Application of Fuzzy Logic Data Analysis Method for Business Development

Milind Gupta[1], Bahaaeddin Alareeni[2], Liudmila Akimova[3], Sandeep Kumar Gupta[4](✉), and Marta O. Derhaliuk[1,2,3,4,5]

[1] ABES Engineering College, Ghaziabad, India
milind0110@gmail.com
[2] Business Administration Program, Middle East Technical University, Northern Cyprus Campus, Kalkanli, Mersin, Turkey
bahaaedu@hotmail.com
[3] National University of Water and Environmental Engineering, Rivne, Ukraine
l.m.akimova@nuwm.edu.ua
[4] Department of Management, IIMT College of Engineering, Dr. A.P.J. Abdul Kalam Technical University, Greater Noida, India
skguptabhu@gmail.com
[5] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
marta17.06@ukr.net

Abstract. The developments in production technologies in recent years and the availability of manufactured products to the global market have increased the expectations of the customer, who has many alternatives for the products that can be purchased. In this context, the importance of product quality has increased and product quality has become a multi-dimensional concept, not a one-dimensional concept. For companies to increase their market share and create competitive advantage in the sector in which they operate, they need to analyze the quality of the products they produce according to the products of their competitors in the industry. One of the methods that can be used to evaluate companies operating in a particular sector in terms of product quality and to determine the best-performing business is "Fuzzy Data Application Analysis (FDAA)" method. In this study, the product quality in Turkey's 5 production sites located on the machine operating in the business, realized with fuzzy data envelopment analysis method.

Keywords: Product quality · Efficiency analysis · Fuzzy data application analysis

1 Introduction

With the developments in the field of technology in recent years, product visuality has increased and all kinds of products have become very easy and widely available all over the world. Customers who have the opportunity to choose many alternatives

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related to the product they want to buy, want the product to meet the expectations and the specified specifications. Meeting the expectations of the customers regarding the products and services to be purchased is related to the quality of the service or product in question. The change in the expectations and perceptions of the customer group has caused the perspectives of the enterprises to change about quality. Assessments and improvement studies regarding product and service quality are carried out according to the product and service quality dimensions. [15] product quality; It has been handled in 8 dimensions: performance, suitability, reliability, service visibility, additional features, durability, aesthetics and perceived quality. [28] aimed to understand the practice of transformational management and its role in achieving institutional excellence from the perspective of workers working in the education directorates in Hebron prefecture. The sample of the study consists of (103) employees. The results showed that service visibility at the transformational management practice level was above the total score and at a moderate level in all areas.

In this research, it is aimed to analyze the product quality effectiveness of industrial machinery production companies with fuzzy data envelopment analysis models and to sort the enterprises according to their product quality effectiveness values.

Accordingly, it is aimed to use a suitable method to analyze product quality, which differs according to subjective evaluations for products and sectors.

With the applied method, it will be possible for the production companies to determine the point of their position in the sector in terms of product quality by evaluating the products of their competitors in their sector and their products. The main purpose of the work of its rivals in the quality of the products produced by the companies operating in Turkey according to product sector will enable the evaluation is to determine a method.

2 Dimensions of Product Quality

The product quality is an indicator of whether the product meets the specified specifications and whether it meets the technical conditions determined by the product design. Although product quality is seen concerning production, it is related to all product-related processes such as sales, service and design. For the customer, the product quality is related to the physical and functional benefit provided by the product, which is suitable for the main purpose of the product. For this reason, product quality is not based on a certain judgment and is defined based on the evaluations made by the customer in terms of various dimensions as a result of comparisons with the other products before the purchase decision [1]. In the studies in the literature, the cost groups emerging in terms of business as a result of low product quality; Prevention costs were evaluated under the heading of assessment costs, internal error costs and external error costs. Cost items under these headings; scrap costs, rework costs, product return costs, production interruptions, product recall costs, costs of product re-inspection, warranty maintenance costs [9, 19, 22, 27]. In some studies, product quality is defined as a multi-dimensional concept, according to different quality dimensions defined by the customer and expressing value to the customer. The most studied classification in the literature on the dimensions of product quality is the product quality dimensions classification developed by [15]. Garvin product quality; It has been handled in 8 dimensions as performance, additional features, reliability, compliance with standards, durability, service visibility, aesthetics and perceived quality [15]. Performance refers to the characteristics of the product that is determined by the designers and fulfils its basic function regarding the purpose of production [20]. Additional features are the secondary features and elements that support the basic function of the product, and reliability is the tendency of a product to perform its function stably during the period of use envisaged in the design phase [21]. Suitability refers to the condition of the product's design features or operation related to the previously determined standards [16]. Durability is technically the amount of use before a product can physically function and become irreparable. Service visibility, product malfunction, etc. in cases, the quality of the maintenance and maintenance process and the quality of the maintenance staff towards the customer [15].

The aesthetic dimension is one of the quality dimensions evaluated based on subjective judgments. The preferences and priorities of the people are determinant in the evaluation of the aesthetic dimension [4]. Finally, the perceived quality is the dimension regarding the brand image of the product in the eyes of the customer and the perception of quality created by advertising [15].

3 Fuzzy Data Application Analysis

Data Application analysis (DAA) is a linear programming-based method for measuring the relative effectiveness of multiple organizational units that produce similar outputs with a large number of similar inputs.

