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APPROACH TO PREDICT PRODUCT QUALITY CONSIDERING CURRENT CUSTOMERS' EXPECTATIONS

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Purpose: The purpose was to develop an approach to predict product quality considering current customers' expectations.
Design/methodology/approach: The approach includes integrated techniques, i.e.: SMART(-ER) method, a questionnaire with the Likert scale, brainstorming (B&M), WSM method, and Naïve Bayes Classifier. This approach refers to obtaining customers' expectations for satisfaction from the current quality of products and the importance of these criteria. Based on the satisfaction of customers, the quality of the product was estimated and classified. Then, the quality of the product was predicted for current customers.
Findings: It was shown that it is possible to predict product quality based on current customer expectations, and so based on the current existing product.
Research limitations/implications: The proposed approach does not include the possibilities of determining the expected quality of the product. The approach focuses on predicting customers' satisfaction with the current quality of the product. Therefore, if there is a need for improvement actions, further analyzes should be carried out to determine which criteria should be modified and how.
Practical implications: The presented approach can be used for any product. Therefore, it is a useful tool for any kind of organization, which strives to meet customer satisfaction. Despite the possibility to predict the quality of the product, the proposed approach can indicate at an early stage to the organization that it is necessary to make improvement actions.
Social implications: It is possible to reduce the waste of resources by predicting that improvement actions are necessary. Moreover, the approach supports an entity (e.g., expert, enterprise, interested parties) in predicting current customers' satisfaction.
Originality/value: Originality is predicting product quality based on current customers' expectations. A new combination of quality management techniques, decision support, and machine learning was implemented.

Keywords: predict, product quality, decision support, Naïve Bayesian Classifier, Weighted Sum Model, customer expectations.

Category of the paper: research paper.

1. Introduction

Dynamical customer expectations make it difficult to effectively improve the product (Pacana, and Siwiec, 2021). The main problem is that products improve with right way. It refers to predicting which changes are expected by customers. In this way, organizations can prepare to take improvement actions, and then implement them at the right time (Ulewicz et al., 2021; Siwiec, and Pacana, 2021). Thus, the position of the organization on the market becomes more competitive. In modern organizations, they are using different instruments to support this process. The based techniques were questionnaires (surveys) to obtain customers' expectations. Additionally, the popular and often used method is the QFD method (Quality Function Deployment) (Hauser, 1993), which has application to design and improve products considering Voice of Customer (VoC) (Siwiec, and Pacana, 2021). Another example is the FAHP method (Fuzzy Analytic Hierarchy Process) (Geng, and Geng, 2018), which mainly been used to precise customer expectations (Siwiec, and Pacana, 2021). Despite that, we are still searching for different methods to predict product quality.

The literature review shows that quality of product was improved by integrated methods, i.e., QFD and AHP (Analytic Hierarchy Process). The idea of this combination was to process customer expectations into technical criteria, where the importance of these criteria was determined by the AHP method (Erkarslan, and Yilmaz, 2011). In a similar context, this method was used to exact customer requirements, i.e. by the authors (Ellman, Wendrich, and Tiainen, 2014; Geng, and Geng, 2018; Li, Chin, and Luo, 2012). Additionally, these methods were integrated with the Kano model as part of determining customer satisfaction (Sun, Mei, and Zhang, 2009; Yamagishi, Seki, and Nishimura, 2018). The mathematical models with ordinal scales were used, i.e. the LGP model LGP (Wang, and Chin, 2011). In turn, the authors of the work (Franceschini, Maisano, and Mastrogiacomo, 2015), the Yager algorithm was used to determine the importance of customer expectations. Furthermore, for improving product quality, the TRIZ method (Theory of Innovative Problems Solving) was used (Ding, Yang, and Bao, 2012; Melemez et al., 2014; Wang et al., 2014). Whereas, in the context of predicting product quality, the Bayesian network (Naïve Bayesian Classifier) was used. It consisted mainly of verified quality for possible product changes of product (Wang, and Tseng, 2014; Jiao, Yang, Zhong, and Zhang, 2015; Yang, Bian, Stark, Fresemann, and Song, 2019; Jiao, Yang, and Zhang, 2017). For this purpose, the Markov chain was used relatively often used (Shi, and Peng, 2020; Wu, and Shieh, 2006; Song, Ming, and Xu, 2013). In this view, customer expectations were analyzed according to probability. However, a single and consistent approach to predicting product quality is still needed, taking into account customer expectations.

