

## EVALUATION OF EXCAVATOR TECHNOLOGIES: APPLICATION OF DATA FUSION BASED MULTIMOORA METHODS

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**Abstract.** Excavators are quite expensive vehicles. Therefore, there may be huge losses for decision makers if a wrong decision is made during the purchasing process. A good evaluation of excavator alternatives both reduces costs and increases the benefits the excavator for the purchaser. The aim of this study is to prioritise excavator technologies to help decision makers during the purchasing process and to apply three different “data fusion methods” instead of the “theory of dominance” of the original MULTIMOORA method. The MULTIMOORA method is composed of three methods, namely: the ratio analysis as a part of MOORA, Reference Point Theory (the reference point approach as a part of MOORA) and the Full Multiplicative Form. It is used to prioritise excavator technologies in this study. The MULTIMOORA method combines three results obtained from these three methods using the theory of dominance. Dominance directed graph, Rank position method and Borda count method as data fusion methods are also used to combine these three results instead of the “theory of dominance”. The results from this study show that there is no difference between the data fusion methods and the MULTIMOORA method can be applied to technology evaluation of the excavator alternatives successfully.

**Keywords:** excavator technologies, MULTIMOORA, dominance directed graph, rank position method, Borda count method, decision making.

### Introduction

Machinery and equipment selection is essential to firms in order to be successful in a business environment. The selection of unsuitable machinery negatively affects all aspects of business performance. This also leads to failure in meeting the requirements of the customers in terms of quality, time and cost. Therefore, the selection of the most suitable machine among alternatives increases firms' competitiveness.

The purchasing function has received considerable attention because it is vital in determining the survival and profitability of businesses (Bayazit *et al.* 2006). The process of buying a machine is complex and consists of many stages. In this process, different business managers try to determine the machine which will be bought with respect to certain criteria and to influence the selection decision based on their own selection priorities. They also consider different evaluation criteria with respect to whether they are buying a machine for the first time.

Selecting the best excavator technologies (in terms of criteria considered) is not easy since there are many criteria, and they can be quantitative or qualitative, with equipment characteristics judged as beneficial and non-

beneficial. The aim of the excavator selection process is to choose the option that reduces costs and increases benefits compared with alternative excavators.

In Turkey, ongoing urban renewal is increasing the demand for excavation equipment, and is making choosing the right equipment all the more important. Both domestic and foreign investors have begun to invest in the heavy equipment sector in Turkey due to its anticipated growth (Dunya newspaper 2014). On a project scale, the selection of the most suitable excavator – an essential vehicle in urban renewal – is important in order to obtain maximum efficiency and effectiveness. According to the Industry Directorate-General study (2010), in Turkey, 11,500 units of business machinery were sold in 2007, of which 3,830 were excavators.

Inappropriate excavator selection increases costs and decreases the benefits of the excavator for decision makers. This paper presents a real-life case study on the successful application of the MULTIMOORA method for the selection of excavator technologies. The MULTIMOORA method provides evaluation of technology alternatives from multiple perspectives. The major contribution of this paper is to extend different data fusion methods,

namely dominance directed graph, rank position method and the Borda count method, in conjunction with the MULTIMOORA method for excavator selection.

The MULTIMOORA method was introduced by Brauers and Zavadskas (2010). This method prioritises alternatives easily in the presence of cost and benefit criteria. It is composed of three methods: the ratio analysis as a part of MOORA, Reference Point Theory (the reference point approach as a part of MOORA) and the Full Multiplicative Form. The MULTIMOORA method combines three results obtained from these three methods using the theory of dominance. Instead of the theory of dominance in the original MULTIMOORA method, the dominance directed graph, rank position method and the Borda count method are also used to combine these three results in this paper.

## 1. Literature review

The research considered different criteria in the literature for the selection of excavator technologies. Among them, Cebesoy (1999) took into account bucket size, engine power, weight, breakout force, crowd force, speed, cut height, digging height, and digging depth for excavator selection using an improved quality comparison method. Soykan (2009) selected an excavator using conjoint analysis and considered walking system, scoop movement, catalogue language, scoop storage, and working load as criteria. In addition to these studies, Aykul *et al.* (2007) selected hydraulic excavator/truck and surface miner/truck combinations for highly selective excavation surface coal mining. Kirmanli and Ercelebi (2009) also developed an expert system for hydraulic excavators and truck selection in surface mining.

The MULTIMOORA method has been successfully applied in many fields, such as evaluation of the economy of the Belgian regions (Brauers, Ginevičius 2010), project management (Brauers, Zavadskas 2010; Brauers 2012), evaluation of Lithuania's position in the European Union (Baležentis *et al.* 2010), ranking heating losses in a building (Kracka *et al.* 2010), the selection of bank loans (Brauers, Zavadskas 2011a), selection of building elements for renovations important for energy savings (Brauers *et al.* 2012), evaluation of the construction sector in twenty European countries (Brauers *et al.* 2013), evaluation of public debt risk (Stankevičienė, Rosov 2013), ranking climate change mitigation policies in Lithuania (Streimikiene, Baležentis 2013), evaluation of the financial stability of commercial banks (Brauers *et al.* 2014) and special education and rehabilitation center selection (Özçelik *et al.* 2014). In addition to these studies, Brauers and Zavadskas (2012) provided information about the robustness of the MULTIMOORA method. A survey of the applications of the MULTIMOORA method can be found in T. Baležentis and A. Baležentis (2014).