DEA measures how efficiently an organizational unit uses its available resources. DAA is a non-parametric efficacy measurement method and is therefore expressed as non-parametric programming. The effectiveness of the units with many different inputs and inputs and outputs measured with different measurement units can be measured with DAA based on linear programming principles [3]. Effectiveness score calculated with DEA is expressed as follows.

$$\text{Activity} = \frac{\text{Total of weighted outputs}}{\text{Total of weighted entries}}$$

One of the most important advantages of the DAA method is determining to what extent ineffective decision-making units need to improve the input and output variables to reach efficiency. Reference sets are determined for ineffective decision-making units according to the value of the λ variable in the dual DEA model created for this purpose. For an ineffective decision-making unit, improvement rates are calculated based on the values of the input and output variables of the active decision-making units in the reference group. DEA method not only determines the position of the decision-making unit compared to other decision-making units but also determines the extent to which the inactive decision-making unit should improve its input and output to be effective.

In such situations, "Fuzzy Data Application Analysis" (FDAA) models have been developed to measure the effectiveness of decision-making units [24]. FDAA provides relative effectiveness measurement for decision-making units where there is uncertainty or incompleteness in terms of inputs and outputs [6].

In some cases, the exact values of the inputs and outputs of decision-making units cannot be measured. Service quality level, quality of input sources, level of satisfaction, etc. Data on variables are examples of data that are difficult to measure as exact values. Such data are expressed as variables suitable for the fuzzy logic approach and fuzzy data envelopment analysis can be used to measure efficiency [2]. In some cases, the input and output variables evaluated are expressed in sequential linguistic values such as "Better", "Good", "Medium", "Bad" [17]. For these and similar situations, it is recommended to use fuzzy data envelopment analysis [23]. Data used in fuzzy data envelopment analysis; The data with unknown exact value, limited data determined as an upper and lower limit, and sequential data expressed as size and size [12]. FDAA models are classified into three headings according to the type of data used. First group models; These are FDAA models for ordered and exact data. Models in the second group; These are FDEA models for sequential, constrained and known precise data. The models in the third group are; It is expressed as FDEA models for limited and definite data [25].

The Cook - Kress - Seiford model to be used in this study is explained briefly below.

4 Cook - Kress - Seiford Model

Cook - Kress - [11] Seiford (1993) model was first applied as a FDAA model used for sequential data. Later, it was developed in 1996 and turned into a model applied for sequential and known data. The purpose of the model is expressed as both quantitative data with known exact value and using sequential qualitative data in data envelopment analysis [11].

s has a known output, w is a sequential output, m has a known exact value, and f has a sequential input. The decision making unit is assumed. The input-oriented Cook - Kress Seiford model for the decision-making unit in question is created as follows [24].

Purpose Function:

$$\text{Maks } \sum\nolimits_{r=1}^{s} u_r y_{rz} + \sum\nolimits_{h=1}^{w} \sum\nolimits_{l=1}^{L} u_h^l y_{hz}^l \tag{2}$$

Constraints

$$\sum_{r=1}^{s} v_i x_{iz} + \sum_{b=1}^{f} \sum_{l=1}^{L} v_b^l x_{bz}^l = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} + \sum_{h=1}^{w} \sum_{l=1}^{L} u_h^l y_{hj}^l - \sum_{r=1}^{s} v_i x_{ij} + \sum_{b=1}^{f} \sum_{l=1}^{L} v_b^l x_{bj}^l \leq 0$$

$$jj = 1 \ldots nn, rr = 1 \ldots .MM\,, ii = 1 \ldots mm, h = 1 \ldots ww\,, bb = 1 \ldots ff$$
$$uu; vv_6 \geq \varepsilon\varepsilon, LL \leq nn$$

The smallest sequential data (greater than \$ 10%) every h. difference between the sequential output for output > 0.

The smallest sequential data (greater than \$ 10%) every b. Difference between sequential entries for input > 0 In the model given above;

*uu*E: known exact value i. the weight value of the output,

vvE: known exact value i. the weight value of the input,

uu') (: j. the weight value of the h-row output for the decision-making unit,

vvB (): j. for the decision-making unit b. It refers to the weight value of the ordered input.

Sequence numbers of the ordered outputs in the model $LL \ni ll$ In this case, the L set is formed as $\mathrm{L} = \{1, 2,\ 3,\ 4\}$. Form a cluster.

For example, it is possible to take the same order value of multiple decision-making units as important (1), important (2), (l) for input or output data. Get rankings was added [24].

Application

In this research, depending on the product quality dimensions developed by Garvin, the product quality efficiency of the machinery manufacturing sector enterprises will be analyzed. For this purpose, the fuzzy data envelopment analysis method was used. For fuzzy data envelopment analysis, a scale that allows machine manufacturing sector companies to evaluate their products in terms of product quality dimensions and low product quality was applied to determine the input and output variable values. The scale consists of 3 groups of questions. In the first group,

There are 3 questions aimed at evaluating the general quality levels of the products produced by the enterprises. In the second group, industrial machinery production companies to evaluate their product quality 22 regarding product quality dimensions to ensure.

The question is included. In the third group, the evaluation of the consequences of low product quality questions is included. Questions in the first group.

It was developed in the light of information obtained from the literature. The questions in the second group were used in the study by [19]. It was obtained by adapting the scale. Place in third group questions on the cost of poor quality is based on the information obtained from the studies in the literature.

