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# Prediction of Quality Level of Product Considering Current Customers' Expectations

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**Abstract**
The activities of the organisation concentrate mainly on meeting customers' requirements. For this purpose, various activities are being conducted for customer satisfaction surveys. In this context, it is important to predict the quality of the product and the changes in the cost of the purchase product. The purpose of this study is to propose a method for predicting the quality level of a product and change the cost of the product considering current customers' requirements for a combination of product feature states and pro-quality changes. The method includes the calculation of the quality level of the product using the punctation-formalised method, where the level depends on a combination of values of states (parameters) attributes of the product, that is, current and modified. The method was tested as an example of a household vacuum cleaner for which 20 attributes were determined. According to the Pareto rule (20/80), the four product attributes important for customers were selected. Thereafter, for important attributes, possible combinations of the values of these attributes were determined. In addition, an algorithm for determining the possible combinations of product attribute states in the MATLAB program was developed. Additionally, the change in the current cost of the product considering the change in the quality level was estimated. The product cost changes were determined based on the actual cost of the product and the current product quality level. The method allows the determination of all combinations of values of state attributes of the product, such that it is possible to take appropriate improvement actions both in terms of quality and cost. The results from the method allow the prediction of product satisfaction for customers and they are favourable in terms of production cost. Therefore, it is possible to design the product in advance and support the producer in preparatory activities.

**Keywords**
Quality, Production engineering, Cost of product, Product modification, Predict.

## Introduction

Dynamical changes in customer requirements (Pacana, Siwiec, & Bednarova, 2020) and the need for an improvement of products (Realyvasquez-Vargas et al., 2018) generate the need for supporting organisations in designing products oriented to the customer (Li, Pomegbe, & Dogbe, 2018; Pacana & Ulewicz, 2020). This support concerns among others developing methods such as designing the products (Aliyu et al., 2019; Huang et al., 2017; Kwong & Bai, 2002), or determining the quality level of the product (He et al., 2017; Pugna et al., 2016; Wang & Tseng, 2014).

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The quality function deployment (QFD) method is a single key method for designing a product that satisfies the customer (He et al., 2017; Shi & Peng, 2020). This method does not allow for estimating the change in the cost of a product relative to changing the quality level or changing the values of states (parameters) of attributes of the product (Hardesty & Leff, 2010; Simpson et al. 2006; Siwiec, Bednarova, & Pacana, 2020; Turisova, 2015). In turn, the aforementioned cost of the product refers to the cost of the product borne by customers as part of its purchase. In this context, it has been attempted, for instance, determined by the Kano model, to determine the impact of the cost of the product on customer satisfaction (Turisova, 2015; Turisova et al., 2020); however, it still did not provide an estimate of the change in the cost of a product relative to the change in its quality level. This problem results from a lack of possibility prediction, such as inflation, costs of production, or wages (Bils & Chang, 2000; Jaravel & O'Connell, 2020). In a large enterprise, research on changing the cost of a product relative to changing its quality level is conducted by adequate marketing departments (Hardesty & Leff, 2010; Siwiec, Bednarova, & Pacana, 2020). These studies are relatively expensive, particularly for small and medium-sized enterprises (Simpson et al., 2006). Hence, it is necessary to study other methods to change the cost of the product depending on the quality of the product. After a literature review, it has been shown that studies concentrate mainly on determining the quality level of a product, for instance, by mentioning the QFD method, which with the Kano model was often combined (He et al., 2017; Pugna et al., 2016; Wang & Tseng, 2014). In addition, the relations between different attributes of a product and customers' requirements were described, for instance, by using a naive Bayes classifier (Jiao, Yang, & Zhang, 2017; Wang & Tseng, 2014). However, the quality level that satisfies customers was sought as part of integrating the Kano model with other techniques (He et al., 2017; Huang et al., 2017; Pugna et al., 2016; Shi & Peng 2020; Turisova, 2015). Among others, the Kano model with theory and innovative problem solving method was integrated (Huang et al., 2017) or with the health, weapon, wealth, prospect model (Pugna et al., 2016). The aim of these combinations was to design products considering customers' requirements. The research has so far not considered the possibility of determining the quality level and the related change in the cost of the product (Turisova, 2015). On this basis, it was assumed that a single coherent method was not yet developed, and it will be possible to determine the change in the cost of the product relative to the change in quality product level that results from the combination of values of state attributes of the product.

The aim of this study is to propose a method to predict the quality level of a product and change the cost of the product, considering current customers' requirements for a combination of product attribute state values. Hence, it was assumed that it is possible to predict the quality level of the product resulting from the combination of product attribute state values, where the level is calculated based on assessments of customers for current product attribute state values and changes in the values of these states. Testing of the assumed thesis was performed to verify the proposed method as an example of a household vacuum cleaner.