Therefore, the objective was to develop an approach to predict the quality of the product quality considering current customers. A test of the approach was performed for the domestic vacuum cleaner.

2. Approach

In the proposed approach, it was assumed to predict product was predicted considering current customers. To this aim, the combined techniques were used, i.e. SMART(-ER) method (Lawlor, and Hornyak, 2012), questionnaire with the Likert scale (Alexandrov, 2010), brainstorming (BM) (Samarraire, and Hurmuzan, 2018), Weighted Sum Model (WSM) (Vilutiene, and Zavadskas, 2003; Supriyono, and Sari, 1977), Naïve Bayesian Classifier (Yang, Bian, Stark, Fresemann, and Song, 2019; Jiao, Yang, and Zhang, 2017). The idea of the approach relies on obtaining customers' expectations. These expectations refer to customers' satisfaction with the quality of the current product, quality and importance (weights) of the product criteria. Then, according to customer satisfaction, was estimated and product quality was classified. The WSM method was used for that. Then, the Naïve Bayesian Classifier was applied to predict product quality from current customers' expectations. The scheme of implementing the proposed approach is shown in Figure 1.

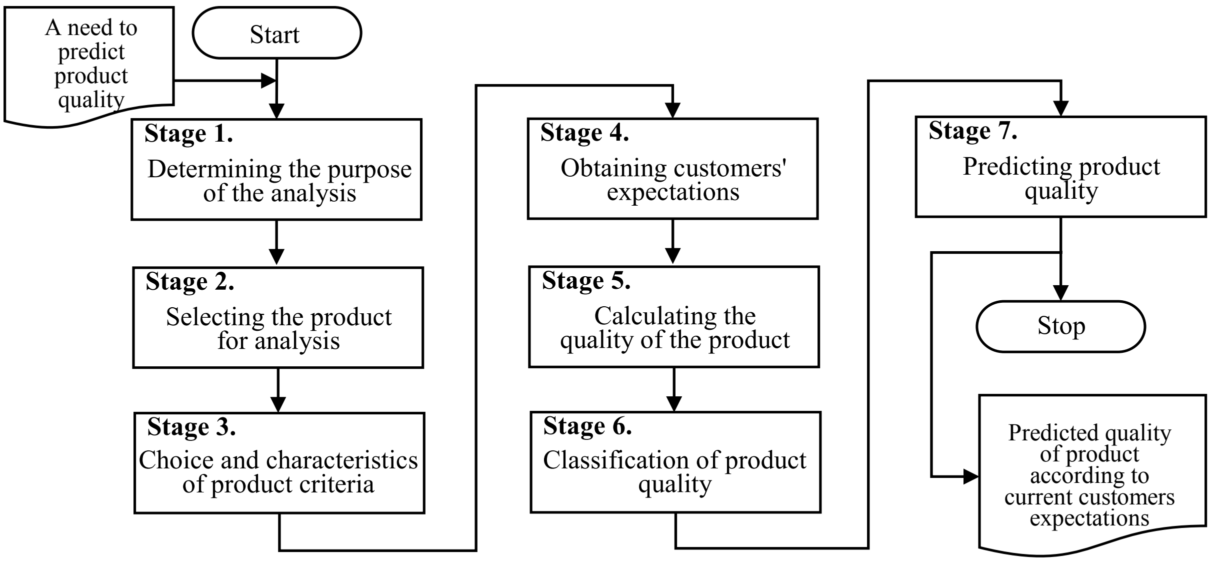

Figure 1. Scheme of realizing the proposed approach to predict product quality.

The short characteristic of the stages of the method is shown in the next part of the study.

Stage 1. Determining the purpose of the analysis. It was assumed that the aim is determined by the entity (expert). In the proposed approach, the purpose is to predict the quality of the product considering current customers. As part of determining the aim, it is adequate to use the SMART(-ER) method (Lawlor, and Hornyak, 2012).

