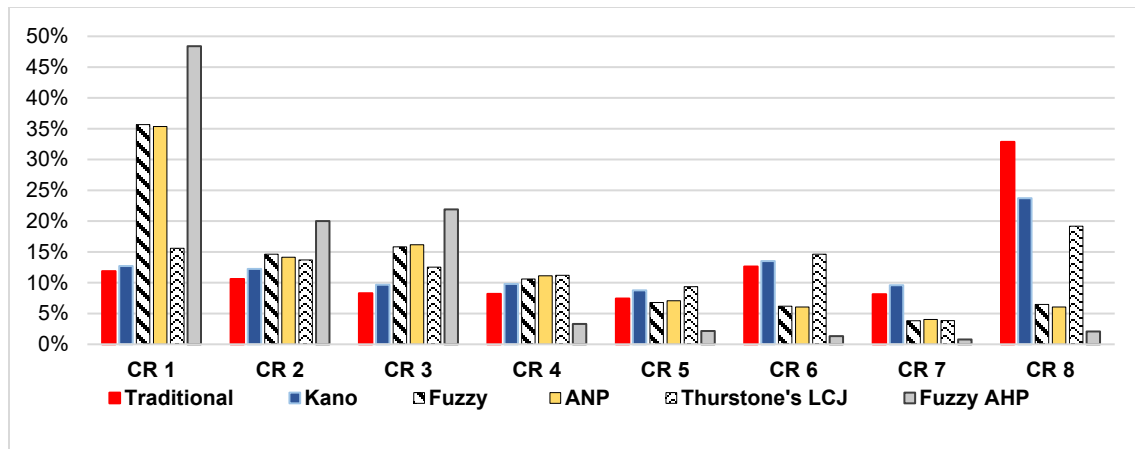


Figure 5. Variation of the importance of the CRs in function of the applied methods.

For example, in the traditional HoQ the differences among CR3 (8,30 %), CR4 (8,20 %) and CR7 (8,13 %) are minor, as well as in the Kano model (CR3 (9,66 %), CR4 (9,81 %) and CR7 (9,59 %)). Moreover, the ranking of the CRs also varies from one approach to another, as shown in Table 7.

Table 7. CR rankings according to each method.

|      | Traditional | Kano | Fuzzy | ANP | Thurstone's LCJ | Fuzzy AHP |
|------|-------------|------|-------|-----|-----------------|-----------|
| CR 1 | 3           | 3    | 1     | 1   | 2               | 1         |
| CR 2 | 4           | 4    | 3     | 3   | 4               | 3         |
| CR 3 | 5           | 6    | 2     | 2   | 5               | 2         |
| CR 4 | 6           | 5    | 4     | 4   | 6               | 4         |
| CR 5 | 8           | 8    | 5     | 5   | 7               | 5         |
| CR 6 | 2           | 2    | 7     | 6   | 3               | 7         |
| CR 7 | 7           | 7    | 8     | 8   | 8               | 8         |
| CR 8 | 1           | 1    | 6     | 7   | 1               | 6         |

More in detail, on the one hand, the Fuzzy, Fuzzy AHP and ANP approaches provided very similar results: i.e. they emphasize more some requirements than others in a similar manner (for instance CR8 has a high impact according to all the three tools, as well as CR1 has a low one). On the other hand, the traditional HoQ and the Kano model showed close analogies. It has to be noted that Thurstone's LCJ approach provided a different ranking of CRs from the ones proposed by the other approaches (yet a few similarities can be found with the ANP and Fuzzy AHP methods).