## Method

The aim of the proposed method is to predict the quality level of a product and change its cost considering customers' requirements for current and modified values of state product attributes. The idea of the method is to support organisations in improving the product, to make a decision on which product attributes need to change to achieve customer expectations. Simultaneously, the method includes the possibility of estimating the change in the cost of a product relative to changing the quality product level. The algorithm of this method is shown in Figure 1 and Figure 2 on which shown an algorithm with the main stages of method considering proposed methods,

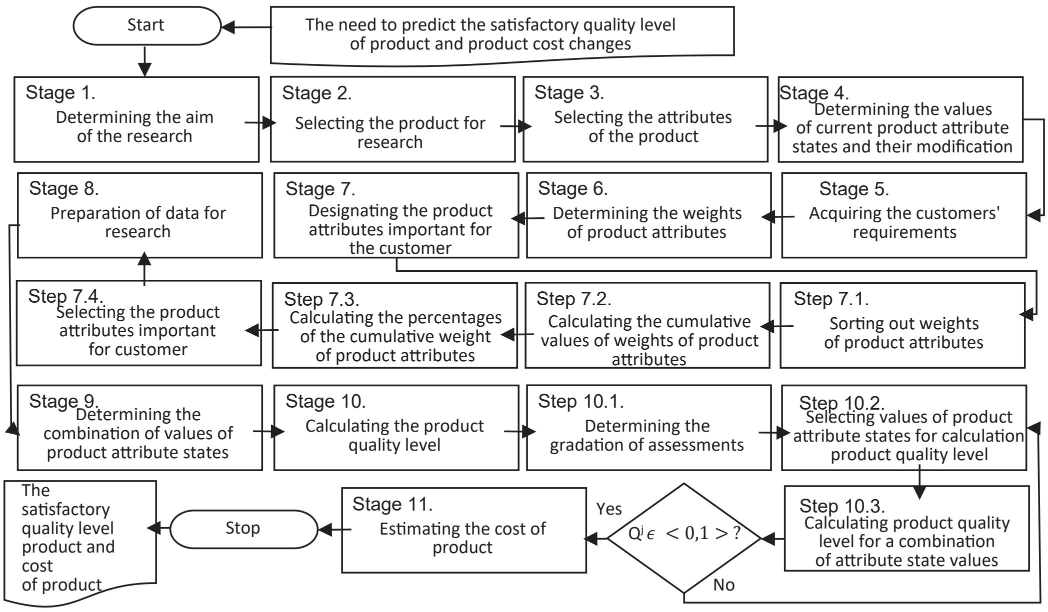


Fig. 1. Algorithm to predict the product quality level and product cost changes

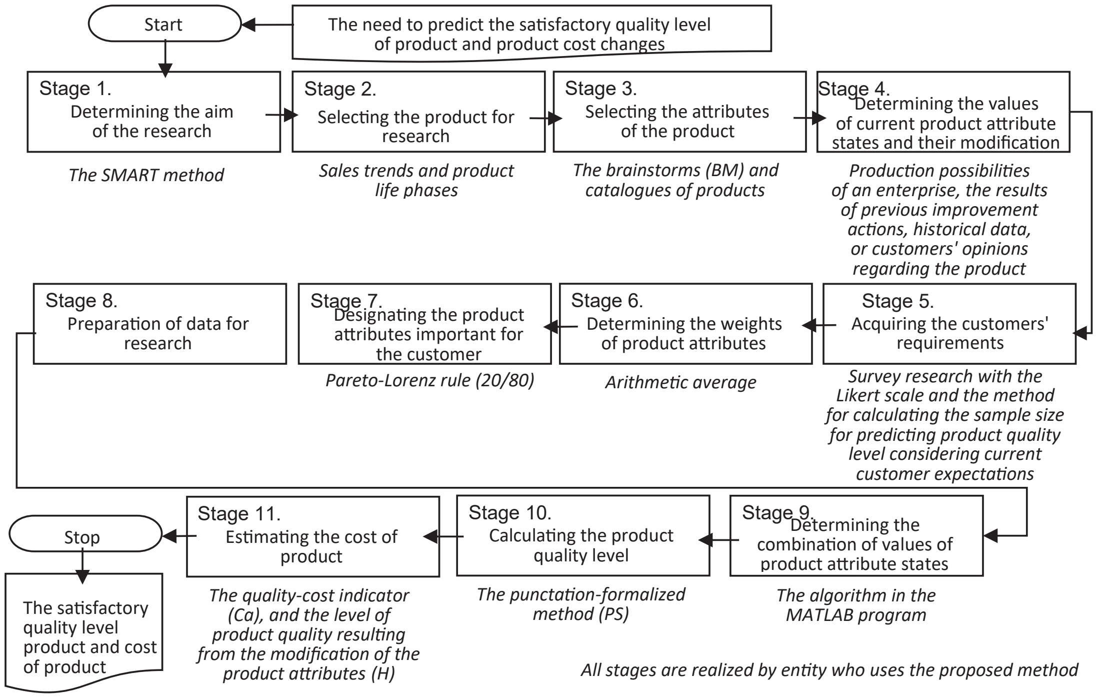


Fig. 2. Algorithm with the main stages of method considering supporting methods, tools, and data