The MULTIMOORA method is composed of the ratio analysis as a part of MOORA, Reference Point Theory (the reference point approach as part of MOORA)

and the Full Multiplicative Form. The MOORA method is applied in many different fields, such as materials selection (Karande, Chakraborty 2012), privatisation in a transition economy (Brauers, Zavadskas 2006), evaluation of inner climate (Kalibatas, Turskis 2008), assessment of road design alternatives (Brauers *et al.* 2008a), contractors' ranking (Brauers *et al.* 2008b), assessment of regional development in Lithuania (Brauers *et al.* 2010), evaluating contractors' alternatives in the facilities sector in Lithuania (Brauers, Zavadskas 2009), robustness in regional development in Lithuania (Brauers, Ginevičius 2009), decision-making in the manufacturing environment (Chakraborty 2011) and parametric optimisation of the milling process (Gadakh 2011). Galetakis *et al.* (2015) developed an expert system for the prediction of the performance of bucket-wheel excavators. In some studies, researchers focused on equipment selection for excavators. For example, Morley *et al.* (2013) used discrete event simulation for excavator hauler fleet selection; Qunzhang *et al.* (2011) proposed analytical hierarchy method for monitoring the parameters selection of the hydraulic system of an excavator. Wang *et al.* (2009) proposed a combined simulation and analysis to compare the performance of excavator types.

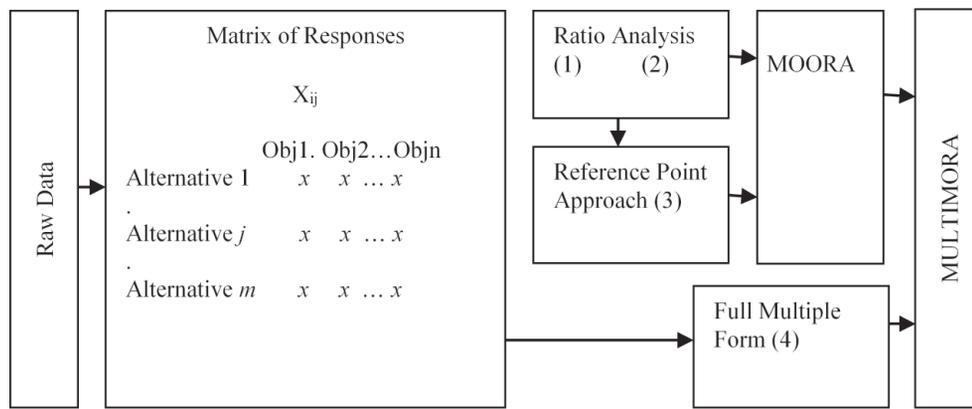
The combination of the MULTIMOORA method and other methods has been extensively documented in the literature; for example, the combination of the MULTIMOORA method and data envelopment analysis for multi-criteria assessment and comparison of farming efficiency (T. Baležentis, A. Baležentis 2011a), the combination of the MULTIMOORA method and data envelopment analysis for assessing the efficiency of the Lithuanian transport sector (T. Baležentis, A. Baležentis 2011b), the combination of the MULTIMOORA method and grey set theory for robot selection (Datta *et al.* 2013) and the combination of the MULTIMOORA method and interval value grey number sets for CNC machine tool evaluation (Sahu *et al.* 2014). Liu *et al.* (2014) proposed interval 2-tuple linguistic MULTIMOORA method for health-care waste treatment technology selection.

In the literature, the usage of the MULTIMOORA method is generally preferred if the presence of quantitative criteria is known and there is a possibility to construct the decision matrix easily. However, in this paper, the excavator selection problem is solved by group decision makers and according to the quantitative and qualitative criteria of the MULTIMOORA method. In addition, this is the first study that extends the original MULTIMOORA method using different data fusion methods, namely, Dominance directed graph, Rank position method and Borda count method.

## 2. Methods

### 2.1. MULTIMOORA

The MULTIMOORA is a relatively new multi-criteria decision making method consisting of three parts: the ratio analysis as a part of MOORA, Reference Point Theory



The number between brackets refers to the basic equation used for the related method. Details on the methods are given in the following.

Fig. 1. Diagram of MULTIMOORA (Brauers et al. 2012)

(the reference point approach as a part of MOORA) and the Full Multiplicative Form (T. Baležentis, A. Baležentis 2014). The MULTIMOORA method makes it a possible to increase the robustness of the results due to the aggregation of these approaches (Brauers, Zavadskas 2011b). In the MULTIMOORA method, the theory of dominance is proposed by Brauers and Zavadskas (2011a) to combine the results of these methods. Details on the theory of dominance can be found in Brauers and Zavadskas (2011a) and Brauers et al. (2012). The dominance directed graph, Rank position method and Borda count method are also used to obtain a ranking of alternatives. Figure 1 summarises the MULTIMOORA method.

2.1.1. The ratio analysis as a part of MOORA

The steps of the ratio analysis as a part of MOORA are given below in stepwise fashion.

Step 1: Construct the decision matrix of responses (see Fig. 1).

Step 2: Normalize the decision matrix by using Eqn (1):

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}}, \quad (1)$$

where:  $x_{ij}$  – response of alternative  $j$  on objective  $i$ ;  $j = 1, 2, \dots, m$ ;  $m$  is the number of alternatives;  $i = 1, 2, \dots, n$ ;  $n$  is the number of objectives.

