Applying flexible fuzzy numbers for Likert scale-based service quality evaluations based on a healthcare example

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Abstract

The purpose of the paper is to introduce a flexible fuzzy number based methodology in order to enhance the reliability of Likert scale-based evaluations. The novelty of the presented methodology lies in the flexibility of fuzzy numbers as they can present various shapes and therefore, can illustrate the uncertainty embedded in the evaluation process in various ways. Owing to its properties, flexible fuzzy numbers can be utilized for multidimensional evaluation of service quality by aggregating the results into one flexible fuzzy number expressing the overall goodness of the studied service quality characteristic, which are demonstrated through a healthcare example.

Keywords: Flexible fuzzy number, Likert scale, Healthcare

Introduction

In the era of competitive environment, the service sector is under extreme pressure to increase the effectiveness and efficiency of services, deliver continuous performance improvements while being stakeholder-, primarily customer-focused at the same time (Talib, 2015). In recent years, healthcare has become one of the extremely complex industries in the world (Bertolini et al., 2011). Therefore, the need to increase the effectiveness and efficiency of healthcare services in the present situation is the need of the hour and requires attention towards service quality measurement and evaluation.

Nowadays SERVQUAL (Parasuraman et al., 1988) is the best-known service quality instrument and has been widely used to measure service quality in various service industries and has earned a great popularity in healthcare settings as well. Babakus and Mangold (1992), O'Connor et al. (2000) and Sower et al. (2001) studied its effectiveness in healthcare settings and demonstrated the prevalence of application for SERVQUAL.

Measuring service quality, the satisfaction of stakeholders and the relative importance of service dimensions in healthcare are mainly realized through the application of Likert scales (see e.g. Ramsaran-Fowdar, 2008; Singh and Prasher, 2017; Pai and Chary, 2016). In these kinds of Likert scale investigations, crisp values are used to present the stakeholders' feelings and subjective perceptions of service quality (Hu et al., 2010). Due to intangible and subjective information embedded in the evaluation process, crisp values are inadequate to present the evaluation ratings of the different stakeholders. This means that people carrying out the analysis of these evaluations would have difficulties in understanding the differences and uncertainties in human's semantic expression.

Rating items in a questionnaire can be considered as a complex task as assessors make multiple decisions under uncertainty. The number of 'values' to choose from is small (Gil and González-Rodríguez, 2012) which means that the variability, diversity and subjectivity associated with an accurate rating is usually lost. Another disadvantage originates from the fact that when values are encoded by their relative position in accordance with a certain ranking, differences between codes cannot be interpreted as differences in their magnitude. It means that only statistical conclusions addressed to ordinal data can be reliable and relevant information can be lost (Lubiano *et al.*, 2016). Another major issue related to the application of Likert scales is the weighting of aspects as they are usually not equally important for the people taking part in the assessing process. An additional concern arising with expressing overall evaluations is the fact that assessors' attitudes towards the rated item are not homogeneous as time goes on (see e.g. Tóth *et al*., 2017). Third, if assessors' preferences are heterogeneous, it matters how and to what extent it influences the overall evaluation of a rated item. Average scores are supposed to hide the real situation, namely, the performance of the rated item (Kuzmanovic *et al*., 2013). Moreover, when Likert-type data are analysed for statistical purposes, the techniques to analyse them are quite limited (Lubiano *et al.,* 2016). Different studies have been carried out to discuss the reliability of the analysis of these responses pointing out that increasing the number of responses results in an increase of information and reliability (Lozano *et al.*, 2008, de Sáa *et al*., 2015). However, it cannot be achieved by using a natural language (Sowa, 2013).

To manage these disadvantages there is an alternate approach which takes into account that the nature of most attributes related to evaluations, judgements involve subjectivity and certain imprecision (Lubiano *et al*., 2016; Quirós *et al*., 2016). Hesketh *et al.* (1988) proposed the fuzzy rating scale without assessors being constrained to choose among a few pre-specified categories. It is expressive enough to find a value in it fitting appropriately the valuation, opinion, judgement involving subjective perceptions in most real life situations (Gil *et al*., 2015). This kind of scale has the ability to model the imprecision of human rating evaluations, formalize them mathematically, to 'precisiate' them in a continuous way, and to develop mathematical computation with them (Gil *et al.,* 2015; Calcagní and Lombardi, 2014; Gil and González-Rodríguez, 2012). This approach leads to a fuzzy-valued response format enabling a level of variability and accuracy which would not be captured when using a Likert scale.