tools and data supporting this method. These methods, tools, and data are examples, but it is possible to use other techniques adequate for each stage of the method. In the next section, the short characteristics of each stage of the proposed method are presented.

### Stage 1. Determining the aim of the research

The SMART (Specific, Measurable, Achievable, Relevant, Time-bound) method was used to determine the aim adequately (Lawlor & Hornyak, 2012). The purpose is to determine the product quality level and change its cost, which results from a combination of values of product attribute states and the current cost of purchasing the product.

### Stage 2. Selecting the product for research

The selection should include sales trends and product life phases. As part of the precise expression of customer requirements (Wang & Tseng, 2014), the product should be commonly used (Turisova, 2015; Wang & Tseng, 2014; Xie et al., 2016).

### Stage 3. Selecting the product for research

Making brainstorms (BM) and using catalogues of products (Pacana et al., Siwiec and Bednarova, 2020) is effective. The number and types of product attributes can be any. However, for an assessment of the product and its modification, it is assumed that the fewer the number of attributes, the better (Hansen and Bush, 1999; Wang & Tseng, 2014). According to Hansen and Bush (1999) and Huang (1999), Roder, Heidl and Birkhofer (2013), it is beneficial to select between 14 and 25 product attributes. Only the most important attributes for the customer will be selected from among these attributes at a later stage.

### Stage 4. Determining the values of current product attribute states and their modification

The aim of determining the values of product attribute states is to select the client's expectations of the product by comparing (assessing) what it is like now (current state) with how it might be (modified state). Therefore, the value of the current product attribute is adequate to the value of the state of the present (physically existing) attribute. In turn, the value of the modified state is the value contractually accepted (future-currently non-existent). The values of the current and modified states should be determined for each attribute selected in the third stage. For each attribute, a single value of the current state and at least one modified state value should be noted. According to Mu and Pereyra-Rojas (2017), the total number of values of the current and modified states for a single attribute is a maximum of $7 \pm 2$. To determine the value of the current product, an attribute state can be used, for instance, a catalogue of a product (specification). When determining the value of the attribute modification, it is advantageous to consider the production possibilities of an enterprise, the results of previous improvement actions, historical data, or customers' opinions regarding the product (Chen & Wang, 2008). The values of the current and modified states should be determined in an uncomplicated and understandable way for the customer. For instance, by description, visualisation (Jiao & Chen, 2006), parameter (value), or range of values, considering the international metric units.

### Stage 5. Determining the values of current product attribute states and their modification

For this purpose, the survey research was assumed to be (Ali et al., 2020; Chen, Khoo, & Yan, 2003; Lee et al., 2019; Li & Tian, 2019), which are popular, uncomplicated, and one of the most commonly used techniques. It was assumed that in survey research, the Likert scale was used, which is according to Wang and Chin (2011) and Wang et al. (2015), the most preferred scale to acquire customers' requirements. The method for calculating the sample size for predicting product quality level considering current customer expectations is shown by Siwiec & Pacana (2021a), (2021b). Customers evaluate the attributes of the product in terms of the importance of these attributes, as well as their satisfaction with the value of the current state and the modified attribute of the product. The assessment of the importance of the attribute concerns all product attributes (from the third stage). In turn, the assessment of satisfaction from the values of attribute states, that is, current and modified, is the assessment of values from all attribute states from the fourth stage. The importance of product attributes is the significance of the presence of a given attribute in the product, for instance, in the context of using a product.

### Stage 6. Determining the weights of product attributes

This stage refers to calculating an arithmetic average from assessments of the importance of product attributes, which were obtained in the fifth stage. The weight of the product attribute is calculated for each product attribute selected in the third stage (1) as follows:

$$A_{w_i} = \frac{1}{n}\sum_{i=1}^{n} w_i \,, \tag{1}$$

where Aw denotes the weight of product attribute, w the customer's assessment of the importance of the product attribute, and $n$ the number of assessments, $i = 1, 2, 3, \ldots, n$.

Using arithmetic average results because it is an unbiased estimator (Winiarski, 2012), and because it has the greatest credibility of the expected random variable value, the number of events is sufficiently large (>100) (Mishra et al., 2019; Tadeusiewicz, Izworski & Majewski, 1993) or when the distribution of the variable is normal.