Step 3: Calculate the final preference by using Eqn (2):

$$y_i^* = \sum_{i=1}^g x_{ij}^* - \sum_{i=g+1}^n x_{ij}^*, \quad (2)$$

where:  $i = 1, 2, \dots, g$  as the objectives to be maximized;  $i = g + 1, g + 2, \dots, n$  as the objectives to be minimized;  $y_j^*$  – the final preference for  $j^{\text{th}}$  alternative. Each alternative is sorted in descending order with respect to  $y_j^*$ .

2.1.2. The Reference Point Approach as a part of MOORA

The Reference Point Approach as a part of MOORA includes three steps and the first two steps are the same steps as the ratio analysis as a part of MOORA. The steps of the reference point approach as a part of MOORA are given below in a stepwise manner.

Step 1: Construct the decision matrix which shows the matrix of responses (see Fig. 1).

Step 2: Normalize the decision matrix by using Eqn (1).

Step 3: Calculate the reference point by using Eqn (3) and give a preference with respect to the result:

$$Z_i = \min(j) \{ \max(i) | r_i - x_{ij}^* | \}, \quad (3)$$

where:  $Z_j$  – the final preference for the  $j^{\text{th}}$  alternative;  $r_i$  – the  $i^{\text{th}}$  coordinate of the reference point in the normalized decision matrix.

If the objective should be maxima, we choose the highest value as  $r_i$  for related objective. On the other hand, we choose the lowest value as  $r_i$  for related objective, if the objective should be minimal. Herein, the lowest  $Z_i$  value shows the best alternative, while the highest  $Z_i$  value shows the worst alternative.

2.1.3. The Full Multiplicative Form for Multi-Objectives

The Full Multiplicative Form for Multi-Objectives includes two steps, the first of which is that same as the first step of MOORA (both Ratio Analysis and Reference Point Approach). The steps of the full multiplicative form for multi-objectives are given as follows in a stepwise manner.

Step 1: Construct the decision matrix of responses (see Fig. 1).

Step 2: Calculate the overall utilities ( $U_j$ ) by using Eqn (4):

$$U_j = \prod_{i=1}^n x_{ij}. \quad (4)$$

If some objectives are to be maximized and others are to be minimized, we combine these objectives by using Eqn (4’):

$$U'_j = \frac{A_j}{B_j} \tag{4'}$$

$U'_j$  shows the value of the utility of alternative  $j$  with the objectives to be maximized and objectives to be minimized with:

$$A_j = \prod_{g=1}^i X_{gj}, \tag{5}$$

$j = 1, 2, \dots, m$  is the number of alternatives and  $i$  is the number of objectives to be maximized with:

$$B_j = \prod_{k=i+1}^n X_{kj}, \tag{6}$$

$n-i$  is the number of objectives to be minimized.

**2.2. Data fusion methods**

The aim of data fusion methods is to merge results obtained from the different resources. Data fusion methods are extensively used in the literature for the information retrieval system. However, in addition to utilising the theory of dominance proposed by Brauers and Zavadskas (2011a) in the original MULTIMOORA method, the dominance directed graph, the rank position method and the broad count method are also used in this study to merge the results of the ratio analysis part of MOORA, the reference point approach part of MOORA and the full multiplicative form for multi-objectives.

*2.2.1. The dominance directed graph*

The dominance directed graph is known as a tournaments because each ranking obtained from the three methods can be considered to be a tournament. In addition, each alternative (excavator technology) can also be considered a team. In the dominance directed graph, Team A can dominate Team B or vice versa, but not both. The vertex matrix ( $M = [m_{ij}]$ ) of each tournament should be constructed. If Team A dominates Team B,  $m_{AB}$  is equal to 1, otherwise 0. Matrix M shows the dominance relation among alternatives for a tournament. Subsequently,  $M^2$  is calculated and then  $A = M + M^2$ . The row sums of A show its preference. The highest value of the row sums is the best alternative, while the lowest value is the worst alternative. In this study, the sum of each row obtained by each method for each excavator technology is summed for the final ranking.

*2.2.2. The rank position method*

The rank position method, which is also named the reciprocal rank method, considers the current position of each alternative with respect to each method. The following formula shows the rank position score ( $r$ ) for each alternative, and is used to obtain final ranking. The highest value of the rank position score is the worst alternative and the lowest value is the best alternative:

$$r(d_i) = 1 / (\sum_j 1/ \text{position } d_{ij}) \text{ for all } (j), \tag{7}$$

$k$  – number of results obtained from the methods,  $j = 1, \dots, k$ ;  $p$  – number of alternatives,  $i = 1, \dots, p$ .

In this paper,  $k = 3$  (the results of the ratio analysis part of MOORA, the reference point approach part of MOORA and the full multiplicative form for multi-objectives) and  $p = 13$  (the number of excavator technologies).

An example can be given to show how the rank position method works. There are only two possible ways, which equal to  $k$ , to sort the alternatives with respect to their priorities. Each possible way is denoted A and B. There are four alternatives ( $p$ ), namely  $x, y, z, t$ . The ranking lists are given as follows:

$$A = (x, y, t, z);$$

$$B = (t, x, y, z).$$

The computation of rank position of each alternative is given as follows:

$$r(x) = 1 / (1 + 1/2) = 0.67;$$

$$r(y) = 1 / (1/2 + 1/3) = 1.2;$$

$$r(z) = 1 / (1/4 + 1/4) = 2;$$

$$r(t) = 1 / (1/3 + 1) = 0.75.$$

Hence, the final ranked list of the alternatives is:  $x > t > y > z$ .

