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Concept of improvement of product considering the qualitative-ecological interactions and weights of attributes

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Abstract
Due to the need to adjust products to customer expectations, it is important to support these actions. Mostly, that still remains a problem in determining precisely the product criteria expected by customers. In this area, there is a need to identify the customer criteria and then process them into product criteria. In addition, it is important to include the environmental aspect so that the customer is satisfied with the landscape of the product. Therefore, the purpose was to develop a concept for product quality assessment that considers criteria relations. This concept will be created based on qualitative-ecological interactions and will also include the weights of product criteria. The proposed conception relies on combined instruments, for instance, the SMART(-ER) method, a questionnaire with comparison in pair method, AHP method, DAMATEL method, Likert scale, WPM method, and relative state scale. The idea is to support an expert in assessing any product that will be selected by an individual customer. The originality of the concept allows the identification of key technical product criteria correlated with customer expectations for utility and aesthetic criteria.

Keywords
quality, customer expectations, decision support, production engineering, mechanical engineering, DAMATEL

Introduction

Product development improves the consumption of individuals (Abou-Shouk et al., 2024). This is because when firms develop and differentiate their products (Civelek et al., 2024), they satisfy the needs of their customers (Azman & Abdul Majid, 2023; Kuděj et al., 2023) and increase customers' loyalty (Sobre Frimpong et al., 2023) and responsiveness (Odei Addo et al., 2023). In this regard, businesses apply innovation technologies (Lincényi & Bulanda 2023), stimulate their digitalisation (Khatami et al., 2024) and digital transformation process (Civelek et al., 2023a; Santos et al., 2024), and use their innovation ability to create value for their customers (Civelek et al., 2023b) to sustainably increase their profits (Khalifa et al., 2023; Rózsa et al., 2023), strengthen their market position, and enhance long-term competitiveness (Rózsa et al., 2022).

However, customizing products to meet customer expectations is challenging because it requires giving users control over their data (Rózsa et al., 2024) while ensuring the product meets quality standards that drive customer satisfaction. In this case, it is problematic to unambiguously determine which criteria the customer needs (Aránega et al., 2023; Pacana & Siwiec, 2021; Pacana & Siwiec, 2023). Especially if these criteria are determined in a subjective (qualitative) way. Therefore, this applies to the character of the quality of the verification product, which is realized mainly on the basis of technical (measure) criteria (Kurowska-Pysz et al., 2024; Maráková et al., 2023; Siwiec & Pacana, 2022a), while striving to balance objective measures with subjective customer satisfaction (Rozsa & Machova, 2020).

Despite that, the product criteria are for different categories. Their unambiguous correlations are a complex problem and are still verified. Therefore, the effective assessment of product quality according to customer expectations and relations of different types of criteria is a problem and a challenge for many enterprises (Prokop et al., 2024; Siwiec & Pacana, 2019). Among other utility aspects of the product, the mentioned criteria included its impact on customer satisfaction with the landscape (i.e., area localization of the product) (Malindzak et al., 2017; Prokop et al., 2024; Sánchez-Pantoja et al., 2021).