### Stage 7. Designating the product attributes important for the customer

Designating the attributes important for the customer is based on the values of product attribute weights (from the sixth stage). The idea is to select the attributes that are needed to adapt first to customers' requirements, to meet their expectations at a satisfying level. This has resulted from Pareto rule 20/80, that is even a small number of product attributes important for a customer have an important impact on the product-level, where the impact of other attributes are less (Hoła, Sawicki, & Szóstak, 2018; Siwiec, Bednarova, & Pacana, 2020). It has been assumed that the selection of attributes important for the customer is made according to the Pareto rule, which is presented in four steps.

Step 7.1. Sorting out weights of product attributes

It refers to sorting in descending order all arithmetic average values of the importance of product attributes (calculated in the sixth stage) (Hoła, Sawicki, & Szóstak, 2018).

Step 7.2. Calculating the cumulative values of weights of product attributes

The cumulative values are calculated based on the ordered values of the product attribute weights (from step 7.1). The first value is an equal maximum value of product attribute weight, that is, the first value from the ordered weights of attributes as follows (2):

$$C_1 = A_{w_{\max}} \,, \tag{2}$$

where C1 denotes the first value from the cumulative values, whereas $A_{w_{\max}}$ denotes the maximum value of the product attribute weight.

Thereafter, the cumulative values are calculated as follows (3):

$$C_i = C_{i-1} + A_{w_i} \,, \tag{3}$$

where $A_w$ denotes the weight of the product attribute, $i = 2, 3, 4, \ldots, n$.

The cumulative values of product attribute weights are calculated for each attributes and the ordered value of the product attribute weights.

Step 7.3. Calculating the percentages of the cumulative weight of product attributes

The percentage values were calculated based on the cumulative values from step 7.2. For this purpose, the following formula is used (4):

$$C_i^{\%} = \frac{C_i}{C_{\max}} \times 100, \tag{4}$$

where $C\%$ denotes the percentage cumulative value of product attribute weight, $C$ the cumulative value of product attribute weight, $C_{\max}$ the maximum cumulative value from all product attribute weights, $i = 1, 2, 3, \ldots, n$.

The percentage values of the product attribute weights should be calculated for all cumulative values of product attribute weights.

Step 7.4. Selecting the product attributes important for customer

The selection is made on the percentage cumulative values of the product attribute weights (calculated in step 7.3). The Pareto rule (20/80) was used to select attributes. Hence, the percentage cumulative value of product attribute weight near 20% determines a group of important product attributes ($G_I$) and a group of not very important attributes for the customer ($G_N$) as follows (5–6):

$$C_i^{\%} = \frac{C_i}{C_{\max}} \times 100, \tag{5}$$

$$C_i^{\%} = \frac{C_i}{C_{\max}} \times 100, \tag{6}$$

where $C\%$ denotes the percentage cumulative value of product attribute weight, $i = 1, 2, 3, \ldots, n$, $G_I$ the group of attributes important for customers, and $G_N$ the group of attributes not very important for customers.

The visualisation of the obtained results in the Pareto–Lorenz diagram is helpful in defining the attributes important for the customer, as shown by Hoła et al. (2018).

### Stage 8. Preparation of data for research

The data can be prepared, for instance, in a table, and it consists of arranging the acquired customer requirements (from stage 7) according to the groups of attributes important and not important for the customer (from stage 7). For this purpose, all product attributes should be characterized by customers' assessments of the importance of the current state value of the attribute product. Additionally, the important attributes for customers should be determined by customers' assessments about modifying the state value of these attributes.

### Stage 9. Determining the combination of values of product attribute states

The purpose is to determine the combination of values of product attribute states based on which all possible quality product levels are calculated. The combinations should be determined only for important attributes. The number of all attribute combinations is calculated as follows (7):

$$\binom{n}{k} = \frac{n!}{k!(n-k)!}, \tag{7}$$

where $n$ denotes the number of all values of product attribute states, whereas $k$ denotes the number of values of state for a single product attribute.

If the number of all combinations of values of product attribute states is large, it is effective to use, for instance, a computer program. With this aim, the algorithm in the MATLAB program was developed, through which it was possible to determine all possible combinations of values of product attribute states (Fig. 3).

```
N = [u_i u_i u_i];
M = nchoosek(1:n, k);
I_j = [u_ii u_ii u_ii];
II_j = ismember(M, I_j);
S_j = sum(II_j, 2);
F_j = find(any(S_j > 1, 2));
M (F_j, :) = []
```

*where:* u number of current state values and modified state of attributes, n number of initiated values of product attribute states, k number of all attributes, i = 1, 2, 3, …, n, ii = 1, 2, 3, …, k, j = 1, 2, 3, …, n

Fig. 3. Algorithm for determining possible combinations of product attribute states

Not possible combinations are combinations of values of product attribute states that include simultaneously for the same attribute the values of current and modified states. After removing them, the M matrix is the matrix of all possible combinations of values of product attribute states.