*2.2.3. The broad count method*

The broad count method is a simple and effective method (Erp, Schomaker 2000) and does not require any training to combine the rankings (Ruta, Gabrys 2000). The number of alternatives is equal to the number of votes in the method. The highest ranked alternative (in a p-way vote) gets p votes and each subsequent alternative gets one vote less (Nuray, Can 2006). The Broad Count (BC) value is calculated by summing the votes given to each alternative in each method. The final broad score is calculated by the aggregation of each of the individual scores, which denoted by  $BC(i)$  (Moreira 2011).  $BC(i)$  shows the BC value of  $i^{\text{th}}$  alternative. The highest BC value is the best alternative and the lowest value is the worst alternative in the method. Some examples for the introduction of the method can be found in Nuray (2003), Nuray and Can (2006), Bozkur et al. (2007) and Moreira (2011).

The computation of broad count method is presented in the following by considering the previous small example:

$$BC(x) = 4 + 3 = 7;$$

$$BC(y) = 3 + 2 = 5;$$

$$BC(z) = 1 + 1 = 2;$$

$$BC(t) = 2 + 4 = 6.$$

Therefore, the final ranked list of the alternatives is  $x > t > y > z$ . Table 1 summarizes all methods.

Table 1. A summary of all method

No	Method	Formula
1	The Ratio Analysis as a part of MOORA (as a first part of the MULTIMOORA)	$y_i^* = \sum_{i=1}^g x_{ij}^* - \sum_{i=g+1}^n x_{ij}^*$
2	The Reference Point Approach as a part of MOORA (as a second part of the MULTIMOORA)	$Z_i = \min(j) \{ \max(i)   r_i - x_{ij}^*   \}$
3	The Full Multiplicative Form for Multi-Objectives (as a third part of the MULTIMOORA)	$U'_j = \frac{A_j}{B_j}$
4	The dominance directed graph	$A = M + M^2$
5	The rank position method	$r(d_j) = 1 / (\sum_j 1 / \text{position } d_{ij}) \text{ for all } (j)$
6	The broad count method	$BC(i)$

### 3. Application of the proposed method for evaluating excavator alternatives

At the beginning of the study, the construction companies within Bayburt Trade and Industry Cooperation in Turkey were determined. Interviews were carried out with the heads of the companies, and one company was expected to buy an excavator in the near future. Decision makers in the company stated that they would purchase an excavator weighs about 25–30 tonnes with crawler. Subsequently, 13 alternatives meeting the requirements of the decision makers were identified from seven different brands. Then, the factors influencing the excavator choice were analysed through a review of the literature. To find criteria apart from those in the related literature concerning the excavator selection process, the opinions of marketing managers who work in excavator firms were surveyed via e-mail. Eleven quantitative criteria (five beneficial criteria and six non-beneficial criteria) and seven qualitative criteria (all of them beneficial) were determined for the excavator selection.

Some selection criteria were deemed to be missing from the catalogues for quantitative criteria. The sales representatives of the branches of all the brands were called to determine the missing quantitative criteria. A questionnaire was administered to the decision makers group with the aim of measuring their evaluations for qualitative criteria with regard to the 18 criteria and seven brands determined through the literature reviews and the interviews with the marketing managers. All studies up to that point included the stages of problem identification and organising the data. The data obtained subsequently were analysed by using the original MULTIMOORA method. In the final part of the study, alternatives were placed in order using the dominance directed graph, the rank position method, and the Borda count method adjusted MULTIMOORA methods. All these studies, including application, analysis and evaluation, are summarised in Figure 2. Figure 3 presents the hierarchical decision model for the evaluation of excavator technologies.

### 3.1. Criteria

In the literature, researchers use objective (quantitative) criteria only for examining excavator technologies. However, Chernatony and McDonald (2003) indicate that both objective and subjective issues have an impact on the decision makers. In addition, there may be some criteria that should be minimized, while others maximised. Therefore, we tried to determine the criteria affecting the excavator selection process based on the above mentioned lines. Firstly, some criteria were determined by reviewing the related literature. To find criteria apart from those in the related literature that affect the excavator selection process, an e-mail survey was conducted to gather the opinions of marketing managers who work in excavator firms. It should be noted that selected excavator firms are members of the Turkey Construction Machinery Manufacturers and Distributors Association. Finally, the literature review and interviews suggested 11 quantitative criteria (five beneficial criteria and six non-beneficial criteria) and seven qualitative criteria (all of them beneficial criteria) for this study. Criteria and objectives of excavator models are given in Table 2. If there are different units in different multiple objectives, this makes optimisation difficult (Brauwers, Ginevičius 2013). In this study, qualitative criteria were measured via a survey study using a five point Likert scale (1 = “not at all” and 5 = “to a great extent”) except for the “brand experience” criteria. We measured brand experience by conducting a survey, as well as asking decision makers to use a scale between 1 and 3 with respect to their experiences (1 = “negative”, 2 = “no idea” and 3 = “positive”):

- Motor power ( $X_1$ ): There are different excavator models with respect to their motor power. Motor power is an important criterion in terms of the usage area of the excavator and the aim of its usage. Motor power ranges from 93 hp to 464 hp.
- Bucket size ( $X_2$ ): Bucket size is one of the criteria that show excavator capacity. There are different excavator models with respect to bucket size which range from 0.19 m<sup>3</sup> to 6.6 m<sup>3</sup>.