For example, the authors of the article (Hasan et al., 2021) indicated that as part of multicriteria decision-making methods (MCDM), it is possible to compare criteria in pairs. Language interpretations from 1 to 9 are mostly used for this, which depends on the decision-makers. Therefore, opinions about the criteria may be different due to, for example, incomplete information and language ambiguity. However, in the article (Wu & Tsai, 2011), the DEMATEL method was used to assess the validity of the criteria and analyze the causal relationships between them. In addition, causal diagrams were developed for the product criteria, which show the dependencies, taking into account, among others, technological capabilities, service and organization. In the work (Gavurova et al., 2024), the authors use the matrix multiplication method for multicriteria evaluation. This method has an advantage over the process of analyzing hierarchies, which does not require a pairwise comparison of alternatives, and this accordingly reduces the number of calculations. As a result, it can be used for problems with a large number of other options and criteria. Another example is the article of Liao et al., 2013, in which the product criteria were analyzed by combining the concepts of fuzzy set theory, entropy and grey analysis. Criteria validity was assessed according to fuzzy numbers and linguistic values in triangular fuzzy numbers. The entropy method was used to verify the relationship between these criteria. On the other hand, grey analysis was used to combine the criteria weights and their quality ratings. There were also studies, for instance (Radziszewska-Zielina & Szewczyk, 2016), in which time, cost, quality and safety criteria were analyzed. The AHP method was used for this. In turn, the authors of the article (Pamucar et al., 2018) showed that it is possible to obtain better results by considering the relationship between consistency and the required number of criteria of the compared criteria. In addition, the author of the article (Wang, 2014) pointed out that research rarely focuses on determining the importance of criteria, even in the case of FMDCM (Fuzzy Multicriteria Decision Making). A relatively common practice in estimating the importance of criteria is the use of the QFD method in a fuzzy decision-making environment. The aforementioned article proposes to calculate the importance of criteria as a relative preference relationship. A similar approach to the use of fuzzy numbers to develop a ranking of product criteria was proposed by the author Chen, 2022. For this purpose, Pythagorean fuzzy point operators and scalar functions of upper and lower estimates for preference intensity were used. In the work (Skare et al., 2023a), the authors present the multicriteria evaluation approach of heterogeneous projects (alternatives) divided into different categories. Depending on this, evaluation criteria are used for common categories of alternatives, and a set of common criteria is also introduced. Also, a multicriteria decision support model for evaluating and selecting healthcare projects (Gavurova et al., 2023), based on various information models of input data and fuzzy sets, deserves attention. This approach detects uncertainty in the input data, which are expert assessments and do not depend on the number of criteria and their groups. In another approach by Uk Jung et al. (2016), the combination of Kano's model with the Analytical Hierarchy Process (AHP) has been explored. However, bringing together these methodologies can uncover significant evaluation differences and categorize customer requirements more efficiently (Hydar R. Sayah, 2024). Nonetheless, the shift from qualitative to quantitative analysis in Kano-based approaches has produced conflicting outcomes, with no agreement on the most suitable approach (Violante & Vezzetti, 2017). Finally, it was possible to determine the relationship between the criteria and their weights. In turn, in the article (Liu et al., 2023), attention was paid to the consistency of fuzzy reference comparisons to reduce unjustified and incorrect ordering of criteria or alternatives. This was obtained using a mathematical model and algorithms that analyze the best and worst solutions. However, one of the most popular methods for analyzing criteria and their relationships is the QFD (Quality Function Development) method (Wang et al., 2022, Camgoz-Akdag et al., 2016). This method has also been combined with other techniques. The example is a combination of the AHP method (Analytic Hierarchy Process) (Siwiec et al., 2023a) or the FAHP method (Fuzzy Analytic Hierarchy Process) (Liu et al., 2014). In their research, Fung et al. (1996) state that Methods such as Quality Function Deployment (QFD) and the House of Quality (HoQ) can be used to convert customer needs into product specifications. Furthermore, they believe that to enhance decision-making, the Analytic Hierarchy Process (AHP) can be integrated with QFD to assign numerical values and quantify the relationships between customer requirements and product characteristics (Fung et al., 1996). Combining QFD and AHP methodologies in product design and development presents various benefits and obstacles. As per Ginting and Ishak (2020) and Al Jafa (2020), this integrated approach improves decision-making by integrating customer requirements and effectively prioritizing them (Ginting & Ishak, 2020; Al Jafa, 2020). the integration offers several advantages, such as enhanced customer satisfaction (Skare et al., 2023b), better alignment with organizational goals, and more dependable decision-making (Ginting & Ishak, 2020; Al Jafa, 2020). Nevertheless, the integration process can be intricate and may necessitate meticulous implementation to maximize its efficacy (Tu et al., 2011).

Moreover, for the precise assessment of product quality, the QFD, AHP, and Kano models were combined simultaneously (Yamagishi et al., 2018). Another example is a study (Hatakeyama & Alcantara, 2008) which combined QFD with CE (Concurrent Engineering). The purpose of this combination was mainly to determine the weights of the product criteria. Of similar character are the works, mainly taking into account the QFD method shown in the studies (Geng & Geng, 2018; Wang & Chin, 2011; Ding et al., 2012).