### Stage 10. Calculating the product quality level

This stage includes determining all possible quality levels of the product, which result from combinations of values of product attribute states. To calculate the quality level of a product, it is possible to use any method. It is recommended to use simplified methods to calculate quality product levels. One of these methods is punctation-formalised (PS) (Amineha & Kosach, 2016; Kijewska & Mierzwiak, 2014; Kolman, 1992; Ulewicz et al., 2021; Siwiec et al., 2019). The PS method is effective and not complicated for determining the quality of a product. Hence, it is the right alternative to the QFD method, when it is only necessary to calculate the quality level of a product for a large number of combinations of values of product attribute states. The PS method was presented in three main steps.

Step 10.1. Determining the gradation of assessments

It refers to determining the scale in which the customers' requirements were obtained for using the same scale in the PS method. This is because the gradation of assessments in the PS method can be arbitrary, similar to the scale of assessments for obtaining customer requirements. In the proposed approach, the Likert scale is used in which assessment 5 refers to the best value of the attribute state, whereas assessment 1 refers to the worst value of the attribute state (Wang & Chin, 2011; Wang et al., 2015).

Step 10.2. Selecting values of product attribute states for calculation of product quality level

This results from the need to calculate the quality level of a product depending on the combinations of values of product attribute states. Therefore, the set of values of product attribute states for calculating the quality level of a product for a given combination of product attribute values is determined using the following formula (8):

$$S^j_{c_i} = \left\{ y_{i,\ldots,n} \in G_N,\ m^j_{i,\ldots,n} \in G_I \right\}, \tag{8}$$

where $y$ denotes the attribute defined by the value of the current state, $m$ the attribute defined by the state value from a combination of values of attribute states, $i = 1, 2, 3, \ldots, n$, $j$ is a combination of values of attribute states, $j = 1, 2, 3, \ldots, n$, $G_I$ is the group of attributes important for customers, and $G_N$ denotes the group of attributes not very important for customers.

The values of product attribute states for calculating the quality level of a product are determined by the values of the current states for attributes that are not very important for customers, and by the values of states from combinations of states values for attributes important for customers. The number of all quality levels of a product is equal to the number of all combinations of values of product attribute states.

Step 10.3. Calculating product quality level for a combination of attribute state values

It is necessary to calculate all product quality levels from each customer's assessment, depending on the combination of values of product attribute states. Accordingly, (Amineha & Kosach, 2016; Kijewska & Mierzwiak, 2014; Kolman, 1992; Ulewicz et al., 2021; Siwiec et al., 2019) the quality level in the PS method is determined using the following formula (9):

$$H^j_i = G^j_i + K^j_i - C^j_i, \tag{9}$$

where $G$ denotes the main part, $K$ the correction part, $C$ is a constant $= 0.05$, $i = 1, 2, 3, \ldots, n$, $i$ is the customer, and $j$ is the combination of values of attribute states, $j = 1, 2, 3, \ldots, n$.

According to previous studies, (Amineha & Kosach, 2016; (Kijewska & Mierzwiak, 2014; Kolman, 1992; Ulewicz et al., 2021; Siwiec et al., 2019) it has been assumed that to calculate the main and correction parts, the following formulas are used (10–12):

$$G^j_i = \frac{R^j_i}{8n^j}, \tag{10}$$

$$R^j_i = 9a^j_i + 7b^j_i + 4c^j_i + 2d^j_i + e^j_i - n^j, \tag{11}$$

$$K^j_i = \frac{c^j_i + 5d^j_i + 10e^j_i}{200n^j}, \tag{12}$$

where $n^j \in S^j_{c_i}$, $i = 1, 2, 3, \ldots, n$, $j = 1, 2, 3, \ldots, n$, $i$ – customer; $j$ – combination of values of attribute states; $n$ – number of attributes; $a$ – number of assessments equal to 5; $b$ – number of assessments equal to 4; $c$ – number of assessments equal to 3; $d$ – number of assessments equal to 2; and $e$ – number of assessments equal to 1.

The product quality level considering all customers' assessments for a given combination of attribute state values is a quotient of the sum of values for the quality levels of a given combination expressed by customers and the sum of the number of customers who assessed the quality level of this combination as follows (13):

$$Q^j = \frac{\sum H^j_i}{\sum i^j}, \tag{13}$$

where $H$ denotes the quality level for a combination of attribute state values, $j$ the combination of attribute state values, $j = 1, 2, 3, \ldots, n$, and $i$ – customer, $i = 1, 2, 3, \ldots, n$.