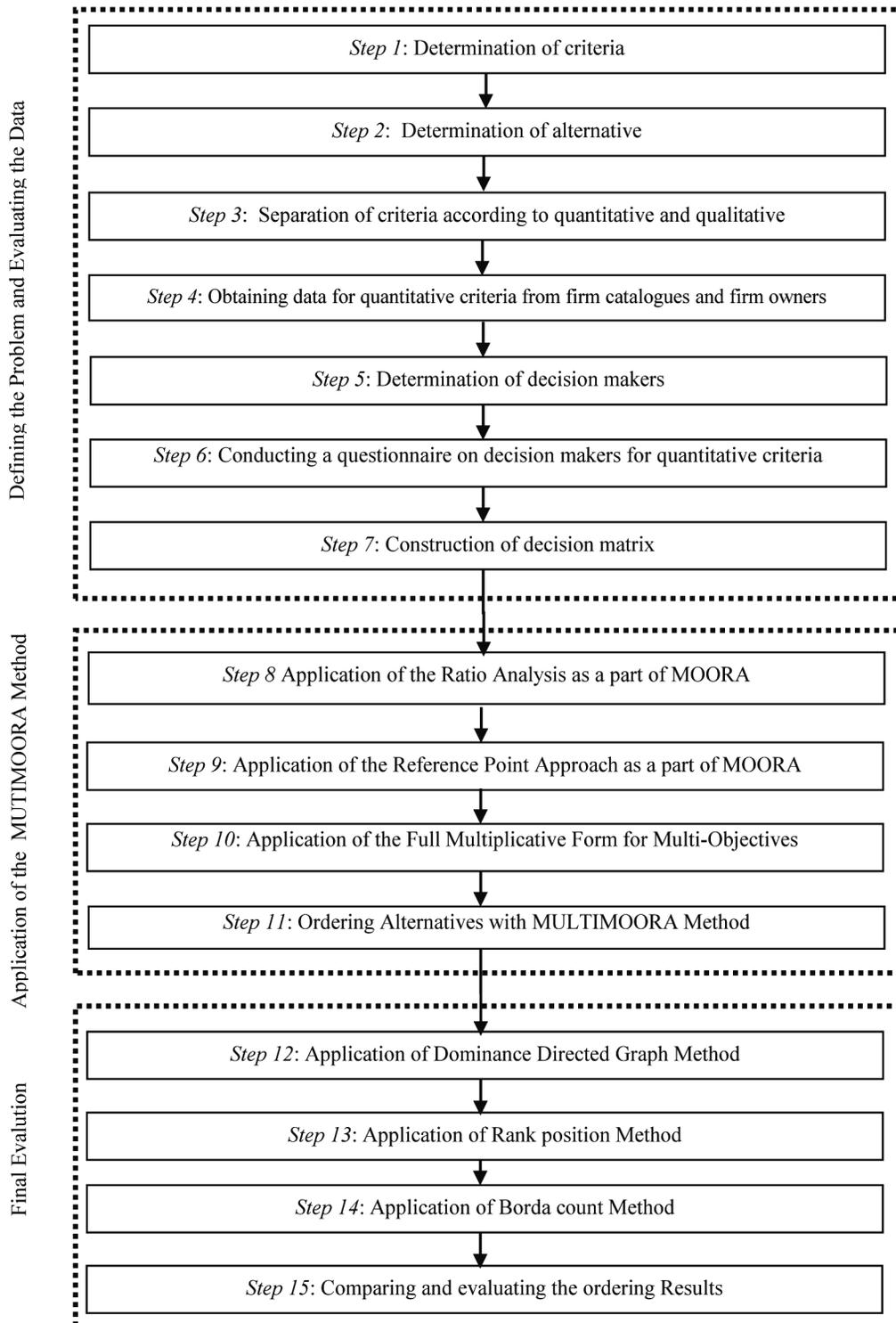


Fig. 2. Application steps

Table 2. Criteria and objectives of excavator technologies

Attributes	Units of measurement	max/min
Motor power ( $X_1$ )	horse power	max
Bucket size ( $X_2$ )	m <sup>3</sup>	max
Language of product catalogue ( $X_3$ )	Turkish / English	max
Lead time ( $X_4$ )	days	min
Cutting Height ( $X_5$ )	mm	max
Digging Depth ( $X_6$ )	mm	max
References ( $X_7$ )*	–	max
Country of origin ( $X_8$ )*	–	max
Product reliability ( $X_9$ )*	–	max
Company reputation ( $X_{10}$ )*	–	max
Easiness of selling in the second-hand market ( $X_{11}$ )*	–	max
Brand confidence ( $X_{12}$ )*	–	max
Brand experience ( $X_{13}$ )*	–	max
Purchasing price ( $X_{14}$ )	Dollar	min
Hydraulic oil consumption ( $X_{15}$ )	liter/hour	min
Engine oil consumption ( $X_{16}$ )	liter/hour	min
Cab comfort ( $X_{17}$ )	dba	min
Fuel consumption ( $X_{18}$ )	liter/hour	min

Note: \*The attribute is measured by scale between 1 and 5 via survey study.