Considering the three most important CRs per each method, the same bias in favor of CR1 can be found in all of them. However, the other priorities change significantly whereas, in the traditional, Kano and Thurstone's LCJ models, the non-sensory CRs (e.g. CR8 - Affordable Price) are brought forth as they are considered separately from the other CRs. However, the fuzzy, ANP and fuzzy AHP models consider the correlations between the non-sensory and sensory requirements (e.g. CR1 - Rich and intense taste) allowing a more comprehensive and coherent assessment of the CRs. Thus, if a company in the food sector decides to satisfy the most relevant customer demands comprehensively, the latter methods can provide quite comparable results, allowing a holistic perception of customers' needs. On the contrary, if the company is interested in focusing more on marketing aspects rather than modifying the ingredients of the product itself, the traditional QFD, as well as Kano's model and Thurstone's LCJ approaches can provide useful information in terms of competitiveness. It has to be noted that the latter approach also provides a differentiation between each CR and the others; hence its use is suggested when decision-makers need a more complete ranking of CRs. Similarly, the importance levels of each EC were evaluated, and their mutual comparison denotes a lower variability compared to the one associated with the CRs. For example, EC15 (texture) undergoes the most variation when the Fuzzy AHP method is applied, with an increase of almost 100% in importance compared to its initial value. Oppositely, EC10 (type of wrapping) and EC6 (size of dried fruits) become the least important as the Fuzzy AHP applied (Figure 6).

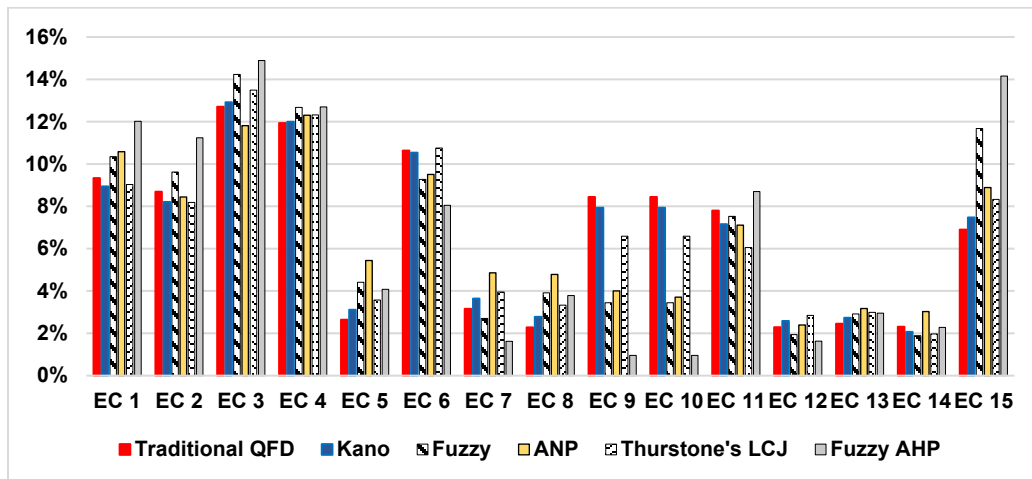


Figure 6. Variation of the importance of the ECs in function of the applied methods.

From the obtained results, no QFD supporting approach can be considered complete and adaptable to any product and context. Given that each approach presents its benefits and disadvantages, their use depends on both the manufacturer's resources and the goal of the analysis. As far as the former aspect is concerned, the Fuzzy AHP and the ANP approaches certainly require a more relevant effort; on the contrary, the application of the Kano model is simpler, while the computational effort for the use of the Thurstone's LCJ approach is directly related to the number of the CRs. When considering the goal of the application, in synthesis we can observe that:

- The Thurstone's LCJ approach provides a clearer ranking of customers' judgments, allowing engineers to differentiate each CR from the others;
- The Fuzzy and Fuzzy AHP allows engineers to better focus on sensorial attributes;
- Marketing aspects are better stressed by the Kano model and Thurstone's LCJ approach;
- When the goal of the analysis is to better understand the balance among all qualitative characteristics of the product, the ANP approach can provide results that are more thorough and comprehensive.

Accordingly, from a more general perspective, it emerged that fuzzy and hierarchical approaches are more accurate as they bring forward the importance of the subjective criteria that a quantitative assessment cannot capture. This accomplishes the research approach proposed by Dolgun and Köksal (2017), who used AHP to prioritize CRs from the customers' perspective and Kansei Engineering (KE) to better capture the customers' feelings. Conversely, since they need experienced users and require certain computational efforts, Thurstone's LCJ approach might represent a good solution especially when a preliminary feasibility analysis is needed while developing a new product. Furthermore, the study confirmed the difficulties in interpreting customer needs and expectations when dealing with a food product, envisaging the benefits that the use of the QFD can provide in this context. This is in line with the findings of the few studies that addressed such issues (de Fátima Cardoso et al. 2015). In fact, as argued by Benner et al. (2003), it is very difficult to interpret the consumer wishes properly, as this relies on the understanding of their perceived quality. Hence, when analyzing the quality of a food product both its intrinsic and extrinsic attributes need to be addressed (Ikeda et al. 2004). Based on this, despite its large popularity and potentials, the use of QFD is limited in the food sector (Bevilacqua et al. 2012). For this reason, our study can augment the knowledge the use of such a tool in capturing the customers' preferences for adequate decision-making when developing the food product.