After the literature review, it was concluded that research referred mainly to the analysis of inconsistencies and uncertainties in the assessment of criteria, the analysis of the relationship between the criteria, and the determination of the importance of criteria. It is shown in Figure 1.

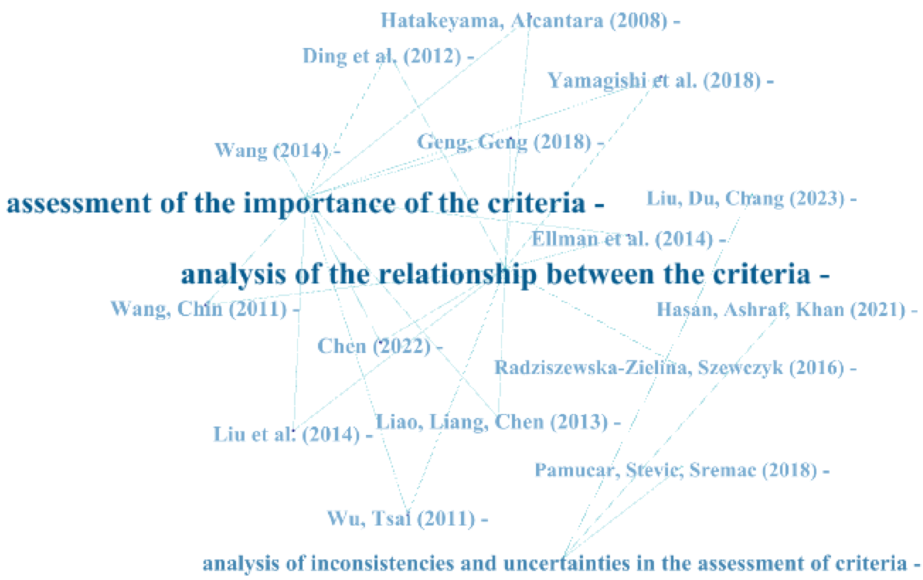

Fig. 1. Comparison matrix in pairs to obtain customer expectations. Source: Own study.

The literature review has shown that different methods are used to determine the quality of products based on product criteria. The quality of products was determined mainly based on criteria from customer expectations. There were qualitative criteria for a product. Also, these criteria were correlated with the technical (quantitative) criteria of the product. Other examples of categories of criteria were landscape, cost, or impact on the natural environment (Siwiec et al., 2023b; Siwiec & Pacana, 2021a). The most popular method to analyze the correlation of product criteria was the QFD method (Siwiec et al., 2023a). This method was combined with other methods.

Despite that there is, it was considered that there is still a lack of a universal concept of product quality assessment considering simultaneously analysis of inconsistencies and uncertainties in the assessment of criteria, analysis of the relationship between the criteria, and also determining the importance of criteria.

Hence, the purpose was to develop a concept for product quality assessment considering criteria relations, which will be created based on qualitative-ecological interactions and also include the weights of product criteria.

The idea was to support the entity (broker, bidders, expert) in assessing the quality of any products the individual customer selects.

Concept of research

The concept refers to assessing the product's quality and considering the customer's expectations. These expectations are determined by qualitative-ecological interactions for product criteria. The qualitative-ecological interactions mentioned refer to customer satisfaction with the utility (quality) of the product and its impact on the landscape. These criteria are criteria from groups: utility (customer), aesthetic (landscape), and technical.

It was assumed that product quality assessment is realized as part of the combined techniques, i.e., SMART(-ER) method (Specific, Measurable, Achievable, Relevant, Time-bound, Exciting, Recorded) (Lawlor & Hornyak, 2021), questionnaire with comparison method in pairs, AHP method (Analytic Hierarchy Process) (Vilutiene & Zavadskas, 2003; Sisodia et al., 2018; Pacana et al., 2018), DAMATEL method (Decision making trial and evaluation laboratory) (Si et al., 2018; Kijewska et al., 2018; Korzyński et al., 2009; Nusenu et al., 2019), Likert scale (Siwiec & Pacana, 2021b; Alexandrov, 2010), Weighted Product Model WPM) (Pacana & Siwiec, 2022b; Vilutiene & Zavadskas, 2003), and Relative states scale (Pacana et al., 2014).

