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THE TECHNIQUE TO PRECISELY DESIGN THE PRODUCT IN A HOUSE OF QUALITY CONSIDERING CURRENT CUSTOMERS' REQUIREMENTS

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Dominika Siwiec[1] – *orcid id: 0000-0002-6663-6621*
Andrzej Pacana[1] – *orcid id: 0000-0003-1121-6352*
[1]Rzeszow University of Technology, Rzeszow, **Poland**

Abstract: The competitive and turbulent environment generates the need to use various techniques to determine the level of product quality. In this aim, it is necessary to determine the direction of improvement attributes and function of the product based on customer requirements, which are usually uncertain. Therefore, the aim of the article is to propose the technique to improve the product quality by precisely determine the customers' requirements and the importance of the quality parameters for the current attributes of the product. This technique is a combination of methods i.e.: the QFD method (Quality Function Deployment) with the GRA method (Grey Relational Analysis). Using the QFD method, customer requirements were translated into technical features of the product. In turn, using the GRA method the imprecise customers' requirements were reduced and the importance of quality parameters was determined in a more accurate way. A test of a combination of the QFD and GRA methods for the household vacuum cleaner was made. The originality of the article is ensuring a precise study of the current attributes of the product from the point of customer satisfaction.
Keywords: QFD, GRA, customer requirements, mechanical engineering, production engineering

1. INTRODUCTION

As part of effective including customers' requirements during the designing of the product, it is necessary to transform these requirements into attributes of the product (Pacana et al., 2019, Gazda et al., 2013, Pacana et al., 2020, Siwiec et al., 2020). Often it is done by using the QFD method (Quality Function Deployment), which is one of the most popular methods of design of the product (Chen et al., 2009; Li, 2013; Liu et al., 2018; Rahim and Baksh, 2003; Xie et al., 2016). However, this method is not allowed to precisely determine the customers' requirements, which are often determined in a fuzzy way (uncertain) (Ulewicz et al., 2021, Siwiec et al., 2020, Pacana et al., 2018). The literature review has shown, that for this purpose the QFD method was combined with the FAHP method (Fuzzy Analytic Hierarchy Process) (Chen et al., 2009) or with the RAHP method (Rough Analytic Hierarchy Process) (Xie et al., 2016). As part of the FAHP method, the fuzzy numbers were used, in turn of the RAHP method, the rough numbers were used. The aims of these methods were prevention in uncertain customers' requirements. Additionally, for this purpose, the combination of the QFD method with 2-tuple linguistics was used (Li, 2013), which also not allowed for loss of important customer requirements. Mentioned 2-tuple linguistics are simultaneous determine the requirements of customers in form of term and a numerical value. Another example is a combination of the QFD method with the GRA method (Grey Relational Analysis) (Liu et al., 2018), which allows transforming precisely the customers' requirements (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015). The purpose of this combination was e.g. determine uncertain customers' requirements based on trends of changes in these requirements. However, it was concluded that the method to precisely determine the customers' requirements to the importance of quality parameters for currents attributes of the product was not developed yet. Therefore, the new combination of the QFD method with the GRA method was proposed. The aim is to propose the method to improve product quality by accurately determine the customers' requirements and the importance of the quality parameters for the current attributes of the product. The originality is ensuring a precise study of the current attributes of the product from the point of customer satisfaction. Additionally, the propose method allows predicting which of product quality parameters should be firstly improved to achieve the needs' quality product level. This method is a new proposition to design the product based on current customers' requirements, and also to precisely determine the quality attributes which are more difficult to determine in the traditional way, for example by subjectivity or different interpretations.

2. METHODOLOGY OF RESEARCH

The proposed technique has on aim to more accurately determine the importance of quality parameters of the product by reducing imprecise customers' requirements. This technique is a combination of the QFD method (Quality Function Deployment) with the GRA method (Grey Relational Analysis). Using the QFD method the customers' requirements onto the technical attributes of the product were modified. In turn, using the GRA method the imprecise customers' requirements were reduced, and also the importance of quality parameters in a more precise way was determined. The technique was developed in nine stages (Fig. 1).