- Language of product catalogue ( $X_3$ ): Soykan (2009) emphasises that the decision makers prefer the language of the product catalogue for excavators to be in both Turkish and English. However, parts of the product catalogue may be written in only one language, i.e. Turkish or English. We use a three-point scale (1 – English language, 2 – Turkish language, 3 – both English and Turkish language).
- Lead time ( $X_4$ ): Decision makers expect a short lead time. If the lead time is high for one excavator model, this negatively affects the company. Delivery speed and timely deliveries affect the decision as to which excavator to purchase.
- Cutting Height ( $X_5$ ): Decision makers want to buy an excavator that has a high cutting height due to the fact that this provides high work capacity. It enables the performance of high jobs with less movement, especially in road works.
- Digging Depth ( $X_6$ ): Digging depth is quite important when the excavator works on infrastructure. Therefore, decision makers prefer an excavator with greater digging depth.
- References ( $X_7$ ): References are indicative of the supplier's relationships with its existing customers that can be used to evaluate the supplier's product or service, management and cooperation performance (Salminen 2001). Customer references can also be considered important marketing tools for companies (Jalkala, Salminen 2009). Ruokolainen and Igel (2004) indicate that the references can be more important than price, delivery capability, or new technological features.
- Country of origin ( $X_8$ ): Negative perceptions of the product's country of origin can affect buyers' perceptions towards that product (Samiee 1994). For example, Gdm and Kavas (1996) researched the Turkish industrial purchasing managers' perceptions of foreign and national industrial suppliers. The results of their study indicate that the managers in Turkey prefer German and Japanese suppliers to US and national suppliers. Therefore, decision makers' perceptions related to country of origin affect the buying decision. Details on the studies related to country of origin criteria can be found in review studies (Al-Sulaiti, Baker 1998; Dinnie 2004).
- Product reliability ( $X_9$ ): Product reliability attracts increasing attention from manufacturers as this is a vital factor in a competitive world (Jiang *et al.* 2010). Murthy *et al.* (2008) give the following definition: "product reliability conveys the concept of dependability, successful operation of performance and the absence of failures". Homburg and Rudolph (2001) emphasise that product reliability is one of the satisfaction criteria related to product dimension.
- Company reputation ( $X_{10}$ ): Reputation addresses the image of the company to all its constituents, including investors (Mudambi 2002). The company's reputation has a strong influence on buying decisions in many business markets (Cretu, Brodie 2007). A buyer's expectation is also affected by a company's

- reputation and its service offering information (Yoon et al. 1993).
- Easiness of selling in the second-hand market ( $X_{11}$ ): Second-hand products have previously been used by an end user or consumer (Mehrabad et al. 2010). Decision makers prefer excavators that are easier to re-sell in the second-hand market. Baykasoğlu et al. (2012) also addressed the truck selection problem by considering the “easiness of selling in the second-hand market” criteria.
  - Brand confidence ( $X_{12}$ ): There are many brands of excavator. During the purchasing process, the buyer considers the brand confidence to decrease the possibility of defects related to the product in the future.
  - Brand experience ( $X_{13}$ ): Brand experience is a new consumer psychology concept (Brakus et al. 2012). Brakus et al. (2009) defined brand experiences as “subjective, internal consumer responses (sensations, feelings and cognitions) as well as behavioral responses evoked by brand-related stimuli that are part of a brand’s design and identity, packaging, communications and environments”.
  - Purchasing price ( $X_{14}$ ): One of the key factors affecting the purchasing decision is total price. Stock (2005) defined purchasing price as the actual price paid by a customer, including all of the costs. Decision makers want to buy the cheapest excavator that meets their requirements.
  - Hydraulic oil consumption ( $X_{15}$ ): Many thousands of litres of hydraulic oil are consumed for the operation of an excavator. The hydraulic oil pan must be refilled when it becomes empty, which is costly. Therefore, decision makers want to buy an excavator that consumes the least amount of hydraulic oil per hour.
  - Engine oil consumption ( $X_{16}$ ): Engine oils reduce wear by reducing friction between moving parts. Engine oil consumption for an excavator may be high depending upon the amount of usage. Therefore, decision makers want to select an excavator that consumes the least amount of engine oil per hour during its operation.
  - Cab comfort ( $X_{17}$ ): Cab comfort affects operator fatigue and efficiency directly. The excavator cab should have sound absorption properties, a wide viewing angle, air conditioning and an ergonomic design. These factors influence decision makers and the decision to buy.
  - Fuel consumption ( $X_{18}$ ): Fuel for vehicles can be considered one of the most important criteria currently. Decision makers prefer to buy an excavator which consumes less fuel, especially due to the higher cost of fuel in Turkey.

As can be seen from Table 1, there are 12 criteria that should be maximised while the others are minimised. These 12 criteria are called as beneficial criteria. This

means that the outcome of these criteria is desired to be as high as possible by decision makers to increase the work capacity and efficiency of an excavator. For example, the language of the product catalogue ( $X_3$ ) is preferred to be both in Turkish and English by decision makers. A three-point scale (1 – English language, 2 – Turkish language, 3 – both English and Turkish language) is used to measure this criterion and high outcome for an excavator alternative indicates that this meets the standard of the decision maker with respect to  $X_3$  criterion. In addition, the value of References ( $X_7$ ) and Country of origin ( $X_8$ ) are beneficial criteria and they are measured by a scale in between 1 and 5 via survey study. Similar to  $X_3$  criterion, the outcome of  $X_7$  and  $X_8$  criteria are desired to be as high as possible due to these being beneficial criteria. If a decision-maker marked “5” for an excavator alternative in the survey study for  $X_7$  criterion, this means that customers have a good perception in the market for the excavator alternative and it meets the standard of the decision – maker with respect to  $X_3$  criterion. Similarly, a decision-maker can mark “1” or “2” for an excavator alternative in the survey study for  $X_8$  criterion if he/she has negative perceptions of the product’s country of origin. Decision-makers want to buy an excavator that has high values for beneficial criteria and less value for non-beneficial criteria.