Stage 2. Selecting the product for analysis. The product is selected by the entity (expert). It was assumed that the product can be an existing (produced) product and should be known by customers. The product may be in decline or in maturity, where it is recommended to take improvement actions (Siwiec, and Pacana, 2021).

Stage 3. Choice and characteristics of product criteria. It is necessary to choose criteria (attributes) of the product that generate the quality of the product. It is recommended to select technical criteria (quantitative, measurable), because for these criteria the measure of customers satisfaction is more effective. These criteria are determined by an entity or group of experts during brainstorming (BM) (Putman, and Paulus, 2011). During determining, the criteria will be useful catalogs of product. Following the authors (Siwiec, and Pacana, 2021; Ulewicz et al., 2021), it was assumed that the number of all criteria should be equal from 10 to 25 criteria. Then, all criteria should be characterized, i.e., described by parameter, value or range of values. It refers to marking each of the criteria by the current parameter according to the specification of product.

Stage 4. Obtaining customers' expectations. The purpose is to obtain customers' expectations about product quality. In the proposed approach, it refers to determining customers' satisfaction with current product criteria. In addition, it was assumed to determine the importance (weights) of these criteria for customers. The number of customers (sample size) should be calculated according to the method to determine the number of customers to predict product quality, that is, as shown in work (Siwiec, and Pacana, 2021). According to (Muttaqi'in, and Katias, 2021), to obtain customers' expectations, it is effective to use a survey with the Likert scale. The first stage of the survey includes assesses of the current quality of product criteria, where 1 – criterion is practically unsatisfactory and 5 – criterion is very satisfactory. It is necessary to assess all the criteria selected in the third stage of the approach. The second stage of the survey includes assessing the importance of importance under these criteria. It relies on assessing all criteria selected at the third stage of the approach, where 1 – criterion is practically unimportant, and 5 – criterion is essential. The customer expectations are used in the next part of the analysis.

Stage 5. Calculating the quality of the product. It refers to calculating the quality of the analysis product considering current customers' expectations. This relies on the estimated quality of the product according to customers' satisfaction from the quality of the current criteria and the weights of these criteria. In this aim, it is effective to use the Weighted Sum Model (Siwiec, and Pacana, 2021; Kumar, et al., 2021; Keshavarz-Ghorabaee, 2021), which allows estimating quality of the product without normalization of customers' assesses. In the proposed approach, it is necessary to separately estimate the quality of the product for each customer. The formula (1) is used for this:

$$A_i^{WSM} = \sum_{i=2}^{n} w_j^t x_{ij} = Q_i \tag{1}$$

where:

w – assess the importance (weight) the criterion,

x – assess of satisfaction from quality of the criterion,

i – customer, i, j = 1, 2, …, n.

According to the assumed concept, the number of product quality levels (Q) is equal to the number of customers who participated in the survey.

Stage 6. Classification of product quality. The classification of product quality refers to determining initial customers' satisfaction with the current product quality. It is necessary to classify all the quality levels estimated at the fifth stage of the approach. In this aim, the product quality level (Q_i) is processed into decimal value (Q_i^p) according to formula (2):

$$Q_i^p = \frac{Q_i}{1000} \tag{2}$$

where:

Q – product quality,

i – customer,

i – 1, 2, …, n.

It is necessary to process all the product quality levels calculated in the fifth stage of the model. Then, the state of customer satisfaction is noted for each value. The state is determined based on the maximum and minimum value of product quality, where the maximum value is the high satisfaction, and the minimum value is the lower satisfaction. The average value of the maximum and minimum values of product quality levels is little satisfaction. The product quality levels that were classified in this way are used to predict the current quality of products. It is shown in the next stage of the approach.