The proposed concept of product quality assessments considering relations of criteria is shown in Figure 2.

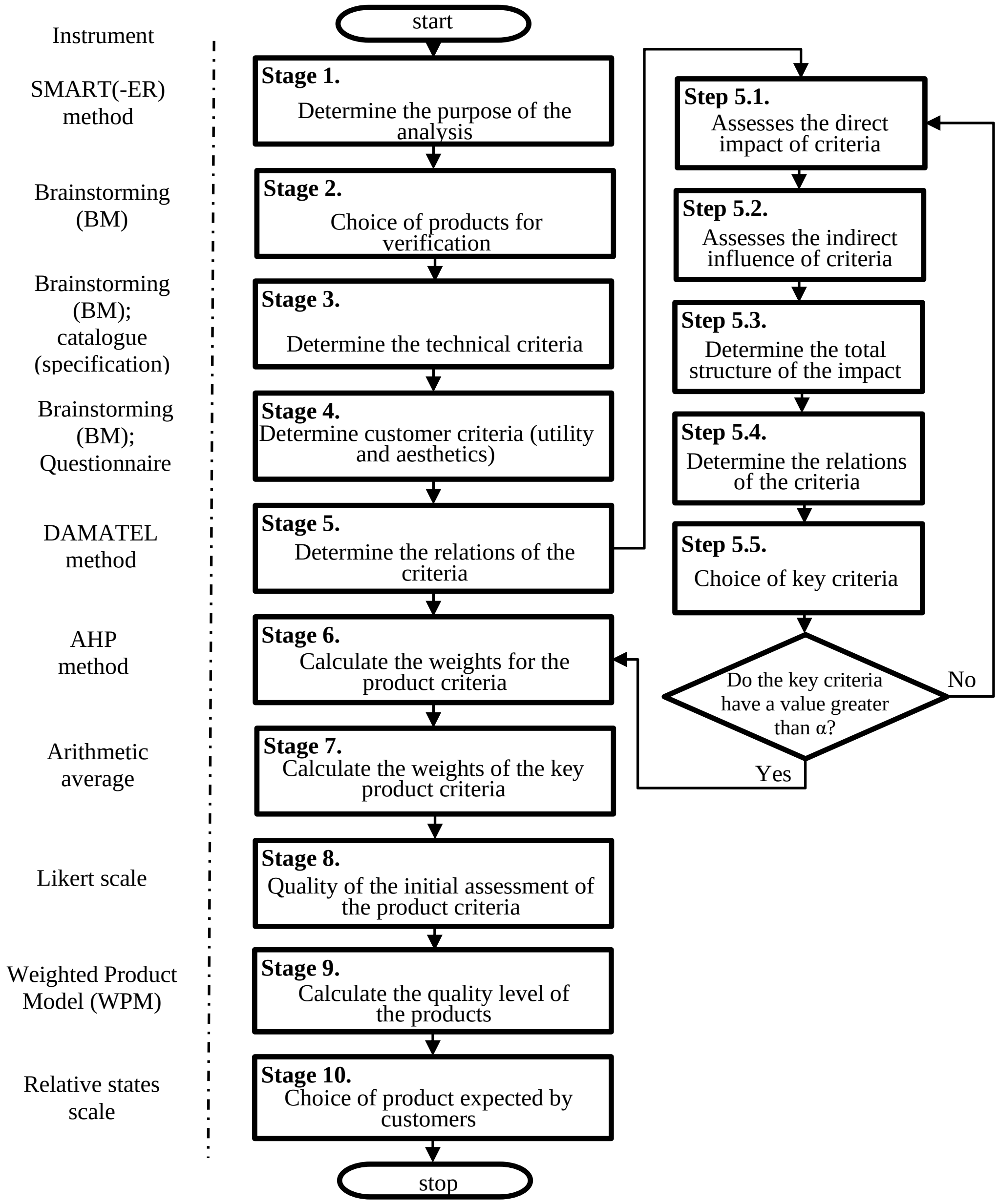

Fig. 2. Scheme of product quality assessments considering relations of criteria. Source: Own study.