### 3.2. Results

Table 3 presents the matrix of responses of alternatives on objectives. Based on this matrix as an input, the ranking of the 13 excavator technologies according to the two parts of MOORA, namely, the ratio analysis and the reference point approach, and the full multiplicative form are performed. Details on the calculation of the two parts of MOORA can be found in Tables 7–10 in Appendix A. In addition, Table 11, which is presented in Appendix B, includes the calculation of the full multiplicative form for multi-objectives. Furthermore, Appendix C, which is composed of Tables 12–14, gives the details of the dominance directed graph calculation. Table 4 shows the ranking by the dominance directed graph based the MULTIMOORA method. Table 5 presents ranking by rank position based the MULTIMOORA method and Borda count method based on the MULTIMOORA method, and Table 6 gives the original MULTIMOORA result for excavator technologies. As can be seen in Tables 4, 5 and 6, the ranking of excavators according to the original MULTIMOORA and data fusion methods based MULTIMOORA methods have the same ranking (P – preferred to): **E3 -P- E8 -P- E11 -P- E9 -P- E2 -P- E1 -P- E13 -P- E10 -P- E12 -P- E5 -P- E7 -P- E4 -P- E6**. The results from this study show that there is no difference between the data fusion methods and the MULTIMORA method can be applied to an excavator selection problem successfully. Excavator 3 (E3) can be recommended to the firm since it ranked first in all results.

Table 3. Matrix of responses of alternatives on objectives:  $(x_{ij})$

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>	X <sub>9</sub>	X <sub>10</sub>	X <sub>11</sub>	X <sub>12</sub>	X <sub>13</sub>	X <sub>14</sub>	X <sub>15</sub>	X <sub>16</sub>	X <sub>17</sub>	X <sub>18</sub>
E1	169	1.61	1	6	11575	6655	5	5	5	4.6	3.6	5	2.6	224941.86	750.00	30	75	18
E2	202	1.70	2	1	14890	14210	3	2.2	3	3.8	3.8	4	2	184043.34	925.00	38	74	18
E3	177	1.50	3	1	10290	7290	4.6	5	4.6	5	4.6	5	2.6	208582.45	700.00	27	70	20
E4	227	1.85	1	15	1140	7790	3	3.2	2.2	4	4.2	4.2	2.6	181440.00	640.00	24	70	21
E5	230	1.85	1	15	11400	8090	3	3.2	2.2	4	4.2	4.2	2.6	147960.00	330.00	24	70	21
E6	197	1.80	1	20	1069	723	4.4	4.4	4	4.2	2.8	4.2	3	170410.50	301.25	22	74	21
E7	216	1.80	1	20	11261	7619	4.4	4.4	4	4.2	2.8	4.2	3	193586.32	181.25	38	74	21
E8	188	1.60	2	10	10130	6940	4.4	5	4.8	4.6	3.6	4.6	2.6	190331.18	330.00	23	74	18
E9	179	1.40	2	10	10000	6920	4.4	5	4.8	4.6	3.6	4.6	2.6	215708.66	337.50	23	74	21
E10	180	1.80	1	5	10730	7600	4.4	3.4	4.8	4.2	3.2	4.2	2.6	159504.22	800.00	32	73	17
E11	170	1.80	1	5	18207	14347	4.4	3.4	4.8	4.2	3.2	4.2	2.6	179953.48	320.00	30	71	22
E12	192	2.10	1	5	11650	7580	4.4	3.4	4.8	4.2	3.2	4.2	2.6	170410.50	1000.00	32	73	17
E13	195	1.40	1	5	10700	7300	4.4	3.4	4.8	4.2	3.2	4.2	2.6	197676.18	400	30	71	22

Table 4. Ranking by Dominance directed graph

	Ratio analysis	Reference point approach	Full multiplicative form	Sum	Rank
E1	36	36	28	100	<b>6</b>
E2	28	45	45	118	<b>5</b>
E3	80	66	78	224	<b>1</b>
E4	0	3	1	4	<b>12</b>
E5	6	10	3	19	<b>10</b>
E6	1	1	0	2	<b>13</b>
E7	3	0	6	9	<b>11</b>
E8	68	78	55	201	<b>2</b>
E9	56	55	36	147	<b>4</b>
E10	15	15	10	40	<b>8</b>
E11	68	28	66	162	<b>3</b>
E12	10	6	15	31	<b>9</b>
E13	21	21	21	63	<b>7</b>

Table 5. Ranking by Rank position and Borda count methods

	Rank position method		Borda count method	
	r(d <sub>i</sub> )	Rank	BC(i)	Rank
E1	1.76	<b>6</b>	26	<b>6</b>
E2	1.50	<b>5</b>	28	<b>5</b>
E3	0.40	<b>1</b>	38	<b>1</b>
E4	3.98	<b>12</b>	6	<b>12</b>
E5	3.31	<b>10</b>	12	<b>10</b>
E6	4.11	<b>13</b>	5	<b>13</b>
E7	3.73	<b>11</b>	8	<b>11</b>
E8	0.60	<b>2</b>	35	<b>2</b>
E9	1.28	<b>4</b>	30	<b>4</b>
E10	2.77	<b>8</b>	17	<b>8</b>
E11	0.86	<b>3</b>	32	<b>3</b>
E12	2.98	<b>9</b>	15	<b>9</b>
E13	2.33	<b>7</b>	21	<b>7</b>

Table 6. The original MULTIMOORA results for excavator models

	Ratio analysis	Reference point approach	Full multiplicative form	MULTIMOORA
E1	5	5	6	<b>6</b>
E2	6	4	4	<b>5</b>
E3	1	2	1	<b>1</b>
E4	13	11	12	<b>12</b>
E5	10	9	11	<b>10</b>
E6	12	12	13	<b>13</b>
E7	11	13	10	<b>11</b>
E8	3	1	3	<b>2</b>
E9	4	3	5	<b>4</b>
E10	8	8	9	<b>8</b>
E11	2	6	2	<b>3</b>
E12	9	10	8	<b>9</b>
E13	7	7	7	<b>7</b>