Overall, even though the QFD supporting tools are largely examined in the literature, a comparative analysis among them is scarcely discussed. Hence, this study can certainly contribute to better understand the potential and limitations of the examined approaches. Since it was performed in a practical context and with the support of a multifunctional group of experts, the achieved results can be considered consistent and useful for practitioners. Moreover, the outputs of this study can also contribute to augment the scientific knowledge on the use of QFD, especially in the food sector. The results obtained confirm the difficulties that practitioners can find when dealing with the HoQ's "mechanism" and the ambiguity of qualitative assessment criteria (Burke et al. 2002; Olewnik and Lewis 2008; Raharjo et al. 2011). Still, they can guide engineers in selecting the proper approach depending on their sought goals and the availability of their resources. Besides these positive aspects, some limitations need to be outlined. Firstly, although the numerous studies reviewed, the number of supporting tools used cannot be considered exhaustive. We selected five of the main diffused approaches discussed in the literature to augment the effectiveness of QFD.

Nevertheless, other tools can certainly be found, such as the Design Structure Matrix (DSM) and the Domain Mapping Matrix (DMM) (Eppinger and Browning 2012), the Axiomatic Design (Carnevalli et al. 2010), the Spherical fuzzy QFD (SF-QFD) (Gündoğdu and Kahraman 2020), or the Hesitant Fuzzy QFD (Onar et al. 2016). Moreover, since the study was carried out in the food sector, the “qualitative” nature of the parameters used in the HoQ makes the assessment of their interdependencies more difficult (Benner et al., 2003). Thus, a larger number of customers involved in the study can provide more precise results, especially when using the ANP and the Thurstone’s LCJ approaches.

## 5. Conclusions

Despite its global diffusion and large use, the QFD methods present some limitations especially concerning the evaluation and the prioritization of customers’ needs. This article proposed a comparative analysis of some of the most well-known approaches that are used to address such a problem utilizing a practical case study at a company operating in the food sector. The results achieved have brought to light the different potentials of such approaches in maximizing the benefits of the HoQ and reducing its “softness”, which mainly relies on the difficulties arising from the dependency on the human assessment abilities, i.e. the problem of transforming qualitative judgments into quantitative values by means of an ordinal scale. In summary, our study provides practical insights in addressing the use of the HoQ and several of its supporting approaches to better understand and prioritize customers’ needs through a case-based research. Accordingly, the article can serve as a reference for further investigations in the food products’ development, where both intrinsic and extrinsic qualities need to be addressed. However, to reduce the above-mentioned limitations further research work is needed. In particular, the application of the proposed approach in a different context, as well as its implementation with the support of a larger number of questionnaires (i.e. more customers involved) can certainly help in improving the validity of our practical findings.