It was prepared as. According to the results of the explanatory factor analysis for the scale used, the scale Six of the twenty-nine variables included are cross factor load problem was excluded from the analysis.

According to the result of factor analysis, for product quality dimensions, “Rework” and “Product return” dimensions.

According to the results of the reliability analysis made separately.

Reliability values for all factors are in Table 1.

As can be seen, it is accepted as the limit of acceptability. The value exceeded 0.60. For 23 of the 31 questions in the developed scale, one of the scale development techniques “the scale of difference on a continuous line” was used.

The technique of specifying the difference on a continuous line is generally applied based on placing a mark on a line, which is 13 cm and has extreme alternatives on both sides. Evaluation results are determined by measuring the distance of the markings made on the line to the ends [24]. The reason for choosing the scale development technique in question is a more objective and accurate evaluation than the five-point scale to allow it to be done. Among the dimensions of product quality, service visibility, aesthetics and perceived quality dimensions are expressed in the first part as dimensions that are evaluated based on subjective judgments and which are more difficult to make concrete

Table 1. Reliability analysis results regarding the factors in the scale

Factors	Performance	Additional features	Reliability	Compliance with standards	Durability	Service visibility	Aesthetics	Perceived quality	Product returns	Rework
C.alpha	0,791	0,611	0,867	0,807	0,782	0,631	0,75	0,645	0,922	0,656

numerical evaluations than other dimensions. For this reason, the evaluation was made according to linguistic variables in 8 questions determined for these 3 product quality dimensions.

According to the expressions given in the six questions in the scale, the respondents were asked to choose one of the “Very Bad”, “Bad”, “Moderate”, “Good” and “Very Good” options. The last 2 questions are; according to the statement given.

It has been prepared in such a way that one of the options “Very low”, “Low”, “Medium”, “High” and “Very High” is preferred.

Using the data obtained from the scale, product quality efficiency scores were calculated for industrial machinery manufacturers with BVZA method. Super efficiency analysis has been conducted to rank the enterprises that are found effective as a result of the fuzzy data envelopment analysis, that is, the efficiency score is one.

Using the efficiency values obtained as a result of the super efficiency analysis, the enterprises were ranked in terms of product quality efficiency. Product quality dimensions include dimensions that can be evaluated based on both objective criteria and subjective judgments. Among the product quality dimensions, service visibility, aesthetics and perceived quality dimensions are evaluated using sequential linguistic variables whose exact value is known, while other product quality dimensions were evaluated with numerical variables with known exact values. Therefore, the relative efficiency analysis was performed using the Cook - Kress - Seiford (CKS) model, which is the only BVZA model in the literature whose exact value is known and applied for ordered variables. The Cook - Kress - Seiford model is a BVZA model in the form of an input-oriented CCR model applied for sequential data with the known exact value. Therefore blurry the efficiency analysis was carried out with an input arrow.

For this reason, factor scores related to “Service visibility”, “Aesthetics” and “Perceived quality” dimensions were used as sequential data. Also, efficiency analysis was performed using the input-focused CCR model and the results obtained with the two models were compared.

The main purpose of the study is to reveal a method that allows businesses to analyze the quality of the products they produce compared to their competitors. For this purpose, the results obtained on product quality dimensions for the relative product quality efficiency analysis were used as outputs in the BVZA method. As input variables of relative efficiency analysis related to product quality, product quality.

“Reprocessing” and “Product return” factors, which are considered to be the consequences of being low in terms of the business, are discussed.

Since product quality dimensions are considered as the main factors determining product quality in the literature, output variables are considered for the relative efficiency analysis.

The most important reason for the preference of the results of low product quality as the input variable is that a significant portion of the studies on product quality in the literature has been focusing on the results of low product quality. As a result of the low product quality in the literature, repair and maintenance costs, scrap costs, quality control costs, etc. It is expressed as many poor quality cost items.

However, the said poor quality costs are associated with low product quality, as well as the customer’s appropriate use of the product, malfunctions in production technologies, etc. It can also occur in connection with other factors. Therefore, relative efficiency "Product return" and "Rework" factors, which are evaluated directly in connection with the low product quality, were selected in the analysis [17].

For product quality relative efficiency analysis, 30 enterprises operating in 5 provinces among the industrial machinery manufacturing enterprises were included in the efficiency analysis. These 30 enterprises were included in the application by contacting the industrialists and businessmen associations operating nationally and obtaining the information of their members operating in the sector. Including a small number of decision-making units in the relative efficiency, analysis causes a large number of decision-making units that are effective. Therefore, the minimum number of decision-making units to be included in efficiency analysis has been determined in the literature. [7] decided to reach reliable results of the study. He stated that the number of delivery units should be at least m + n + 1 to express m input number and n output number [7]. Dyson et al. (2001) stated that the number of m inputs should be at least 2m + n so that n is the number of outputs [12].

The high number of decision-making units included in the analysis also affects the efficiency analysis result and causes the number of effective decision-making units to increase. The number of output variables to be used for relative efficiency analysis is 8, and the number of input variables is 2. According to this; Considering the above opinions, the number of enterprises included in the application has been determined as 30, which will be above the minimum values given in terms of the number of decision-making units for which efficiency analysis is performed and will not affect the efficiency results. Also, decision-making units included in the relative efficiency analysis with data envelopment analysis should be of homogeneous size [26]. For this reason, 30 enterprises included in the application were selected among enterprises with similar sizes in terms of workforce and turnover.