In the service quality literature several initiatives confirm the recent shift towards the utilization of fuzzy ratings (Lin, 2010a). Liou and Chen (2006) demonstrate that fuzzy linguistic assessment of service quality is much closer to human thinking than methods based on crispy numbers. As a result, recent studies provide a number of modifications of service quality models based on fuzzy rating (Chien and Tsai; 2011; Liu *et al*., 2015; Mashhadiabdol *et al*., 2014; Lupo, 2016; Zhang *et al*., 2010).

Utilizing the advantages proposed by fuzzy set theory during the assessment of service quality is much closer to human thinking and judgement compared to methods applying crisp numbers (Lupo, 2013; Lin, 2010b; Deng, 2008). The results of fuzzy set theory have been increasingly utilized in healthcare service quality evaluations as well (e.g. Woldegebriel et al., 2015, Akdag et al., 2014; Singh and Prasher, 2017; Tsai et al., 2010; Büyüközkan et al., 2011; Hu et al., 2010; Lupo, 2016).

The flexible fuzzy number based methodology introduced in this paper offers a viable alternative technique addressing these evaluation goals. The novelty of our paper lies in the flexibility of fuzzy numbers, that is, the fuzzy number can present various shapes and therefore, can illustrate uncertainty embedded in evaluation process in various ways. The methodology proposed in the next section highlights some important properties of flexible fuzzy numbers that can be utilized during the evaluation phase.

Methodology

In our approach, the values on a Likert-scale are represented by fuzzy numbers; that is, instead of expressing an opinion by selecting a particular x crisp value on the scale, we allow the evaluator to select an 'approximately x' value that is given by a fuzzy number.

Flexible fuzzy numbers and some of their properties

Definition 1. The membership function $\mu(x; l, m, r, \omega)$ of the flexible fuzzy number $N^{(\omega)}(l, m, r)$ is given by

$$\mu(x; l, m, r, \omega) = \begin{cases} 0, & if\ x \le m \\ \dfrac{1}{1 + \left(\dfrac{m - x}{x - l}\right)^{\omega}}, & if\ l < x \le m \\ \dfrac{1}{1 + \left(\dfrac{r - x}{x - m}\right)^{-\omega}}, & if\ m < x < r \\ 0, & if\ r \le x, \end{cases} \tag{1}$$

where $l < m < r$, $\omega > 0$, $x \in \mathbb{R}$.

The flexible fuzzy number $N^{(\omega)}(l, m, r)$ represents the soft equality 'x is equal to m'. The parameters l and r determine the left hand side and right hand side limits of the flexible fuzzy number, respectively; that is, the truth of the statement that 'x is equal to m' is zero, if $x \le l$ or $x \ge r$. It can be shown that depending on the value of parameter ω the membership function of the fuzzy number $N^{(\omega)}(l, m, r)$ can exhibit various shapes such as triangular ($\omega = 1$), bell ($\omega > 1$) or 'reverse bell' ($0 < \omega < 1$). This flexibility of $N^{(\omega)}(l, m, r)$ allows us to represent the vagueness of the performance evaluation in various ways. The parameters can be interpreted as follows. The perceived performance is not less than and not greater than the values of parameters l and r, respectively, while the parameter m may be viewed as the crisp value which represents the most likely perceived performance. Figure 1 shows some membership function plots of flexible fuzzy numbers. Note that he membership function $\mu(x; l, m, r, \omega)$ can be derived from the kappa function that is a well know modifier operator in fuzzy theory (Dombi, 2012).