The product quality level in the PS method ranges from 0 to 1. To obtain values that do not meet the required range, the calculation process should be repeated starting from step 10.2.

**Stage 11. Estimating the cost of product**

The purpose is to estimate the change in the cost of purchasing a product depending on the change in product quality level resulting from combinations of values of product attribute states. With the actual cost of the product ($P_a$) and quality level determined from customers' assessments of product attributes determined by values of the current state ($Q_a$), it is possible to determine the quality-cost indicator ($C_a$) for the actual cost of the product and current product quality level as follows (14):

$$C_a = \frac{P_a}{Q_a}\,, \tag{14}$$

where $P_a$ denotes the actual cost of the purchase product (PLN), whereas $H_a$ denotes the current product quality level.

Because the higher the quality, the higher the cost of the product (Amineha & Kosach, 2016; Kijewska & Mierzwiak, 2014; Kolman, 1992; Ulewicz et al., 2021; Siwiec et al., 2019), it was assumed that to estimate the change in the cost of the product, which results from a combination of product attribute state values, it is necessary to use the following formula (15):

$$C^j_{mi} = C_a \times H^j_i \quad \text{where: } H^j_i \neq Q_a\,, \tag{15}$$

where $H$ denotes the level of product quality resulting from the modification of the product attributes (from nine stages), $C_a$ the quality-cost indicator for the actual cost of purchasing the product and the current product quality level, $Q_a$ the product quality level for product attributes determined by values in the current state, $i = 1, 2, 3, \ldots, n$.

Create a ranking based on product cost change values. The maximum value (first position in the ranking) is the best product quality level according to the customer and the highest cost of the product. It is possible to select a combination of values of product attribute states that will be satisfactory in terms of both quality and cost. This selection is based on the value of changing the cost of the product. Hence, based on these results, it is possible to predict the satisfactory quality level of the product and the cost of purchasing the product.

## Test of method

The research to verify the developed method was conducted to determine the product quality level and change the cost of the product, which results from the combination of product attribute state values and purchase product costs. As part of the second stage of the method, the research product was a household vacuum cleaner. Thereafter, according to the third stage of the method, the product of 20 attributes was characterised, and these attributes were selected based on a catalogue of the product. Subsequently, as was shown in the fourth stage of the method, for each attribute, the values of the current and modified states were determined. To determine the destination of changing customers' expectations, the modifications of product attributes by the values above and below the current state were determined. In line with step five of the method, customer requirements were obtained through a survey conducted from April 2020 to March 2021. In survey research using a Likert scale, the stage of assessment of the importance of product attributes and assessment of customer satisfaction from current and modified states were included (Table 1).

The customer compared the current state of the product attributes with possible modifications at a higher or lower level. In this way, he was able to relatively accurately express his expectations. For the manufacturer, however, it is necessary to average these expectations. The use of the mean resulted from a large sample. The use of the mean resulted from a large research sample. Therefore, further calculations were made. Consequently, a sample of 166 customers was obtained. As determined in the sixth stage of the method, from the assessments of customers' requirements, the weights of product attributes were calculated as an arithmetic average from customers' assessments of the importance of the product attributes. For the weights of product attributes, the Pareto (20/80) rule was used, based on which the four product attributes important for the customer were selected. Thereafter, according to the eight stages of the method, the data for future analyses were prepared. For this aim, to all product attributes, customer assessments of the values of the current product state were noted. In turn, to select four attributes important for customers, assessments of the modified states of these attributes were noted. The prepared data for this research are listed in Table 2.

Thereafter, by using the algorithm developed in the MATLAB program, all possible combinations of states for four important product attributes were determined. Consequently, 81 possible combinations of product attribute state values were obtained (Table 3).

Subsequently, the product quality levels depending on all combinations of product attribute values were calculated based on the PS method (formula 9). For this purpose, the PS method with gradation as-

Table 1
Current and modified product attribute states

| Product attribute | An ordinal number of the state of the product attribute [u] | | |
|---|---|---|---|
| | Current state | Modification state1 | Modification state 2 |
| A1 | < 15 m | 15 m | > 15 m |
| A2 | < 19 m | 19 m | > 19 m |
| A3 | < 900 W | 900 W | > 900 W |
| A4 | < 67 dB | 67 db | > 67 dB |
| A5 | lack | automatic | – |
| A6 | < 6 pieces | 6 pieces | > 6 pieces |
| A7 | automatic | manual | – |
| A8 | < 10 l | 10 l | > 10 l |
| A9 | yes | optional | no |
| A10 | < 7.7 kg | 7.7 kg | > 7.7 kg |
| A11 | no | yes | – |
| A12 | basic | Hepa | antiallergic |
| A13 | no | yes | – |
| A14 | reusable | paper | without |
| A15 | < 15 m | 15 m | > 15 m |
| A16 | < 2.8 m | 2.8 m | > 2.8 m |
| A17 | < 35×42×32 cm | 35×42×32 cm | > 35×42×32 cm |
| A18 | usually | rubber | – |
| A19 | sliding | Push | knob |
| A20 | < 36 Ø | 36 Ø | > 36 Ø |