5 Findings

Cook - Kress - Seiford model is an FDAA model in input-oriented CCR form which is known for its exact value and applied for sequential data, as stated in the third section.

Factor scores of input and output variables were determined first to make relative effectiveness analysis with the said model. For this purpose, factor scores regarding the performance, suitability, additional features, durability, reliability, reprocessing and product return dimensions, which were evaluated quantitatively, were calculated by taking the arithmetic means of the variables depending on the factors.

The service evaluated with linguistic variables consists of visibility, aesthetics and two variables. According to the membership function of the said dimension-values, it has been converted to run for calculating a single factor score related to the membership ranks. For this, in the first stage, the numerical values corresponding to the lower limit and upper limit variables for the values taken by the linguistic variables were determined in Table 2 and the blurring process was applied and determined as seen.

For the blurring of the data, the monotonic increasing membership function, which is given in Fig. 1, is preferred.

Table 2. Linguistic variables and corresponding numerical values

Language expressıon	Numerical Provision
Too Bad, Too Little	1
Bad, Little	2
Moderate	3
Good, High	4
Very Good, Very High	5

[24] Monotonic increasing membership The mathematical representation of the function is shown below.

$$\left\{ \begin{matrix} 1 & x \geq U \\ \frac{x-l}{u-l} & L < x < U \\ 0 & x \leq L \end{matrix} \right\}$$

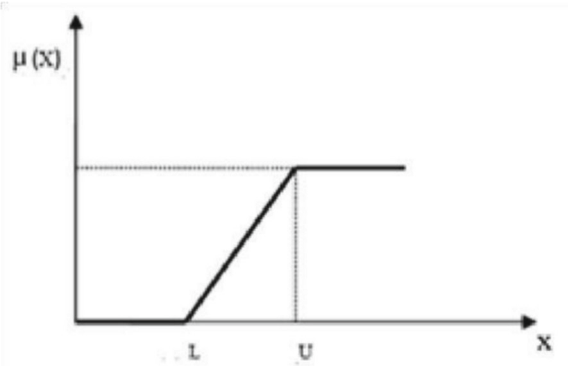

Fig. 1. Monotonic ıncreased membership function

In the next step, the values expressed as membership degrees were rinsed with a weighted average method and converted into a single value. The rinsed output variable values obtained after converting multiple value linguistic variables into a single numerical value were converted back to linguistic variables based on the ranges in Table 3.

For example, 3 linguistic expressions derived from 3 variables regarding the assessment of the service visibility dimension for the first business to be analyzed for product quality effectiveness are converted into a single linguistic variable as follows. For the first decision-making unit, the evaluation results obtained from the questionnaire related to 3 variables depending on the service visibility dimension are “MEDIUM DEGREE” for SERVICE _1 variable,

Table 3. Rinsed value ranges and corresponding linguistic variables

Interval	Language variable
$0,5 \leq xx < 1,5$	Too Bad, Too Little
$1,5 \leq xx < 2,5$	Bad, Little
$2,5 \leq xx < 3,5$	Moderate
$3,5 \leq xx < 4,5$	Good, High
$4,5 \leq xx \leq 5$	Very Good, Very High

"MEDIUM DEGREE" for SERVICE _2 variable and "MEDIUM DEGREE" for SERVICE_3 variable. The numerical values corresponding to these linguistic expressions are determined as 3, 4 and 3, respectively. The lowest value that can be taken by 3 variables depending on the service visibility dimension is "Very Bad" and the highest value is "Very Good". The variables depending on the service visibility dimension took the values 3, 4 and 3 as stated above. According to the monotonic increasing membership function, the degree of membership for three values is "0.50" and the degree of membership for four values is "0.75".

According to the centre of gravity method, three variables with the mentioned membership degree are rinsed as follows and converted into a single variable

$$0{,}5 * 3 + 0{,}75 * 4 + 0{,}5*(3)/0{,}5 + 0{,}75 + 0,5 = 3.42 \; (3)$$

According to the value ranges in Table 2, the linguistic variable corresponding to the value of 3.42 for the service visibility dimension is "MEDIUM DEGREE". 3 linguistic expressions, in which the service visibility dimension was evaluated, were converted into a single linguistic variable with the above-mentioned process.

$$\frac{\Sigma\mu(x) - x}{\Sigma} \frac{0{,}5 * (3) + 0{,}75 * (4) + 0{,}5 * (3)}{(3)}$$

$$\mu(x) - (x) = 0{,}5 + 0{,}75 + 0{,}5 = 3{,}42$$

$$\mu x x$$

In Table 4, the numerical equivalents of the values received by the variables depending on the "Service visibility", "Aesthetic" and "Perceived quality" dimensions and the linguistic variable values obtained for the dimension as a result of rinsing are given. The linguistic evaluation results regarding the "Service visibility", "Aesthetic" and "Perceived quality" dimensions in Table 3 must be converted into sequential variables to be used as output scores in fuzzy data envelopment analysis models.

Output values obtained by converting linguistic variables into sequential data are given in Table 5.

After determining the value of the output variables for FDAA, the values of the input variables were determined by taking the averages of the reprocessing and product return variables, which are considered as input variables in the efficiency analysis as low product quality results.