## References

- Abdolshah, M., and Moradi, M., Fuzzy quality function deployment: an analytical literature review, *Journal of Industrial Engineering*, pp. 1-11, 2000.
- Akao, Y., *Quality function deployment: integrating customer requirements into product design*, Productivity Press, Cambridge, 1990.
- Benner, M., Linnemann, A. R., Jongen, W. M. F., and Folstar, P., Quality Function Deployment (QFD) - Can it be used to develop food products? *Food Quality Preference*, vol. 14, no. 4, pp. 327-339, 2003.
- Bevilacqua, M., Ciarapica, F. E., and Giacchetta, G., A fuzzy-QFD approach to supplier selection, *Journal of Purchasing and Supply Management*, vol 12, no.1, pp.14-27, 2006.
- Bevilacqua, M., Ciarapica, F. E., and Marchetti, B., Development and test of a new fuzzy-QFD approach for characterizing customers rating of extra virgin olive oil, *Food Quality Preference*, vol. 24, no. 1, pp. 75–84, 2012.
- Burke, E., Kloeber Jr, J. M., and Deckro, R. F., Using and abusing QFD scores, *Quality Engineering*, vol. 15, no. 1, pp. 9-21, 2002.
- Büyükoçkan, G., and Feyzioğlu, O., Group decision making to better respond customer needs in software development, *Computers in Industrial Engineering*, vol. 48, no. 2, pp. 427-441, 2005.
- Carnevalli, J. A., and Miguel, P.C., Review, analysis and classification of the literature on QFD-Types of research, difficulties and benefits, *International Journal of Production Economics*, vol. 114, no. 2, pp. 737-754, 2008.
- Chen, L. H., Ko, W. C., and Yeh, F. T., Approach based on fuzzy goal programming and quality function deployment for new product planning, *European Journal of Operational Research*, vol. 259, no. 2, pp. 654-663, 2017.
- Chen, S., Liu, J., Wang, H., and Augusto, J. C.: Ordering based decision making - a survey, *Information Fusion*, vol. 14, no. 4, pp. 521-531, 2013.
- Chin, K. S., Wang, Y. M., Yang, J. B., and Poon, K. K. G., An evidential reasoning-based approach for quality function deployment under uncertainty, *Expert Systems with Applications*, vol. 36, no.3, pp. 5684-5694, 2009.
- de Fátima Cardoso, J., Casarotto Filho, N., and Miguel, P. A. C., Application of Quality Function Deployment for the development of an organic product., *Food Quality Preference*, vol. 40, pp.180-190, 2015.
- De Pelsmaecker, S., Gellynck, X., Delbaere, C., Declercq, N., and Dewettinck, K., Consumer-driven product development and improvement combined with sensory analysis: A case-study for European filled chocolates. *Food Quality Preference*, vol. 41, pp. 20-29, 2015.
- Dolgun, L. E., and Köksal, G., Effective use of quality function deployment and Kansei engineering for product planning with sensory customer requirements: a plain yogurt case, *Quality Engineering*, pp. 569-582, 2017.
- Dror, S., Bashkansky, E., and Ravid, R., House of security: a structured system design & analysis approach. *International Journal of Safety and Security Engineering*, vol. 2, no. 4, pp. 317-329, 2012.
- Eppinger, S. D., and Browning, T.R., *Design structure matrix methods and applications*, MIT Press, Cambridge, 2012.