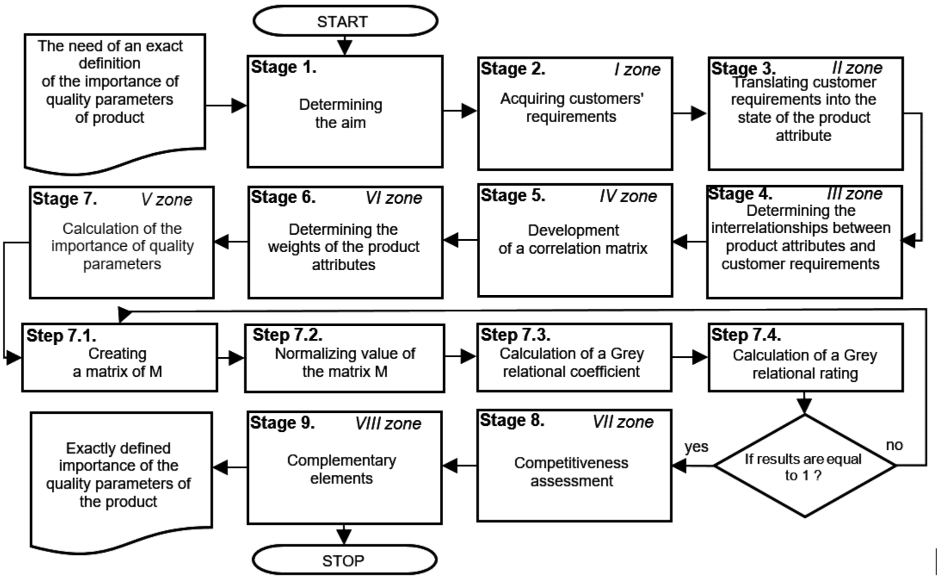

Fig. 1. An algorithm of exact expression of the quality parameters of product in the QFD method

The short characteristic of selected stages of the combined QFD method with the GRA method is shown in the next part of the article.

Stage 1. Determining the aim. For determining the aim it is adequate to use the SMART method (Lawlor and Hornyak, 2012). The purpose should apply to precisely determining the importance of quality parameters of the product as part of using the QFD method and GRA method in a combined way.

Stage 2. Acquiring customers' requirements (I zone). This stage refers to acquiring the so-called voice of customer (VOC) about requirements and expectations towards the product (Rahim and Baksh, 2003). In this aim, it is possible to apply any techniques of acquiring requirements. The most used is a survey (Ali et al., 2020; Chen et al., 2003). In the proposed approach, it is recommended to take into account the possibility of assessing the importance of product attributes, e.g. on the Likert scale (Wang and Chin, 2011; Wang et al. 2015). Based on customers' requirements about the importance of product attributes it is possible to select important attributes for the customers. Hence, it is proposed the calculate arithmetic average from customers assessments for attributes of the product (Winiarski, 2012). The choice of attributes importance for customer can be done according to the Pareto-Lorenz rule (20/80) as is shown e.g. (Hoła et al., 2018).

Stage 3. Translating customer requirements into the state of the product attribute (II zone). It relies on determining the measurable condition of product attribute (Rahim and Baksh, 2003). These attributes should be important attributes of product.

Stage 4. Determining the interrelationships between product attributes and customer requirements (III zone). In this aim, it is necessary to assess the interaction, where 1 - weak, 3 - indirect, and 9 - strong (Rahim and Baksh, 2003).

Stage 5. Development of a correlation matrix (IV zone). This stage is determining the strength of correlation between attributes of the product, where a positive correlation (+) is a mutual, positive change of attributes, a negative correlation (-) is a mutual, negative change of attributes, and neutral correlation (0) is no mutual influence of changes in attributes.

Stage 6. Determining the weights of the product attributes (VI zone). In the proposed method, it was assumed that in this zone the weights (importance) for technical attributes of the product were replenished (from II zone). These weights were calculated on stage 2 as an arithmetic average from assessments of customers about the importance of product attributes.

Stage 7. Calculation of the importance of quality parameters (V zone). Hence, in the proposed method the implementation of the GRA method (Grey Relational Analysis) was made. This stage is developed in 4 steps.

Step 7.1. Creating a matrix of M. The matrix is M = m×n, where m – VI zone, n – II zone. Therefore, the M matrix is the product of the weights of a given product attribute (VI zone) and the value of mutual relations between the product features (II zone) and customer requirements (III zone).