In Table 6, scores of input variables related to input variables are given.

$$\sum_{r=1}^{s} u_r y_{rj}^L + \sum_{h=1}^{w} u_r y_{hj} - \sum_{i=1}^{m} v_i x_{ij}^L + \sum_{b=1}^{f} v_i x_{bj} \leq 0$$

The product quality efficiency values obtained with the Cook - Kress - Seiford model and the product quality efficiency rankings of the machinery manufacturing enterprises according to these efficiency values are given in Table 7.

For businesses that show an event value as a value, the value given in parentheses is the super activity score calculated for active businesses.

To perform product quality effectiveness analysis with Çook - Kress - Seiford model, the model included in the formulation number 2 was written separately for each decision-making unit and product quality effectiveness scores were calculated for all machinery manufacturing enterprises. For the effective decision-making units to be ranked according to their activity scores, a super activity model developed. In the super effectiveness model, the constraint in the formula "3" which is in the data envelopment analysis model and ensures the maximum of effectiveness scores is not included in the model created for the decision-making unit where the effectiveness analysis is made.

Result

The main purpose of this study is to determine the point where machine manufacturing enterprises are in their sector in terms of product quality and which dimensions should be improved to improve product quality. In the classification of product quality dimensions introduced by Garvin, there are both quality dimensions whose exact value is expressed according to objective evaluations, expressed in numerical data and expressed based on subjective evaluations. For this reason, the fuzzy data application analysis (FDAA) method was used instead of the "Data Application Analysis" (DAA) method for the relative effectiveness analysis conducted to evaluate the level of the quality of the enterprises in the sector in terms of product quality. Cook - Kress - Seiford model, where product quality effectiveness analysis is conducted, is a model suitable for areas where there are input-output variables that are evaluated based on personal judgments with linguistic variables such as quality. Therefore, the model in question was applied for relative effectiveness analysis. When the results obtained with the Cook - Kress - Seiford model

Table 4. Linguistic variable assessment scores and output variable values

KVB	Variable scores	Service visibility	Variable scores	Aesthetics	Variable scores	Perceived quality
1	3, 4, 3	MEDIUM DEGREE	3, 3	MEDIUM DEGREE	3, 3	MEDIUM DEGREE
2	4, 3, 3	MEDIUM DEGREE	3, 5	GOOD	3, 4	GOOD
3	5,4, 5	VERY GOOD	4, 4	GOOD	4, 4	GOOD

(*continued*)

Table 4. (*continued*)

KVB	Variable scores	Service visibility	Variable scores	Aesthetics	Variable scores	Perceived quality
4	3, 5, 3	GOOD	3, 4	GOO	4, 4	GOOD
5	4, 4, 4,	GOOD	4, 4	GOOD	3, 4	GOOD
6	3, 4, 4	GOOD	3, 3	MEDIUM DEGREE	2, 3	MEDIUM DEGREE
7	4, 5, 4	GOOD	4, 4	GOOD	4, 4	GOOD
8	3, 3, 4	MEDIUM DEGREE	4, 4	GOOD	3, 4	GOOD
9	3, 4, 4	GOOD	3, 3	MEDIUM DEGREE	4, 4	GOOD
10	3, 4, 4	GOOD	4, 4	GOOD	4, 5	VERY GOOD
11	4, 4, 4	VERY GOOD	4, 4	GOOD	3, 4	GOOD
12	4, 4, 5	GOOD	5, 4	VERY GOOD	3, 4	GOOD
13	4, 4, 4	GOOD	3, 2	MEDIUM DEGREE	3, 4	GOOD
14	4, 4, 5	GOOD	4, 4	GOOD	4, 4	GOOD
15	4, 4, 5	GOOD	3, 4	GOOD	3, 4	GOOD
16	5, 5, 5	VERY GOOD	4, 4	GOOD	4, 5	VERY GOOD
17	3, 4, 3	MEDIUM DEGREE	4, 4	GOOD	3, 4	GOOD
18	3, 4, 3	MEDIUM DEGREE	4, 4	GOOD	4, 3	GOOD
19	4, 4, 4	GOOD	4, 4	GOOD	2, 4	GOOD
20	4, 4, 4	GOOD	4, 5	VERY GOOD	4, 4	GOOD
21	4, 5, 4	GOOD	5, 5	VERY GOOD	5, 5	VERY GOOD
22	4, 5, 5	VERY GOOD	3, 4	GOOD	4, 5	VERY GOOD
23	4, 5, 5	VERY GOOD	4, 3	GOOD	4, 3	GOOD

(*continued*)

Table 4. (*continued*)

KVB	Variable scores	Service visibility	Variable scores	Aesthetics	Variable scores	Perceived quality
24	5, 4, 5	VERY GOOD	4, 4	GOOD	4, 4	GOOD
25	4, 4, 4	GOOD	4, 3	GOOD	3, 5	GOOD
26	4, 5, 3	GOOD	4, 4	GOOD	3, 3	MEDIUM DEGREE
27	3, 4, 4	GOOD	4, 4	GOOD	4, 4	GOOD
28	4, 4, 4	GOOD	4, 4	GOOD	3, 4	GOOD
29	4, 4, 4	GOOD	4, 4	GOOD	4, 4	GOOD
30	3, 4, 3	MEDIUM DEGREE	4, 4	GOOD	3, 4	GOOD

are examined, it is seen that 5 enterprises with maximum value in terms of sequential output values are found to be active.