The concept was developed in ten main stages. The short characteristics of these stages are shown in the next part of the study.

Results and discussion

The purpose was to develop a concept for product quality assessment considering criteria relations, which will be created based on qualitative-ecological interactions and also include the weights of product criteria. The concept was developed in ten main stages. The short characteristics of these stages are shown in the next part of the study.

Stage 1. Determine the purpose of the analysis. It was assumed that the purpose of the analysis is determined according to the SMART(-ER) method (Specific, Measurable, Achievable, Relevant, Time-bound, Exciting, Recorded) (Lawlor & Hornyak, 2021). In the proposed approach, the purpose of product quality is assessed by considering the relationship of criteria. Here, these criteria refer to three groups: technical, utility, and aesthetic. The aim is determined by the entity that has applied the proposed concept, e.g., an expert or bidder.

Stage 2. Choice of products for verification. The entities' choice of products for analysis, so the products offered to the customer. Therefore, there can be products at his disposal. The number of products for verification is not limited. However, products of the same type (kind) should be considered as the so-called alternatives of choice.

Stage 3. Determine the technical criteria. These criteria are measurable (quantitative). It was assumed that these criteria are the basis of product criteria, which have determined its quality. These criteria are determined by an entity or a group of experts. The brainstorming method (BM) is used for that. Additionally, technical criteria should be obtained from the product specification (catalogue) for verification. After the literature review, it was assumed that the number of technical criteria should be equal from 14 to 25 criteria (Huang, 1999; Roder et al., 2013).

Stage 4. Determine customer criteria (utility and aesthetics). It was assumed that at this stage, the customer's expectations are obtained, i.e., the expected criteria and their importance to the customer. The idea is to obtain customer criteria, which are then processed into technical criteria. In this context, it refers to the determination of qualitative criteria (subjective, immeasurable).

These criteria should be referred to as utility product criteria and aesthetic criteria (landscape). Utility criteria are criteria that constitute the quality of a product, so technical criteria are in a subjective (qualitative) form. Examples of utility criteria are high power, high performance, cinematic, or small weight. However, aesthetic criteria are criteria which determine landscape value during the use of the product or after its installation in a given place, for instance, colour, degree of integration, visibility, and texture (Malindzak et al., 2017; Sánchez-Pantoja et al., 2021). Customer criteria are obtained during an interview or questionnaire. The questionnaire was considered useful for the customer in determining his preference. Therefore, the questionnaire must propose possible criteria, for instance, based or innovative, about which the customer does not have consciousness. The number of proposed criteria is not limited. These criteria are determined by a group of experts during the brainstorming method (BM). Additionally, the customer should be able to point out his own criteria. Then, the weights (importance) are determined only for the expected criteria.

Following the authors of the works (Vilutiene & Zavadskas, 2003; Sisodia et al., 2018; Pacana et al., 2018), it was assumed that the weights of the criteria are determined by the technique of comparison in pairs. The aim is to increase the precision in determining the requirements of the customer. According to the work (Siwiec & Pacana, 2021c), the customer can effectively compare 5 to 9 criteria. Therefore, it was assumed that the customer should determine the number of criteria as expected. In turn, the weights of the criteria are determined on the Likert scale (1-5), which is popular and preferred to obtain customer expectations (Wang & Chin, 2011). An example of the questionnaire with the technique of comparison in pairs is shown in Figure 3.

	5	4	3	2	1	2	3	4	5	
criteria	**Absolutely more important**	**Much more important**	**More important**	**A little more important**	**Equally important**	**A little more important**	**More important**	**Much more important**	**Absolutely more important**	criteria
Criterion 1										Criterion 2
Criterion 1										Criterion 3
Criterion 1										Criterion n

Fig. 3. Comparison matrix in pairs to obtain customer expectations. Source: Own study.