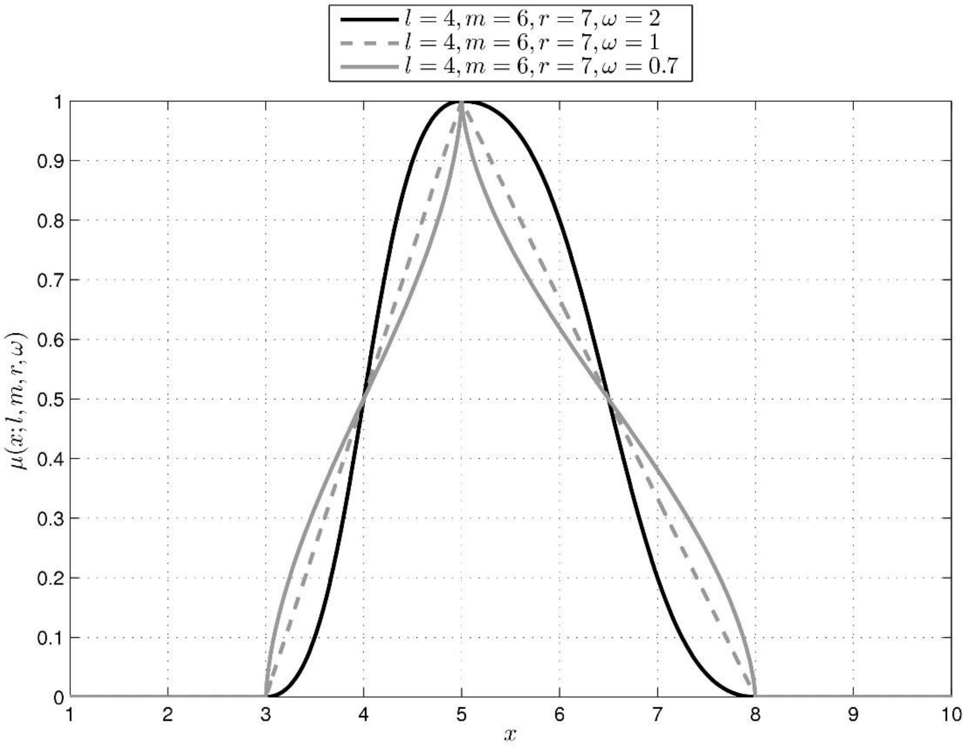

Figure 1 – Plots of membership functions of some flexible fuzzy numbers

The following theorem demonstrates a key property of flexible fuzzy numbers which allows us to utilize them in Likert scale-based evaluations.

Theorem 1. The weighted average of the flexible fuzzy numbers

$N^{(\omega)}(l_1, m_1, r_1)$, $N^{(\omega)}(l_2, m_2, r_2), \dots, N^{(\omega)}(l_n, m_n, r_n)$

with the weights $w_1, w_2, \dots, w_n$, respectively, is the flexible fuzzy number $N^{(\omega)}(l, m, r)$, where

$$l = \sum_{i=1}^{n} w_i l_i \tag{2}$$

$$m = \sum_{i=1}^{n} w_i m_i \tag{3}$$

$$r = \sum_{i=1}^{n} w_i r_i, \tag{4}$$

and $w_i \geq 0, \sum_{i=1}^{n} w_i = 1$.

Proof. It can be shown that the α-cut of the flexible fuzzy number $N^{(\omega)}(l_i, m_i, r_i)$ is the interval $[x_{\alpha,l_i,m_i}, x_{\alpha,r_i,m_i}]$, where

$$x_{\alpha,l_i,m_i} = \frac{m_i + l_i \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}} \tag{5}$$

$$x_{\alpha,r_i,m_i} = \frac{m_i + r_i \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}} \tag{6}$$

$\alpha \in (0,1)$, $i = 1,2,\dots,n$, $l_i < m_i < r_i$. Utilizing interval arithmetic operations, the α-cut of the fuzzy set $\sum_{i=1}^{n} w_i N^{(\omega)}(l_i, m_i, r_i)$ is

$$\left[\sum_{i=1}^{n} w_i x_{\alpha,l_i,m_i}, \sum_{i=1}^{n} w_i x_{\alpha,r_i,m_i}\right] = $$
$$= \left[\frac{\sum_{i=1}^{n} w_i m_i + \left(\sum_{i=1}^{n} w_i l_i\right)\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}, \frac{\sum_{i=1}^{n} w_i m_i + \left(\sum_{i=1}^{n} w_i r_i\right)\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}\right] = \tag{7}$$
$$= \left[\frac{m + l\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}, \frac{m + r\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\omega}}}\right],$$

where $l = \sum_{i=1}^{n} w_i l_i$, $m = \sum_{i=1}^{n} w_i m_i$ and $r = \sum_{i=1}^{n} w_i r_i$. That is, the weighted average of the α-cuts of the flexible fuzzy numbers $N^{(\omega)}(l_1, m_1, r_1)$, $N^{(\omega)}(l_2, m_2, r_2), \dots, N^{(\omega)}(l_n, m_n, r_n)$ is the α-cut of the flexible fuzzy number $N^{(\omega)}(l, m, r)$, where $l = \sum_{i=1}^{n} w_i l_i$, $m = \sum_{i=1}^{n} w_i m_i$ and $r = \sum_{i=1}^{n} w_i r_i$. Since this fact holds for any $\alpha \in (0,1)$, the proposition of this theorem has been proven. ■