At the same time, the efficiency values of the companies that have maximum value in terms of sequential output values appear to be higher than the efficiency values obtained for the same enterprises in other models. The reason for this can be stated as the fact that the ordered output values have high weight values for decision units where the ordered output values are maximum in the Cook - Kress - Seiford model. Decision-making units and inputs and outputs are converted into linear programming models in case of large numbers, DAA models become more complex and difficult to implement. There are many computer applications used to facilitate DAA applications for these situations.

However, for fuzzy FDAA models, there is no program in which sequential and restricted data can be defined and relative effectiveness analysis can be made. According to the decision-making unit and the number of input and output, hundreds of decision variables and models requiring constraints require a long time and effort to solve. DEA method determines the position of the decision-making unit in which efficiency analysis is made compared to other decision units, as well as determining which inputs and outputs to improve the efficiency and to what extent. Due to this feature, the DAA method has also been used in some studies in the literature as a method that helps businesses choose the best benchmarking partner. It is possible to use the FDAA method in the benchmarking activities that will be carried out on areas that are evaluated based on objective data and subjective judgments, such as quality, human resources, public relations. Using fuzzy data envelopment analysis models for relative effectiveness analysis makes it possible to use input and output variables that cannot be expressed by subjective and numerical values. However, it also allows the relative effectiveness analysis to be applied in wider areas. As stated above, one of the most important advantages of DAA method is determining to what extent ineffective decision-making units should improve the input and output variables to reach the efficiency. For an ineffective decision-making unit, improvement rates are calculated based on the values of the input and output variables

Table 5. Fuzzy data application analysis output variable values

F	Performance	Additional features	Reliability	Compliance with standards	Durability	Service visibility	Aesthetics	Perceived quality
1	10,50	10,45	8,20	7,40	8,70	$Y_{6,1} < Y_{6,4}$	YY(,$ < YY(,)	$Y_{8,1} < Y_{8,2}$
2	11,25	11,35	10,30	8,90	9,90	$Y_{6,2} = Y_{6,1}$	$Y_{7,2} < Y_{7,12}$	$Y_{8,2} < Y_{8,10}$
3	11,25	11,20	10,80	10,05	10,60	$Y_{6,3}$	YY(,- = YY(,)	$Y_{8,3} = Y_{8,2}$
4	10,25	10,15	7,95	8,45	9,25	$Y_{6,4} < Y_{6,1}$	YY(,' = YY(,)	$Y_{8,4} = Y_{8,2}$
5	11,55	11,80	9,95	8,70	9,95	$Y_{6,5} = Y_{6,4}$	$Y_{7,4} = Y_{7,2}$	$Y_{8,5} = Y_{8,2}$
6	10,95	10,90	7,85	7,40	8,45	$Y_{6,6} = Y_{6,4}$	YY(," = YY(,$	$Y_{8,6} = Y_{8,1}$
7	12,25	12,50	11,25	9,45	10,50	$Y_{6,7} = Y_{6,4}$	YY(,(= YY(,)	$Y_{8,7} = Y_{8,2}$
8	9,85	10,50	8,65	8,90	9,30	$Y_{6,8} = Y_{6,1}$	$Y_{7,8} = Y_{7,2}$	$Y_{8,8} = Y_{8,2}$
9	10,45	10,95	8,40	9,30	9,40	$Y_{6,9} = Y_{6,4}$	YY(,/ = YY(,$	$Y_{8,9} = Y_{8,2}$
10	11,35	11,75	8,70	8,90	9,55	$Y_{6,10} = Y_{6,4}$	$Y_{7,10} = Y_{7,2}$	YY*,$,
11	10,50	10,90	8,90	9,55	9,60	$Y_{6,11} = Y_{6,3}$	$Y_{7,11} = Y_{7,2}$	$Y_{8,11} = Y_{8,2}$
12	12,10	12,50	11,35	9,75	10,75	$Y_{6,12} = Y_{6,4}$	YY(,$)	$Y_{8,12} = Y_{8,2}$
13	10,80	10,95	8,55	9,45	9,10	$Y_{6,13} = Y_{6,4}$	YY(,$- = YY(,$	$Y_{8,13} = Y_{8,2}$
14	10,40	11,60	10,05	9,80	9,90	$Y_{6,14} = Y_{6,4}$	$Y_{7,14} = Y_{7,2}$	$Y_{8,14} = Y_{8,2}$
15	10,95	11,15	9,60	8,45	9,95	$Y_{6,15} = Y_{6,4}$	$Y_{7,15} = Y_{7,2}$	$Y_{8,15} = Y_{8,2}$
16	12,20	12,65	11,95	9,80	11,95	$Y_{6,16} = Y_{6,3}$	$Y_{7,16} = Y_{7,2}$	$Y_{8,16} = Y_{8,10}$
17	11,85	11,90	10,85	9,25	10,20	$Y_{6,17} = Y_{6,1}$	$Y_{7,17} = Y_{7,2}$	$Y_{8,17} = Y_{8,2}$
18	11,05	11,60	8,75	9,05	9,25	$Y_{6,18} = Y_{6,1}$	$Y_{7,18} = Y_{7,2}$	$Y_{8,18} = Y_{8,2}$

(*continued*)

Table 5. (*continued*)