A1 – Engine power; A2 – Vacuum in the suction pipe; A3 – Length of the power cord; A4 – Power cord winding system; A5 – Working range; A6 – Dimensions; A7 – Libra; A8 – Tank capacity; A9 – Noise level; A10 – Dust filter type; A11 – Bag type; A12 – Suction pipe diameter (suction pipe); A13 – Length of the suction pipe (suction pipe); A14 – Possibility to control negative pressure in the working handle; A15 – Rubber protectors; A16 – Type of material of road wheels; A17 – On/off type; A18 – Term security; A19 – Electric brush socket; A20 – Number of accessories included with the vacuum cleaner (suction tubes and nozzles)

Table 2
Data for research

| Product attribute | | An ordinal number of the state of the product attribute [u] | | |
|---|---|---|---|---|
| | | Current state | Modification state1 | Modification state 2 |
| $G_I$ | A2 | 1 | 2 | 3 |
| | A1 | 4 | 5 | 6 |
| | A5 | 7 | 8 | 9 |
| | A3 | 10 | 11 | 12 |
| $G_N$ | A5 | 13 | – | – |
| | ... | ... | ... | ... |
| | A20 | 28 | – | – |

*where marked as in Table 1

Table 3
Fragment of a list of combinations of product attribute states

| Combination | An ordinal number of the state of the product attribute [u] | | | |
|---|---|---|---|---|
| 1 | 1 | 4 | 7 | 10 |
| 2 | 1 | 4 | 7 | 11 |
| 3 | 1 | 4 | 7 | 12 |
| ... | ... | ... | ... | ... |
| 81 | 3 | 6 | 9 | 12 |

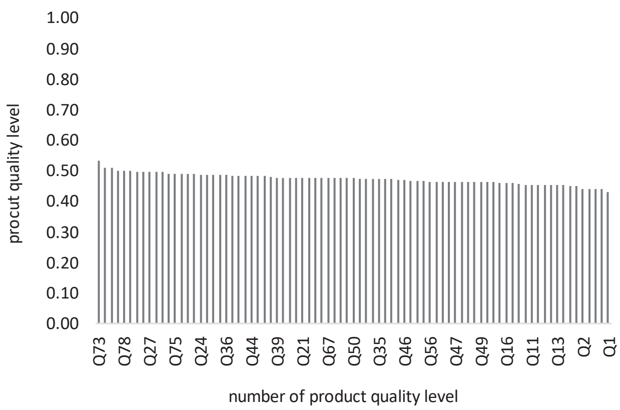


Fig. 4. Product quality levels depend on combinations of values of product attribute states

sessments on a Likert scale was used. Consequently, 81 product quality levels depending on combinations of values of product attribute states were calculated (Fig. 4).

The best quality level of the product reached a value of 0.53, and it was level for a combination of state values marked as $Q^{73}$. Thereafter, according to the actual cost of purchase product ($P_a = 580$ PLN) and quality level determined from customers' assessment of product attributes for current states ($Q_a = 0.49$), the quality-cost indicator was calculated as follows (16):

$$C_a = \frac{P_a}{Q_a} = \frac{580}{0.49} = 1218.64, \tag{16}$$

where $P_a$ denotes the actual cost of the purchase product (PLN), whereas $H_a$ denotes the current product quality level.

Using the formula (16) and the quality-cost indicator, the change in the cost of a product resulting from a combination of values of product attribute states has been estimated (Fig. 5).

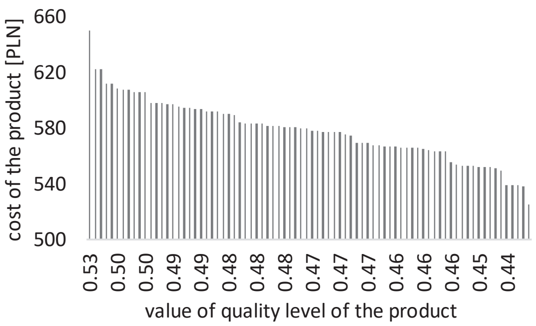


Fig. 5. Product quality levels and change of the cost of the product

It has been estimated that the most expensive product quality level is 650 PLN. This level is the combination of product attribute values equal to $Q^{73} = 0.53$, and it is the most favourable for customers.