Step 7.2. Normalizing value of the matrix M. The aim is to obtain the values from 0 to 1. In the fourth stage of the method, it was determined, that the higher the rating, the greater the impact, so it is assumed that (1) (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015):

$$x_i^*(k) = \frac{max\, x_i^{(0)}(k) - x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - \, min\, x_i^{(0)}(k)} \tag{1}$$

where: i = 1, 2, …, m, k = 1, 2, …, n; $x_i^{(0)}$ – compared section.

Step 7.3. Calculation of a Grey relational coefficient. The coefficient is calculated from formula (2) (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015):

$$\gamma[x_0^*(k), x_i^*(k)] = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}}, \qquad 0 < \gamma[x_0^*(k), x_i^*(k)] \leq 1 \tag{2}$$

where: $\Delta_{0i}(k)$ – sequence of deviations between the original sequence $x_0^*(k)$ and comparison sequence $x_i^*(k)$ calculated from formula (3) (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015):

$$\Delta_{0i}(k) = |x_0^*(k) \, - x_i^*(k)| \tag{3}$$

Similarly, the biggest (4) and the smallest (5) deviation is calculated (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015):

$$\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \left| x_0^*(k) - x_j^*(k) \right| \tag{4}$$

$$\Delta_{min} = \min_{\forall j \in i} \min_{\forall k} \left| x_0^*(k) - x_j^*(k) \right| \tag{5}$$

Coefficient $\boldsymbol{\xi}$ from formula (2) has values [0, 1]. Mainly, it is assumed that $\boldsymbol{\xi}$ = 0,5 (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015).

Step 7.4. Calculation of a Grey relational rating. It is the weighted sum of the Grey coefficients (6), the correctness of the obtained results is proved by the GRA result equal to 1 (7) (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015):

$$\gamma(x_0^*, x_i^*) = \sum_{k=i}^{n} \beta_k \gamma[x_0^*(k), x_i^*(k)] \tag{6}$$

$$\sum_{k=1}^{n} \beta_k = 1 \tag{7}$$

where: $\gamma(x_0^*, x_i^*)$ - Grey relational rating, so the correlation level between of original and comparison sequence, as if they were identical (Ertugrul et al., 2016; Javed et al., 2019; Wang et al., 2015). The results of the GRA method should be completed in the V zone of the QFD matrix.

Stage 8. Competitiveness assessment (VII zone). At this stage, it is necessary to comparison the product with the competitive products. The assessment is made by the customer and the expert, and the assessments should be relatively similar. In turn, often this assessment is made by experts of enterprise production this product (Chen et al., 2009; Li, 2013; Liu et al., 2018; Rahim and Baksh, 2003; Xie et al., 2016).
Stage 9. Complementary elements (VIII zone). In a turn of an entity using the proposed technique, it is possible to include other, any elements e.g. complaints, or special requirements (Rahim and Baksh, 2003; Xie et al., 2016).
The proposed way of design a quality house can be modified depending on the requirements of an entity using the proposed technique, and also because of a subject of study.

3. RESULTS

The proposed technique on an example of a household vacuum cleaner was tested. Firstly, the aim was assumed, i.e. precisely determining the importance of quality parameters of the product as part of using the QFD method and GRA method in a combined way. Next, according to the second stage, pilot studies were carried out in March 2020. By using a survey the requirements from 25 customers were acquired. According to the 20/80 rule, the important for customers attributes of the product were selected on acquired assessments from customers about the importance of the attributes of the product, i.e.: efficiency, mobility and functionality. As in the third stage was shown, the customer requirements into the measurable state of the product attribute were translated. The technical parameters and their current states were: suction power (27000 Pa), length of the power cord (2,8 m), and engine power (900 W). Then, according to the fourth stage, the interrelationships between product attributes and customer requirements were determined (as is shown in Fig. 2 in III zone). Next, as shown in the fifth and sixth stage, the correlation matrix was made and the weights of the product attributes were determined (Fig. 2 in IV zone). These weights were arithmetic average from assessments customers against the importance of attributes product (calculated on the second stage. The most important was suction power (4,42), then length of the power cord (3,84), and then engine power (3,76). Then, according to the seventh stage, using the GRA method importance of quality parameters was calculated. The values from QFD used to create the M matrix in the GRA method are shown in Tab. 1.