F	Performance	Additional features	Reliability	Compliance with standards	Durability	Service visibility	Aesthetics	Perceived quality
19	8,60	10,70	8,55	7,30	8,90	$Y_{6,19} = Y_{6,4}$	$Y_{7,19} = Y_{7,2}$	$Y_{8,19} = Y_{8,2}$
20	12,20	12,15	11,25	10,10	11,60	$Y_{6,20} = Y_{6,4}$	$Y_{7,20} = Y_{7,12}$	$Y_{8,20} = Y_{8,2}$
21	9,25	10,35	9,15	9,00	9,40	$Y_{6,21} = Y_{6,4}$	$Y_{7,21} = Y_{7,12}$	$Y_{8,21} = Y_{8,10}$
22	11,30	7,85	10,50	6,05	10,15	$Y_{6,22} = Y_{6,3}$	$Y_{7,22} = Y_{7,2}$	$Y_{8,22} = Y_{8,10}$
23	9,95	9,70	9,50	9,55	11,85	$Y_{6,23} = Y_{6,3}$	$Y_{7,23} = Y_{7,2}$	$Y_{8,23} = Y_{8,2}$
24	8,45	7,80	9,30	8,45	9,65	$Y_{6,24} = Y_{6,3}$	$Y_{7,24} = Y_{7,2}$	$Y_{8,24} = Y_{8,2}$
25	9,60	8,40	8,15	4,85	7,75	$Y_{6,25} = Y_{6,4}$	$Y_{7,25} = Y_{7,2}$	$Y_{8,25} = Y_{8,2}$
26	6,35	9,20	8,05	8,45	6,65	$Y_{6,26} = Y_{6,4}$	$Y_{7,26} = Y_{7,2}$	$Y_{8,26} = Y_{8,1}$
27	12,30	7,80	6,90	5,60	6,05	$Y_{6,27} = Y_{6,4}$	$Y_{7,27} = Y_{7,2}$	$Y_{8,27} = Y_{8,2}$
28	10,50	10,20	9,95	10,10	10,20	$Y_{6,28} = Y_{6,4}$	$Y_{7,28} = Y_{7,2}$	$Y_{8,28} = Y_{8,2}$
29	10,10	10,00	9,45	9,65	9,35	$Y_{6,29} = Y_{6,4}$	$Y_{7,29} = Y_{7,2}$	$Y_{8,29} = Y_{8,2}$
30	9,95	9,85	8,80	9,50	9,05	$Y_{6,30} = Y_{6,1}$	$Y_{7,30} = Y_{7,2}$	$Y_{8,30} = Y_{8,2}$

Table 6. Fuzzy data application analysis input variable values

	Rework	Product returns
1	3,60	2,77
2	3,25	2,03
3	2,25	2,13
4	3,70	3,23
5	3,20	2,70
6	3,35	2,27
7	3,20	1,53
8	3,00	2,90
9	3,00	2,97
10	3,10	2,43
11	2,90	2,90
12	2,95	1,90
13	3,35	3,03
14	3,30	2,97
15	3,55	2,90
16	1,85	1,07
17	3,05	1,70
18	3,35	2,73
19	3,70	2,97
20	1,35	1,17
21	3,10	3,50
22	1,90	3,93
23	3,05	3,90
24	2,90	3,43
25	3,85	3,57
26	3,65	4,43
27	3,75	4,13
28	2,40	2,60
29	2,55	2,27
30	2,95	3,07

of the active decision-making units in the reference group. In the FDAA method, variable and reference groups can be determined for ineffective decision-making units.

However, it is only possible to calculate the improvement rate for the input and output variables expressed as sequential and constrained data, by converting these variables to

Table 7. Efficiency score by Cook - Kress - Seiford model and activity ranking

Busıness no	Event value	Ranking
1	0,397	24
2	0,531	15
3	0,898	6
4	0,369	29
5	0,423	20
6	0,479	17
7	0,702	7
8	0,465	19
9	0,468	18
10	0,598	13
11	0,680	9
12	1	5
13	0,410	22
14	0,416	21
15	0,382	26
16	1 (3,86)	1
17	0,629	12
18	0,406	23
19	0,372	27
20	1 (2,282)	2
21	1 (1,032)	3
22	1 (0,007)	4
23	0,685	8
24	0,652	10
25	0,359	30
26	0,371	28
27	0,385	25
28	0,639	11
29	0,537	14
30	0,482	16

exact values. It is anticipated that it would be beneficial to develop a proven method in which improvement rates can be calculated for cases where it is not possible to convert sequential and restricted data to absolute value. Data related to input and output variables to perform product quality effectiveness analysis with FDAA was obtained by filling the scale prepared by the company managers as stated above. Enterprises will need input and output data regarding their businesses and competitors to perform effectiveness analysis on any subject within their sector by FDAA and similar method. In an era where the importance of information increases day by day and it is getting harder to access industrial information, it is very difficult to collect data and have information about competitors.

It is thought that businesses can evaluate their businesses and competitors according to this scale by using a scale as in this study.