- Fargnoli, M., and Sakao, T., Uncovering differences and similarities among quality function deployment-based methods in design for X: Benchmarking in different domains. *Quality Engineering*, vol. 29, no. 4, pp. 690-712, 2017.
- Fargnoli, M., and Haber, N., A practical ANP-QFD methodology for dealing with requirements' inner dependency in PSS development, *Computers & Industrial Engineering*, vol. 127, pp. 536-548, 2019
- Fargnoli, M., Lombardi, M., Haber, N., and Guadagno, F. Hazard function deployment: a QFD-based tool for the assessment of working tasks - a practical study in the construction industry. *International Journal of Occupational Safety and Ergonomics*, vol. 6, no. 2, pp. 348-369, 2020.
- Franceschini, F., and Maisano, D., Prioritization of QFD customer requirements based on the law of comparative judgments. *Quality Engineering*, vol. 27, no. 4, pp. 437-449, 2015.
- Gündoğdu, F. K., and Kahraman, C., A novel spherical fuzzy QFD method and its application to the linear delta robot technology development, *Engineering Applications of Artificial Intelligence*, vol. 87, ID 103348, 2020.
- Haber, N., Fargnoli, M., Tronci, M., and Ababneh, A., Managing customer requirements for an effective service implementation in a Product-Service System (PSS), *Proceedings of the 2nd IEOM European Conference on Industrial Engineering and Operations Management, Paris, France, July 26-27, 2018*.
- Haber, N., Fargnoli, M., and Sakao, T., Integrating QFD for product-service systems with the Kano model and fuzzy AHP, *Total Quality Management & Business Excellence*, vol. 31, no. 9-10 pp. 929-954, 2020.
- Haber, N., and Fargnoli, M. Prioritizing customer requirements in a product-service system (PSS) context. *The TQM Journal*, vol. 31 no. 2, pp. 257-273, 2019.
- Ho, W., He, T., Lee, C. K. M., and Emrouznejad, A., Strategic logistics outsourcing: An integrated QFD and fuzzy AHP approach, *Expert Systems with Applications*, vol. 39, no. 12, pp. 10841-10850, 2012.
- Ikeda, G., Nagai, H., and Sagara, Y., Development of food kansei model and its application for designing tastes and flavors of green tea beverage, *Food science and technology research*, vol. 10, no. 4, pp. 396-404, 2007.
- Kamvysi, K., Gotzamani, K., Andronikidis, A., and Georgiou, A. C., Capturing and prioritizing students' requirements for course design by embedding Fuzzy-AHP and linear programming in QFD, *European Journal of Operational Research*, vol. 237, no. 3, pp. 1083-1094, 2014.
- Kannan, G., Implementation of fuzzy quality function deployment in an automobile component to improve the quality characteristics, *Quality Engineering*, vol. 20, no. 3, pp. 321-333, 2008.
- Kano, N., Seraku, N., Takahashi, F., and Tsuji, S., Attractive Quality and Must-Be Quality, *The Journal of Japanese Society for Quality Control*, vol. 14, pp. 147-156, 1984.
- Kwong, C.K., Bai, H., Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach, *IIE Transactions*, vol. 35, no. 7, pp. 619-626, 2003.
- Lam, J. S. L., Designing a sustainable maritime supply chain: A hybrid QFD-ANP approach, *Transportation Research Part E: Logistics Transport Review*, vol. 78, pp. 70-81, 2015.
- Likert, R., *A technique for the measurement of attitudes*, Archives of psychology, New York, 1932.
- Liu, H. T., and Tsai, Y. L., A fuzzy risk assessment approach for occupational hazards in the construction industry. *Safety Science*, vol. 50, no. 4, pp. 1067-1078, 2012.
- Liu, H. T., The extension of fuzzy QFD: From product planning to part deployment, *Expert Systems with Applications*, vol. 36, no. 8, pp. 11131-11144, 2009.
- Lombardi, M., and Fargnoli, M., Prioritization of hazards by means of a QFD-based procedure, *International Journal of Safety and Security Engineering*, vol. 8, no. 2, pp. 342-353, 2018.
- Matzler, K., and Hinterhuber, H. H., How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment, *Technovation* vol. 18, no. 1, pp. 25-38, 1998.
- Munir Ahmad, M., and Alaskari, O., Development of assessment methodology for improving performance in SME's, *International Journal of Production Performance Management*, vol. 63, no. 4, pp. 477-498, 2014.
- Nahm, Y. E., Ishikawa, H., and Inoue, M.: New rating methods to prioritize customer requirements in QFD with incomplete customer preferences, *International Journal of Advanced Manufacturing Technology*, pp. 1-18, 2013.
- Olewnik, A., and Lewis, K., Limitations of the House of Quality to provide quantitative design information, *International Journal of Quality and Reliability Management*, vol. 25, no. 2, pp. 125-146, 2008.
- Onar, S. Ç., Büyüközkan, G., Öztayşi, B., and Kahraman, C., A new hesitant fuzzy QFD approach: an application to computer workstation selection, *Applied Soft Computing*, vol. 46, pp. 1-16, 2016.
- Raharjo, H., Xie, M., and Brombacher, A. C., A systematic methodology to deal with the dynamics of customer needs in Quality Function Deployment, *Expert Systems with Applications*, vol. 38, no. 4, pp. 3653-3662, 2011.
- Revelle, J. B., Moran, J. W., and Cox, C.A., *The QFD handbook*, John Wiley and Sons, New York, 1998.