Stage 5. Determine the relations of the criteria. The idea of this stage is to determine the mutual impact (relation) between technical and customer criteria (utility and aesthetic). The purpose is to determine which technical criteria should be included to determine the quality of the product. In this aim, the decision method is used, i.e., the DEMATEL method (Decision Making Trial And Evaluation Laboratory) (Si et al., 2018; Kijewska et al., 2018; Korzyński et al., 2009). The method is shown in five steps.

Step 5.1. Assesses the direct impact of criteria. Assessments are made by an expert (entity). It is necessary to assess the impact of all technical criteria with respect to all customer criteria. Assessments are made to scale from 0 to 4, where 0 - no impact, 1 - little impact, 2 - significant impact, 3 - large impact, and 4 - extreme impact. It is expressed by formula (1) (Nusenu et al., 2019):

$$z_{ij} = \frac{1}{l}\sum_{k=1}^{l} z_{ij}^{k}, \quad i,j = 1,2,\ldots,n \tag{1}$$

where: z_{ij}^{k} – assessment of customer, l – assessment of expert.

According to the matrix of direct impact, it is possible to develop some of the criteria linkage network, for instance, Nusenu et al., 2019.

Step 5.2. Assesses the indirect influence of criteria. Based on the direct matrix, it is necessary to create an indirect matrix. It relies on normalization according to formula (2) (Si et al., 2018):

$$\mathbf{X} = \frac{\mathbf{Z}}{s} \quad \text{where: } s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}, \max_{1\le i\le n}\sum_{i=1}^{n} z_{ij}\right) \tag{2}$$

where: all elements of the **X** matrix are in the range $0 \le x_{ij} \le 1$, $0\le \sum_{j=1}^{n} x_{ij} \le 1$, and the last element (i) is shown as $\sum_{j=1}^{n} z_{ij} \le s$.

Step 5.3. Determine the total structure of the impact. It relies on the combination of direct and indirect matrix. It is used formula (3) (Korzyński et al., 2009):

$$\mathbf{T} = \mathbf{X} + \mathbf{X}^2 + \mathbf{X}^3 + \ldots + \mathbf{X}^h = \mathbf{X}(\mathbf{I}-\mathbf{X})^{-1}, \quad \text{when } h \to \infty \tag{3}$$

where: **X** – normalized direct matrix of impact, **I** – identical matrix.

Step 5.4. Determine the relations of the criteria. It refers to determining causes-effects dependencies. In the proposed concept, there are relations between technical and customer criteria (utility and aesthetic). As part of determining these relationships, it is necessary to develop a map of relations of impact (4) (Kijewska et al., 2018):

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \qquad C = [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}^{T} \tag{4}$$

where: R – the sum of the values of rows in the matrix of total impact, C – the sum of the values of columns in the matrix of the total impact, r – the sum of the i-th row in the **T** matrix and its determined sum of direct and indirect effects not included in verified elements, c – the sum of the j-th column in the **T** matrix and its determined sum of direct and indirect effects not included in verified elements.

Step 5.5. Choice of key criteria. According to the determined relations of the criteria, it is possible to choose the key criteria. The key criteria are technical criteria, which have a strong correlation with customers' criteria. The idea is to choose criteria based on which the level of product quality will be calculated. To this aim, the average value is calculated (α) from all values of the total impact matrix (5) (Si et al., 2018):

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N} \tag{5}$$

where: markings as in formula (3).

Values above average (α) indicate key criteria. Other criteria should be dismissed in the next stages.

Stage 6. Calculate the weights for the product criteria. It was assumed that the weights of product criteria were calculated based on the weights from the questionnaire. These weights were determined as part of the comparison in pairs. Therefore, according to works (Vilutiene & Zavadskas, 2003; Sisodia et al., 2018; Pacana et al., 2018), the AHP method was assumed to be used for its estimation. These weights are calculated separately for utility and aesthetic criteria. Hence, it is necessary to skip uncorrelated criteria with technical criteria (as shown in step 5.5.). The method is shown in the literature on the subject, e.g. (Sisodia et al., 2018; Pacana et al., 2018).