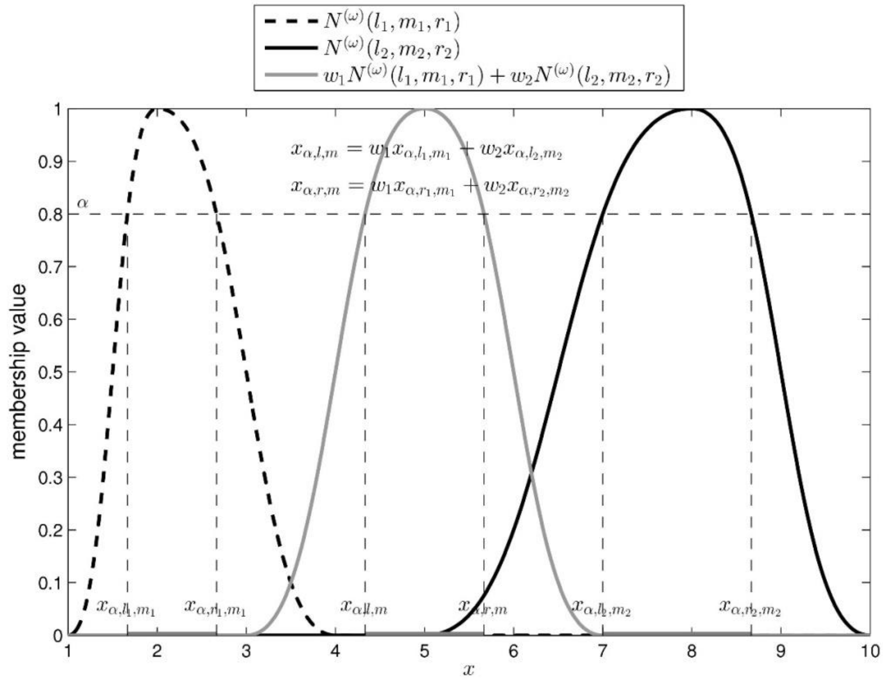

Figure 2 – Weighted average of two flexible fuzzy numbers

Theorem 1 tells us that for any $\alpha \in (0,1)$, the weighted sum of α-cuts of flexible fuzzy numbers is the α-cut of a flexible fuzzy number; that is, the set of flexible fuzzy numbers is closed under the weighted sum operation.

Figure 2 shows plots of membership functions of the flexible fuzzy numbers $N^{(\omega)}(l_1, m_1, r_1)$ and $N^{(\omega)}(l_2, m_2, r_2)$ and a plot of the membership function of their weighted average:

$$N^{(\omega)}(l, m, r) = w_1 N^{(\omega)}(l_1, m_1, r_1) + w_2 N^{(\omega)}(l_2, m_2, r_2). \qquad (8)$$

Theorem 1 allows us to utilize the flexible fuzzy numbers for multidimensional evaluation of a service characteristic. Namely, we can evaluate the characteristic in each dimension by a flexible fuzzy number, and then aggregate the results into one flexible fuzzy number which represent the overall goodness of the studied characteristic. Notice that the weighted averaging of flexible fuzzy numbers results a flexible fuzzy number only if the values of parameter ω are fixed for all the flexible fuzzy numbers.

A demonstrative healthcare example

In order to illustrate the application of the introduced flexible fuzzy number based methodology, a healthcare example is introduced in this section which is a part of an extensive research focusing on the development of a service quality measurement and evaluation framework in healthcare context where generally traditional Likert scales are applied for these purposes. The overall aim of our healthcare research is to compare patients' and healthcare workers' service quality perceptions and identify critical to quality service attributes. Healthcare service quality evaluations mainly focus on patients' perceptions while that of healthcare employees are often neglected. Employees can directly influence patients' service quality perceptions because of their involvement and interaction with patients. The best way to satisfy patients is by viewing employees as internal customers and understanding and meeting employees' needs, wants, expectations, and concerns. Their level of satisfaction can lead to better quality of care and higher patient satisfaction (O'Neill, 2005; Bitner et al., 1990; Hesket et al., 1997; Testa et al., 1998).