- Saaty, T. L., and Sodenkamp, M., Making decisions in hierarchic and network systems, *International Journal of Applied Decision Science*, vol. 1, no. 1, pp. 24-79, 2008.
- Saaty, T. L., *The analytic hierarchy process*, McGraw Hill, New York, 1980.
- Shen, X. X., Xie, M., and Tan, K. C., Listening to the future voice of the customer using fuzzy trend analysis in QFD, *Quality Engineering*, vol. 13, no. 3, pp. 419-425, 2001.
- Sivasamy, K., Arumugam, C., Devadasan, S. R., Muruges, R., and Thilak, V. M. M., Advanced models of quality function deployment: a literature review, *Quality and Quantity*, vol. 50, no. 3, pp. 1399-1414, 2016.
- Taticchi, P., Tonelli, F., and Cagnazzo, L., Performance measurement and management: a literature review and a research agenda, *Measuring business Excellence*, vol. 14, no. 1, pp. 4-18, 2010.
- Thurstone, L. L., A law of comparative judgments, *Psychology Review*, vol. 34, pp. 273-286, 1927.
- Vatthanakul, S., Jangchud, A., Jangchud, K., Therdthai, N., and Wilkinson, B.: Gold kiwifruit leather product development using quality function deployment approach, *Food Quality Preference*, vol. 21, no. 3, pp. 339-345, 2010.
- Vinayak, K., and Kodali, R., Benchmarking the quality function deployment models, *Benchmarking: An International Journal*, vol. 20, no. 6, pp. 825-854, 2013.
- Wang, Y., and Tseng, M.M., Integrating comprehensive customer requirements into product design, *CIRP Annals – Manufacturing Technology*, vol. 60 no. 1, pp. 175-178, 2011.
- Xie, M., Goh, T. N., and Tan, K. C., *Advanced QFD applications*. ASQ Quality Press, Milwaukee, 2003.
- Yager, R. R., Non-numeric multi-criteria multi-person decision making, *Group Decision and Negotiation*, vol. 2, no. 1, pp. 81-93, 1993.
- Yager, R. R., Fusion of multi-agent preference orderings, *Fuzzy Sets Systems*, vol. 117, no. 1, pp. 1-12, 2001.
- Zaim, S., Sevkli, M., Camgöz-Akdağ, H., Demirel, O. F., Yayla, A. Y., and Delen, D., Use of ANP weighted crisp and fuzzy QFD for product development, *Expert Systems with Applications*, vol. 41, no. 9, pp. 4464-4474, 2003.
- Zhang, X., Tong, S., Eres, H., Wang, K., and Kossmann, M., Towards avoiding the hidden traps in QFD during requirements establishment. *Journal of Systems Science and Systems Engineering*, vol. 24, no. 3, pp. 316-336, 2015.
- Zheng, P., Xu, X., and Xie, S. Q., A weighted interval rough number-based method to determine relative importance ratings of customer requirements in QFD product planning, *Journal of Intelligent Manufacturing*, pp. 1-14, 2016.

## Biographies

**Mario Fagnoli** is currently employed at the Italian Ministry of Agriculture as Technical Director and collaborates with Sapienza - University of Rome as Contract Professor, where he teaches machinery safety at the Faculty of Civil and Industrial Engineering. He earned his PhD in 2005 at the Sapienza University of Rome presenting a thesis on the sustainable development of industrial products. He worked at the Department of Precision Machinery of the University of Tokyo as JSPS Fellow Researcher. His research interests mainly concern design for safety, product service systems (PSS), ecodesign, quality function deployment (QFD), as well as other engineering design and management methods.

**Nicolas Haber** is an Industrial Engineer holding a PhD in Industrial Engineering and Engineering Management from Sapienza - University of Rome which he earned in 2017. His field of research is the design of product-service systems in a sustainable manner. He is currently the technical leader for the development of electronic components for PSA group. He previously worked at Heineken and obtained the 6-Sigma black belt certificate.

**Davide Platti** holds a master's degree in Mechanical Engineering from Sapienza - University of Rome. Currently he is Life Testing Laboratory Manager for Fisher & Paykel Appliances Italy (Haier Group). His activities range from the Supplier Quality Assurance to new components homologation and Six Sigma Methodologies.

**Massimo Tronci**, PhD in Energetics, is Full Professor of Industrial Systems Engineering and Director of the PhD School in Industrial and Management Engineering at Sapienza - University of Rome. His teaching activities concern Industrial Systems Engineering, Operations Management and Smart Factory in the Faculty of Civil and Industrial Engineering. His main research topics are: Supply Chain Management, Operations Management, Quality and Safety Management.