Table 1
The values from QFD used to create the M matrix in the GRA method

Attribute of product (II zone)		**Suction power**	**Length of the power cord**	**Engine power**
Weight (VI zone)		4,42	3,84	3,76
I zone	Efficiency	9	3	9
	Mobility	0	9	0
	Functionality	9	9	1

Hence, as it was shown in step 7.1. the M matrix was made (Tab. 2).

Table 2
The M matrix of product attributes

Attribute of product (II zone)		Suction power	Length of the power cord	Engine power
Weight (VI zone)		4,42	3,84	3,76
I zone	Efficiency	39,78	11,52	33,84
	Mobility	0,00	34,56	0,00
	Functionality	39,78	34,56	3,76

Then, the values of M matrix were normalized. Next, the Grey relational coefficient and Grey relational rating were calculated (Tab. 3).

Table 3
The results from GRA method for indicator of importance of quality parameters

Attribute of product (II zone)		Suction power	Length of the power cord	Engine power	Indicator of importance	
Weight (VI zone)		4,42	3,84	3,76	GRA	V zone
I zone	Efficiency	0,33	1,00	0,33	0,56	
	Mobility	1,00	0,33	1,00	0,78	
	Functionality	0,33	0,33	0,82	0,49	

The designed a house of quality is shown in Fig. 2.

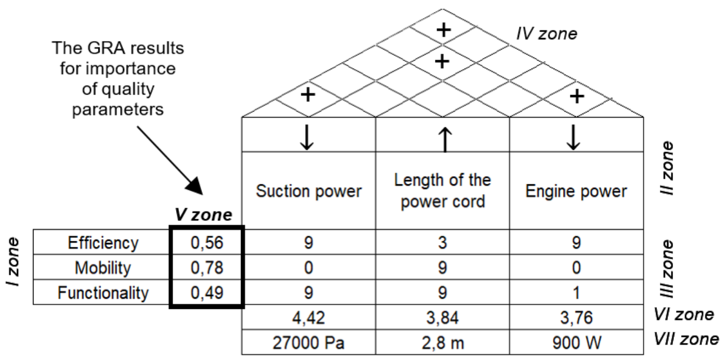

Fig. 2. A fragment of designed a house of quality.

Based on current customers' requirements and important technical product attributes it was shown that the most important is the mobility (0,78 weight) from the other quality parameters. On this stage the analysis was ended, because the aim was achieved, and it was to precisely determining the importance of quality parameters of the product. It was shown, that the most important is mobility of vacuum cleaner (0,78), then efficiency (0,56), and functionality (0,49). It is predicting that first, it is necessary to improve the attributes of mobility to achieve significant improvement in the level of product quality for customers. Then, it is possible to make other actions for attributes that belong to efficiency, and then functionality.

4. DISCUSSION

Mainly benefits obtained from a combination the GRA method with the QFD method are among others:

- reduction the uncertain and imprecise requirements of customers,
- more accuracy in determining the importance of quality parameters of product,
- possibilities to use the GRA method even for a small number of product attributes,
- design of product with greater precision.

These benefits result e.g. from the application of the GRA method to deal with data in an uncertain (fuzzy) environment. The limitation of the proposed method is the determines the ranking of quality parameters only based on important attributes. Hence, future research will be concentrate on extending the QFD about other attributes.

5. CONCLUSION

The design of the house of quality is the main stage of creating the product meeting customers' requirements. For this purpose, it is necessary to use effective methods. Among the most frequently used is the QFD method (Quality Function Deployment). However, in an era of competitive and turbulent environment, the customers' requirements are burdened with uncertainty and imprecision. In the turn of that, the aim of the article was to propose a technique to improve the quality of the product by precisely determining customers' requirements and importance of quality parameters of product for current attributes of product. This technique was developed as a combination of the QFD method with the GRA method (Grey Relational Analysis). Test of technique for example of the household vacuum cleaner was done. Based on pilotage research and accordance with the Pareto rule the attributes of vacuum cleaner were chosen. These attributes were: suction power, length of the power cord and engine power. Additionally, based on customers' assessments the weights of attributes of the product were identified. Sequentially, the house of quality was designed by carrying out individual stages of the proposed technique. As part of the application of the GRA method, the importance of product quality parameters was more precisely defined. Therefore, the proposed technique can be applied to any product design. In future research, it is planned to additionally determine the weights (importance) of product attributes using the GRA method. Despite this, it is planned to enlarge the House of Quality about additional attributes.

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