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References

1. Ackaradejruangsri, P.: The effects of product quality attributes on Thai consumers buying decision. Ritsumeikan J. Asia Pacific Stud. **33**, 14–24 (2013)
2. Agarwal, S.: Efficiency measure by fuzzy data envelopment analysis model. Fuzzy Inf. Eng. **6**, 59–70 (2014). https://doi.org/10.1016/j.fiile.2014.06.005
3. Akyüz, K.C., Çamur, G., Yıldırım, İ: Efficiency measurement with the help of data envelopment analysis in furniture and sheet industry. Turkey J. Forestry **16**(1), 50–59 (2015)
4. Alqallaf, H., Alareeni, B.: Evolving of selected integrated reporting capitals among listed Bahraini banks. Int. J. Bus. Ethics Gov. **1**(1), 15–36 (2018)
5. Andersen, P., Petersen, N.C.: A procedure for ranking efficient units in data envelopment analysis. Manage. Sci. **39**(10), 1261–1264 (1993)
6. Arnheiter, E.D., Harren, H.: Quality management in a modular world. TQM Mag. **18**(1), 87–96 (2006). https://doi.org/10.1108/09544780610637712
7. Azadeh, A., Fam, M.I., Nazifkar, N.: The evaluation and improvement of safety behaviours among contractors of a large steel manufacturing company by fuzzy data envelopment analysis. J. Chinese Inst. Eng. **33**(6), 823–832 (2010). https://doi.org/10.1080/02533839.2010.9671672
8. Boussofiane, A., Dyson, R.G., Thanassoulis, E.: Applied data envelopment analysis. Eur. J. Oper. Res. **52**(1), 1–15 (1991). https://doi.org/10.1016/0377-2217(91)90331-O
9. Chiarini, A.: Effect of ISO 9001 noncomformity procession cost of poor quality in capital intensive sectors. Int. J. Qual. Reliab. Manage. **32**(2), 144–155 (2015)
10. Chorafas, D.N.: Quality Control Application. Springer, Londra (2013)
11. Cook, W.D., Kress, M., Seiford, L.M.: Data envelopment analysis in the presence of both quantitative and qualitative factors. J. Oper. Res. Soc. **47**, 945–953 (1996). https://doi.org/10.2307/3010140
12. Despotis, D.K., Smirlis, Y.G.: Continuous optimization data envelopment analysis with imprecise data. Eur. J. Oper. Res. **140**, 24–36 (2002)
13. Dyson, R.G., Allen, R., Camanho, A.S., Podinovski, V.V., Sarrico, C.S., Shale, E.A.: Pitfalls and protocols in DEA. Eur. J. Oper. Res. **132**, 245–259 (2001). https://doi.org/10.1016/S0377-2217(00)00149-1
14. Garvin, D.A.: What does "product quality" really mean? Sloan Manage. Rev. **26**(1), 25–43 (1984)

15. Gildea, L.F.: The Relationship Between Elements of Quality, Dimensions of Culture and Performance in Manufacturing Companies Located in Inland Northwest. Faculty of the School of Conzaga University, Washington (1991)
16. Güngör, İ, Oruç, K.O.: Comparison of fuzzy data envelopment analysis models: for ordered and restricted fuzzy data. J. Alanya Faculty Bus. **1**(1), 17–32 (2009)
17. Guo, P., Tanaka, H.: Fuzzy DEA: a perceptual evaluation model. Fuzzy Sets Syst. **119**, 149160 (2001). https://doi.org/10.1016/S0165-0114(99)00106-2
18. Harrington, J.: Performance improvement: a total poor quality cost system. TQM Mag. **11**(4), 221–230 (1999)
19. Kenyon, G.N., ve Sen, K.C.: The Perception of Quality. Springer, Londra (2015)
20. Kianpour, K., Jusoh, A., Asghari, M.: Environmentally friendly as a new dimension of product quality. Int. J. Qual. Reliab. Manage. **31**(5), 547–565 (2014). https://doi.org/10.1108/IJQRM-06-2012-0079
21. Mahmood, S., Ahmed, S.M., Pahthi, K., Kureshi, N.I.: Determining the cost of poor quality and its impact on productivity and profitability. Build Env. Project Asset Manage. **4**(3), 296–311 (2014). https://doi.org/10.1108/BEPAM-09-2013-0034
22. Marbini, A.H., Saati, S., Tavana, M.: An ideal seeking fuzzy data envelopment analysis framework. Appl. Soft Comput. **10**, 1062–1070 (2010). https://doi.org/10.1016/j.asoc.2009.12.031
23. Oruç, K.O.: Efficiency measurements in fuzzy environment with data envelopment analysis and an application in universities. (Unpublished Doctoral thesis). Süleyman Demirel University/Institute of Social Sciences, Isparta
24. Oruç, K.O., Güngör, İ, Demiral, M.F.: Fuzzy data envelopment analysis application in measurement of universities. Selcuk Univ. J. Soc. Sci. Inst. **22**, 279–294 (2009)
25. Özdemir, A.: Advanced Research Methods and Applications in Management Science. Beta Edition, Istanbul (2016)
26. Shukla, M.K., Agrawal, P.C.: Impact of cost of poor quality in Indian automobile sector. Int. J. Eng. Res. Appl. **2**(2), 1297–1302 (2012). https://doi.org/10.1504/IJQET.2014.059842
27. Tütek, H., Gümüşoğlu, Ş, Özdemir, A.: Numerical Methods Managerial Approach. Istanbul, Beta (2012)
28. Waller, M.A., Ahire, W.S.: Management perception of the link between product quality and customers view of product quality. Int. J. Oper. Prod. Manage. **6** (9), 23–33 (1996)