In this example specific service quality attributes are evaluated by healthcare workers on Likert scales utilizing flexible fuzzy numbers. In the framework established for the measurement and evaluation of employees' perceptions the statements of the applied survey have been grouped into seven service quality dimensions including accessibility, tangibles and environment, professionalism and skills, interpersonal relations, system and management, processes and outcome. In each service quality dimension, the evaluation is carried out on a 10-point Likert scale, where value 1 stands for the worst, while value 10 represents the best performance. When expressing their judgement, employees in the role of assessors select three values, namely the values of l, m and r on the 10-point Likert scale in each dimension. These three values express that the service performance in the given quality attribute is not worse than l, mostly has the value of m, and is not better than r. As a result of the valuations carried out this way and with the pre-set value of the parameter ω, a flexible fuzzy number is determined.

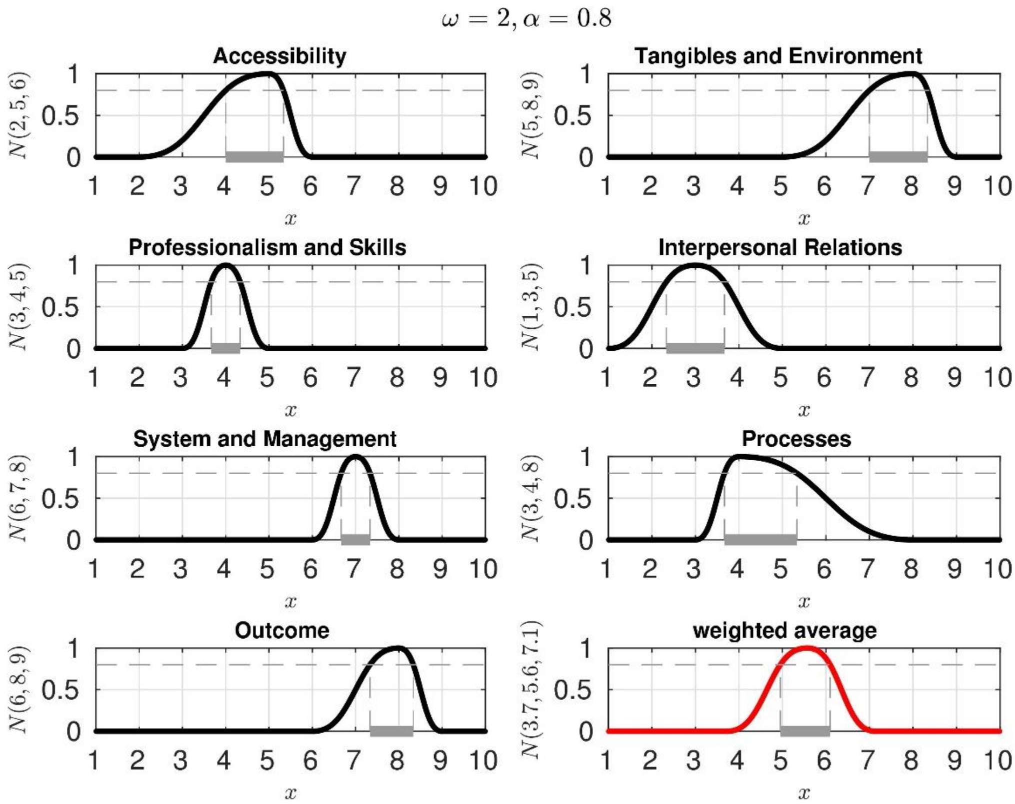

Figure 3 – Evaluation of service quality in seven dimensions using flexible fuzzy numbers