## Discussion

The verification of the method allows to confirm that it is possible to calculate the quality level of the product resulting from a combination of values of product attribute states (current and modified). In addition, it was confirmed that it is possible to determine the change in the cost of purchasing products by changing the product quality level, where the cost is determined based on the actual cost of the purchase product (Fig. 6).

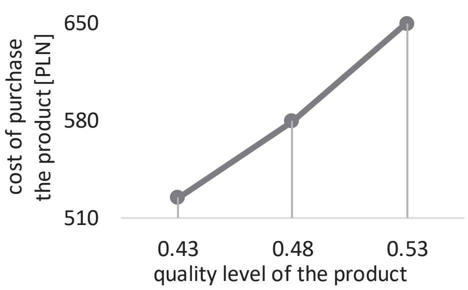


Fig. 6. Difference between the current and modified values of product attribute states and product cost changes

It was observed that achieving the maximum quality level of the product means growth of quality level by approximately 5%; thus, the cost of the product will grow by approximately 70.10 PLN. The difference between product quality levels is relatively small, which results from the relatively high current quality level of the product. Therefore, it is beneficial to consider whether the pursuit of the maximum level of product quality is justified in terms of product cost. Hence, the analysis should include other quality levels and product cost changes resulting from the combination of product attribute state values (Table 4).

Table 4
Fragment of the combination of values of product attribute states

| Combination | $Q^j$ | Increase in product quality [%] | $C_m$ | Product cost increase % |
|---|---|---|---|---|
| 73 | 0.53 | 5.75 | 650.10 | 0.70 |
| 72 | 0.51 | 3.49 | 622.66 | 0.43 |
| 81 | 0.51 | 3.49 | 622.66 | 0.43 |
| 69 | 0.50 | 2.61 | 611.89 | 0.32 |
| ... | ... | ... | ... | ... |

After selecting a favourable combination of product attribute status values, it is possible to take adequate measures to obtain the expected quality level and product cost.

The main benefit of the proposed method is the possibility of predicting the designation of the change of product attributes as part of achieving product quality level, which satisfies the customer, and the entity using the method, that is, organisation production of the product. The other benefits of the method are as follows:

- acquiring customers' requirements regarding the importance of product attributes and preference for the value of product attribute states,
- determining the product attributes that are important for a customer,
- effective determination of the possible combinations of values of product attribute states using the program software, for instance, the MATLAB program,
- calculating the quality levels of a product considering customers' requirements and dependent on combinations of the values of product attribute states,
- estimating the values of product cost changes resulting from product quality levels dependent on a combination of values of product attribute states, and
- the ability to decide the product quality level that will be achievable in terms of cost.

In turn, the disadvantages of the proposed method include a lack of precise determination of the cost of the product, the time-consuming nature of calculating product quality levels depending on the combination of product attributes status values, or the selection of a favourable quality level depending on the preferences of the entity using the proposed method. Additionally, the customers' requirements may change over time; therefore, it is important to improve the actions of the product in a relatively short time.

As part of future research, it is planned to implement the proposed method in computer software to calculate product quality levels and product cost changes in a relatively complicated way and with low time consumption.

## Conclusions

Organisations search for possible solutions in existing products as part of achieving a satisfactory quality product level, and this involves determining the destination of the product attribute state, to increase product quality, as well as customer satisfaction. However, any changes in products refer to changes in the product cost. In turn, it is necessary to include not only the product quality level but also the product cost changes. Therefore, the aim was to propose a method used to predict the quality level of the product and change its cost for combinations of values of product attribute states. The method was tested as an example of a household vacuum cleaner for which 20 attributes were determined. Initially, the requirements of 166 customers were obtained from the survey research on a Likert scale. These requirements concern the importance of product attributes and preferences for the values of product attribute states.

The values of the states were determined by the actual and modified states, by which the modified states were values above and below the current value. Thereafter, based on customer requirements, the weights of product attributes were determined. According to the Pareto rule (20/80), the four product attributes important for customers were selected. Subsequently, for important attributes, possible combinations of the values of these attributes were determined. The algorithm developed in the MATLAB program was used. Consequently, 81 possible combinations of product attribute values were obtained. Next, the PS method was used to calculate the levels of product quality. These levels result from combinations of the product attribute state values. To determine the product cost changes, the actual cost and current quality level of the product were used. Consequently, product quality levels were achieved, along with the resulting product purchase cost. Based on the obtained quality levels of the product and product cost changes, it is possible to determine the most favourable combination of product attribute states in terms of quality and financial (cost). The proposed method can be used in organisations to research existing products to achieve a satisfactory quality level and cost.

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