Stage 7. Predicting product quality. The idea is to predict the quality of product according to the satisfaction of current customers with the initial classified current customers' satisfaction. The purpose is to generalize individual satisfaction as part of the predicting the quality of product for the general customer community. Machine learning was assumed applied, i.e., Naïve Bayesian Classifier (Piątkowski, 2014; Jiao, Yang, and Zhang, 2017). It was assumed that data representing customers' expectations are considered vector $x = [x_1, x_2, \ldots, x_r]$, where its components are attributes (x_k), where r – number of attributes. In the case where k is contractual nature, it is assumed that l_k has different values. The sets of customers' expectations (i.e. vectors) are separated into classes, which are disjoint, and their sum is equal to the whole space. Each point belongs exactly to a single class (subset), where C – subset of all classes, c – a single class, and $c \epsilon C$. The Bayes formula includes conditional probability, where A and B – observation of random events, P(A) – probability of event A, where $P(A|B)$ – probability of A occurrence provided that B has occurred (3) (Wang, and Tseng, 2014; Jiao, Yang, Zhong, and Zhang, 2015):

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \tag{3}$$

where: $A \cap B$ – simultaneously occurs A and B , therefore the probability is determined as (4) (Piątkiwski, 20214):

$$P(A|B) = \frac{P(B|A)P(B)}{P(A)} \tag{4}$$

The Bayes formulas (5-6) allow identifying the most probability class (*np*): (Wang, and Tseng, 2014; Yang, Bian, Stark, Fresemann, and Song, 2019; Jiao, Yang, and Zhang, 2017):

$$c_{np} = arg\ \max_{c \in C} P(c \mid x_1, x_2, \ldots, x_r) \tag{5}$$

$$c_{np} = arg\ \max_{c \in C} \frac{P(x_1, x_2, \ldots, x_r \mid c)\ P(c)}{P(x_1, x_2, \ldots, x_r)} \tag{6}$$

The elements included in the denominator do not depend on the class. Therefore it does not change the result of the classification (7) (Jiao, Yang, and Zhang, 2017):

$$c_{np} = arg\ \max_{c \in C} P(x_1, x_2, \ldots, x_r \mid c)\ P(c) \tag{7}$$

When the probability in formula (7) is known or possible to estimate, it should be used directly to the classification. The optimal Bayes Classifier is achieved. On the basis of that classifier, it is possible to predict product quality. The maximum value of the probability is determined as the predicted product quality according to current customer expectations.

3. Test of approach

The proposed approach was tested as part of the initial research. This research was carried out in 2020 on a sample of 24 customers. The domestic vacuum cleaner was verified.

As part of the first stage, the purpose of the analysis was assumed. The purpose was to predict the quality of the vacuum cleaner considering current customers.

At the second stage, the product for analysis was selected. It was a vacuum cleaner, which was produced in the Podkarpacie enterprise. This vacuum cleaner was in the maturity phase. Until now, little improvement measures have been taken for this type of vacuum cleaner, e.g., changing colour of the product.

According to the third stage, the vacuum cleaner criteria were selected and then characterized. In accordance with the proposed approach, ten technical criteria were determined. These criteria were determined and characterized by brainstorming (BM) and based on a catalogue (specification). These criteria were: bag type, width of the suction hose, length of the suction hose, controllable of the working handle, rubber protectors to protect against knocking, road wheel type, on/off type, overheating or failure indication, electric brush socket and number of accessories included.

At the fourth stage, the customers' expectations were obtained. The survey with the Likert scale was used for that. The survey was carried out in 2020 by an initial sample obtained sample equal to 24 customers. In the survey, the stage of customer satisfaction from the quality of the current criteria of the vacuum cleaner and the evaluations of the importance of these criteria were included. Customers' expectations were obtained for all criteria selected in the third stage of the approach. These customer evaluations were used to calculate the quality of the vacuum cleaner, as is shown in the next stage.

According to the fifth stage, the quality of the vacuum cleaner was calculated. The WSM method was used for that, including assessments of satisfaction from current criteria and weights of these criteria. The levels of the quality of vacuum cleaner were calculated separately for each customer.

According to the quality sixth stage, the classification of vacuum cleaner was done. As was assumed, three states of customer satisfaction from the current quality of the vacuum cleaner were determined. The limit values of the quality of the vacuum cleaner quality defined as the state of satisfaction, i.e., high satisfaction (maximum value equal to 0,15), little satisfaction (average value equal to 0,11) and low satisfaction (minimum value equal to 0,06).

The results of the implementation of the fifth and sixth stages of the proposed approach are shown in Table 1.