In Figure 3 demonstrating an evaluation example, the above indicated dimensions of service quality are represented by flexible fuzzy numbers as $N^{(\omega)}(2,5,6)$, $N^{(\omega)}(5,8,9)$, $N^{(\omega)}(3,4,5)$, $N^{(\omega)}(1,3,5)$, $N^{(\omega)}(6,7,8)$, $N^{(\omega)}(3,4,8)$, $N^{(\omega)}(6,8,9)$ respectively, while parameter ω has the value of 2. According to the introduced methodology, the flexible fuzzy number generally denoted as $N^{(\omega)}(l,m,r)$ express the truth value of the statement that 'x is equal to m'. This truth value is 0, if $x \leq l$ or $x \geq r$, and the truth value is 1, if $x = m$. Therefore, for example, the fuzzy number $N^{(\omega)}(1,3,5)$, which represents the performance in the dimension labelled as 'interpersonal relations' is around 3, but it is not worse than 1, and it is not better than 5. By using the traditional evaluation, it would denote only that performance in this specific dimension is given by a crisp value of 5. Flexible fuzzy number-based evaluation carries much more information as in this case the perceived performance is between 1 and 5, and it usually has the value of 3. Taking the 'interpersonal relations' into consideration, the left hand limit and the right hand limit of the fuzzy number are of equal distance from 3. While in case of 'Processes' with the fuzzy number $N^{(\omega)}(3,4,8)$ the right hand limit is more distant from 3 than the left hand limit, the performance in this service quality dimensions is more likely to be more than 4 than it is lower than 4. These examples highlight that the $r - l$ width of the flexible fuzzy number $N^{(\omega)}(l,m,r)$ may generally be viewed as an indication of performance instability, while the asymmetry of $N^{(\omega)}(l,m,r)$ provides information about the direction that the performance more likely tends to differ from the value of m. It means that utilizing a flexible fuzzy number for evaluation purposes on a Likert scale allows assessors to express their uncertainty in a quantitative way.

Figure 3 shows not only the flexible fuzzy number-based evaluation for the seven previously addressed service quality dimensions, but also the aggregate service performance is illustrated as it may be computed as the weighted average of the dimension specific evaluation results. That is, the weighted average of seven flexible numbers gives the aggregate performance results. In our example, each service quality dimension has the same weight and so the aggregate result was computed as the arithmetic average of the dimension specific evaluation results. The flexible fuzzy number $N^{(\omega)}(3.7,5.6,7.1)$ in red illustrating the aggregate performance of the evaluated service, can be interpreted as the aggregate performance of the service lies between 3.7 and 7.1 and its most likely value is 5.6. It must be noted here that if assessors address importance rates to the different service quality attributes, these importance values could be regarded as weights during the aggregation.

The grey coloured horizontal line segment in each plot of Figure 3 represents that α-cut of the corresponding flexible fuzzy number for $\alpha = 0.8$. In case of the 'Outcome' service quality dimension, the α cut of the flexible fuzzy number $N^{(\omega)}(6,8,9)$ is the interval [7.33, 8.33]. It means that if the evaluation of 'Outcome' is in this interval, then the truth of the statement that the perceived quality equals 8 is at least 0.8. Recall that we proved earlier that the weighted average of α-cuts of flexible fuzzy numbers is the α-cut of the aggregate flexible fuzzy number. Note that the values of parameters l, m and r of the aggregate fuzzy number are independent of the value of parameter ω, but the α-cuts of the individual flexible fuzzy numbers and the α-cut of the aggregate fuzzy number all depend on the value of ω.

It is worth mentioning that if a healthcare institution or any of its department carry out a service quality evaluation by involving specific stakeholders and applying the introduced methodology, then the institutional or departmental level of aggregate service quality can be expressed as the average of the flexible fuzzy numbers representing the performance judgements of the individuals. Since the weighted average calculation over the set of flexible fuzzy numbers is very simple, it is easy to determine the aggregate service quality.

Conclusions

This paper focuses on a challenging problem which is related to how to handle properly the inherent uncertainty of human perceptions embedded in the application of traditional Likert scales as fuzzy assessment is much closer to human thinking than the method based on crisp numbers. The current study proposes the utilization of flexible fuzzy numbers to enhance the reliability of Likert scale based evaluations. By providing this kind of scale to evaluate service quality attributes, patients, healthcare employees and other stakeholders of the healthcare system can express their uncertainty, their contrasting perceptions and the variability of the rated service quality attribute in a quantitative way. The proposed approach can help to deal with the vagueness arising either from the uncertainty of assessors or from the fluctuation of service performance in time. A fuzzy evaluation environment is considered to deal with the inherent uncertainty, subjectivity and vagueness characterizing stakeholders in expressing their own judgements on service quality issues. The methodology proposed in this paper aims at supporting healthcare decision makers and managers in their choice of effective and efficient strategies related to service quality improvements based on more reliable judgement of service quality attributes.

This study should be considered as a theoretical contribution to a more extensive research in the measurement and evaluation of healthcare service quality dimensions perceived by different stakeholders. In its practical contribution, the study described the flexible fuzzy number based methodology in order to contribute to the SERVQUAL literature with the extension of the original methodology with the fuzzy approach.

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