Stage 7. Calculate the weights of the key product criteria. It relies on the arithmetic average calculation of all customer criteria (qualitative and aesthetic) correlated with technical criteria. These weights are calculated in this way for all key criteria, that is, technical criteria correlated with customer criteria (Manikandan, 2011).

Stage 8. Quality of the initial assessment of the product criteria. It refers to the estimate to meet customer expectations by key product criteria (from stage 7). It is necessary to estimate the quality of all key criteria for all verified products (from stage 2). In this aim, it is necessary to note each key criterion of the product value or range values (parameters). It is necessary to base this on the product's catalogue (specification). The evaluation of product quality is carried out on the basis of the characteristics and customer expectations that are obtained. The assessments are done by experts in the Likert scale, where 1 is the lowest quality of criterion, and 5 is the highest quality of criterion (Siwiec & Pacana, 2021a; Alexandrov, 2010).

Stage 9. Calculate the quality level of the products. It is necessary to calculate the quality of all verified products (from stage 2). Quality is estimated considering the weights of key criteria (from stage 7) and initial assessments of the quality of product criteria (from stage 8). Hence, it was assumed that using the Weighted Product Model (WPM) was right. Additionally, this method can be applied to any measure of criteria. This method is shown in the literature of this study, for example (Supriyono & Sari, 2018; Vilutiene & Zavadskas, 2003).

Stage 10. Choice of product expected by customers. At this stage, it is necessary to segregate the value of product quality (from stage 9). The maximum value is the product expected by the customer, that is, satisfaction with the quality of the product. In turn, the minimum value is a product that customers do not expect. In the case of relatively similar quality values, the choice of product can be supported by the relative state scale, as shown in (Pacana et al., 2014; Siwiec & Pacana, 2019). This is the last stage of the proposed concept.

Therefore, in comparison with other studies, this methodology concept allows product quality assessment to simultaneously analyze inconsistencies and uncertainties in the assessment of criteria, analyze the relationship between the criteria, and determine the importance of criteria. Other studies concentrated on analyzing these elements but not simultaneously and coherently. For example, the authors of the studies Hasan et al., 2021; Pamucar et al., 2018; and Liu et al., 2023 analyzed inconsistencies and uncertainties in the assessment of criteria. In turn, the authors of the studies Wu & Tsai, 2011; Liao et al., 2013; and Wang, 2014, have shown a proposition for assessment of the importance of the criteria. In analyzing the relationship between the criteria, it was possible to mention studies Chen, 2022 and Radziszewska-Zielina & Szewczyk, 2016.

Hence, among the predicted benefits of this concept, it can be pointed out:

- possible to determine qualitative-ecological interactions by combining customers' criteria (utility and aesthetic) with technical criteria (based on which quality product level is determined);
- increase precision in determining customer expectations by using a pairwise comparison method;
- consider taking care of the landscape by including aesthetic criteria and attitude toward achieving the expected product quality.

In turn, the predicted limitations are, for instance, the possibility of considering expectations only for a single customer and a lack of consideration of changes in requirements over time.

Conclusion

Due to the need to adjust products to customer expectations, it is important to support these actions. Despite that, the problem is that the quality of product criteria is assessed in different categories. It resulted from a need to determine the relationship between customer satisfaction and the usability of the product and its impact on the landscape. Therefore, the mentioned criteria are utility (customer criteria), aesthetic (landscape), and technical criteria.

Hence, the concept of product quality assessed considering relation criteria was developed. In this conception, it was combined with the following instruments: SMART(-ER) method, a questionnaire with pairwise comparison method, AHP method, DAMATEL method, Likert scale, WPM method and relative state scale.

It was concluded that future research should be based on adjusting the concept to obtain expectations from more customers. Additionally, a computer algorithm is planned to determine qualitative-ecological interactions and assess product quality dynamically.

The proposed concept can be applied to assess any product. Therefore, it can be useful for any entity (bidder, expert) in assessing the quality of a product for any customer.

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