Table 1.
Fragment of estimated and classified current quality of vacuum cleaner

Customer (i)	Quality of vacuum cleaner (Q_i)	Quality of vacuum cleaner (Q_i^p)	Classification of quality of vacuum cleaner according to customer satisfaction
1	144	0,14	high satisfaction
2	65	0,07	low satisfaction
3	119	0,12	a little satisfaction
4	99	0,10	a little satisfaction
5	94	0,09	a little satisfaction
6	75	0,08	low satisfaction
…	…	…	…
24	105	0,11	a little satisfaction

The last stage of the approach was concerned with predicting the quality of the vacuum cleaner according to the satisfaction of current customers' satisfaction. This meant processing the results obtained (from the fifth stage) to predict the current quality for the general customer population. For this purpose, the Naïve Bayesian Classifier supported in STATISTICA 13.3 was used. The estimated and classified quality of vacuum cleaners was used for that. As qualitative dependent variables, states of customers' satisfaction were assumed. In turn, the quantitative predictor was the values of vacuum cleaner quality level. The Naïve Bayesian Classifier results are shown in Table 2.

Table 2.
Predicting quality of vacuum cleaner according to current customers' satisfaction

Class	A priori value	Quality level - average	Quality level - standard deviation
a little satisfaction	0,360000	0,106556	0,000100
low satisfaction	0,280000	0,072857	0,000073
high satisfaction	0,360000	0,1342222	0,000078

After analysis, it was predicted that the current vacuum cleaner quality allowed a high customer satisfaction. It was evidenced by the maximum average value of product quality (0,13), which was determined the state of customer satisfaction. However, the result is the effect of initial research. Therefore, it is appropriate to obtain expectations from a larger number of customers and verify the results.

4. Discussion and Conclusions

Improving the quality of products considering customers' expectations is still a challenge. Therefore, modern enterprises try to predict customers satisfaction from products to make decisions about improving products. Hence, there is still a search for effective instruments supporting this process. Therefore, the objective was to develop an approach to predict the quality of the product quality considering current customers. In this aim, the combined techniques were used, i.e. SMART(-ER), a questionnaire with the Likert scale, brainstorming (BM), WSM method, and Naïve Bayesian Classifier. A test of the approach was performed for the domestic vacuum cleaner. The verified vacuum cleaner criteria were: bag type, width of the suction hose, length of the suction hose, controllable on the working handle, rubber protectors to protect against knocking, road wheel type, on/off type, overheating or failure indication, electric brush socket, and number of accessories included. The customers' expectations were obtained in 2020 from 24 customers. These expectations concerned customer satisfaction with the quality of the current product, quality and the importance (weighting) of the criteria. Then, according to customers' satisfaction, the quality of the product was estimated and classified. The WSM method was used for that. Next, the Naïve Bayesian Classifier was used to predict the quality of the product for current customers. After the analysis, the current quality of the vacuum cleaner was of high satisfaction to the customers. This is evidenced by the maximum average value of quality levels (0,13), which determines the state of customer satisfaction.

Main benefits of the proposed approach, e.g.:

- estimated product quality by simultaneously considering assessments of customer satisfaction with product criteria and assessments of importance of these criteria for customers,
- initial determination satisfaction of individual customers on product quality,
- generalization of customer a small number of expectations of customers to predict quality for general customers,
- predicting the quality of product according to current customers' expectations,
- possibilities of making decisions about necessity and implement improvement actions.

In turn, the disadvantage of the proposed approach is the lack of possibilities of determining the expected quality of the product. The approach focuses on predicting customers' satisfaction with the current quality of the product. Therefore, if there is a need for improvement actions, further analyzes should be carried out to determine which criteria should be modified and how.

Therefore, future research will focus on extending the proposed approach to include the possibility of verifying the expected changes in product criteria. It is also planned to implement an approach in computer software that will support the organization in predicting and subsequently improving product quality.

The presented approach can be used for any product. Therefore, it is a useful tool for any kind of organization, which strives to meet customer satisfaction. Despite the possibility to predict the quality of the product, the proposed approach can indicate at an early stage to the organization that it is necessary to make improvement actions.

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