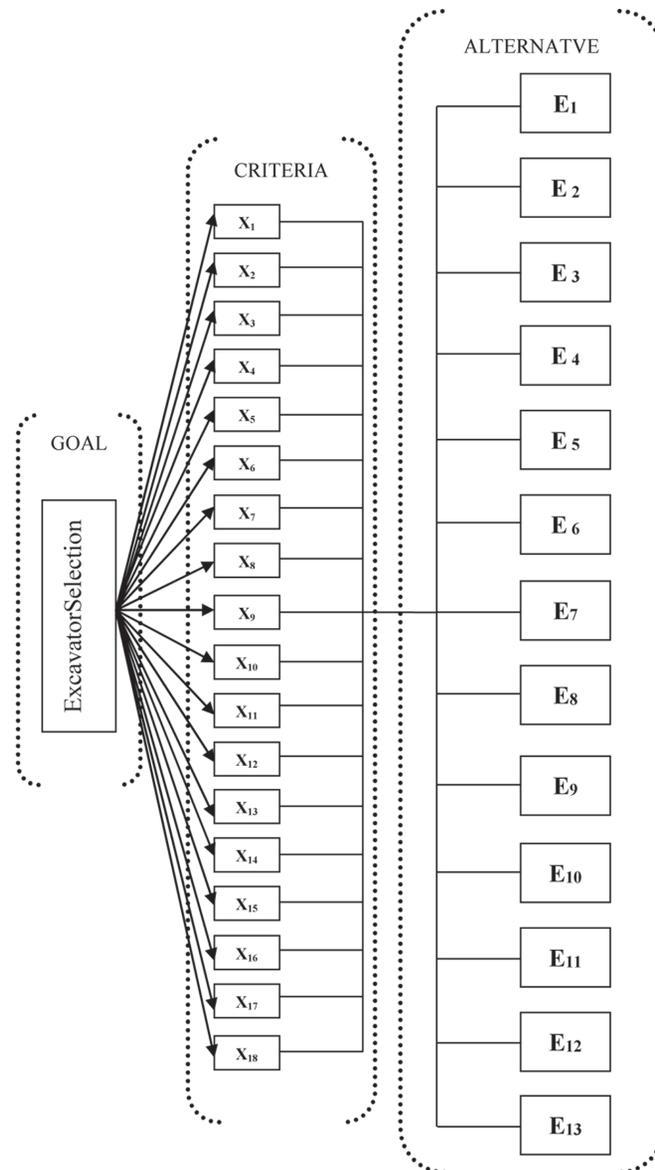


Fig. 3. Hierarchy for excavator technologies evaluation

## Conclusions

Excavators are very important vehicles for business and construction machinery. The selection of the right excavator technology with respect to considered criteria for a firm provides many benefits, such as maximum efficiency, effectiveness and long economic life. Thirteen excavator technologies, which met the requirements of the decision makers, were ranked in this study according to 18 criteria by using the MULTIMOORA method. These included qualitative, quantitative, beneficial and non-beneficial criteria. There are three reasons for the selection of the MULTIMOORA method. First, its robustness is emphasised in the literature. Second, it considers qualitative, quantitative, beneficial and non-beneficial criteria at the same time. Third, it provides the decision makers with a means to assess the technologies through multiple perspectives.

The MULTIMOORA method uses the theory of dominance to combine the result of the ratio analysis as part of MOORA, Reference Point Theory (the reference point approach as part of MOORA) and the Full Multiplicative Form. In this study, the dominance directed graph, the rank position method and the Borda count method as data fusion methods are also used to combine these three results instead of the theory of dominance. The results show that there is no difference between the data fusion adjusted MULTIMOORA methods and the original MULTIMOORA method. In this study, the MULTIMOORA with the dominance theory is not beaten by other data fusion methods, namely dominance directed graph, rank position method and Borda count method for the evaluation of excavator technologies.

It should be noted that there may be equivalence for some alternatives based on the results of the broad count method. For example, there is equivalence for “*t*” and “*y*” if we consider these two ranking list, namely  $(x, y, z, t)$  and  $(t, x, y, z)$ . There are many different criteria for the excavator selection. Most commonly used criteria, which are defined by both reviewing the related literature and marketing managers who work in excavator firms in this paper, are taken into account in the technology evaluation process. More technical criteria such as “breakout force” and “crowd force” can also be considered for evaluation of excavator technology.

For future research, sensitivity analyses can be conducted to examine the best alternative with respect to different criteria values for each alternative technology. In addition, application of the other data fusion methods, such as concordant method and logistic regression, can be conducted. Finally, the importance of the criteria can be taken into account in the evaluation process.

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Appendix A

Table 7. Sum of squares and their square roots

	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$	$X_{11}$	$X_{12}$	$X_{13}$	$X_{14}$	$X_{15}$	$X_{16}$	$X_{17}$	$X_{18}$
<b>E1</b>	28561	2.59	1	36	133980625	44289025	25	25	25	21.16	12.96	25	6.76	50598840380.26	562500	900	5625	324
<b>E2</b>	40804	2.89	4	1	221712100	201924100	9	4.84	9	14.44	14.44	16	4	33871950998.36	855625	1444	5476	324
<b>E3</b>	31329	2.25	9	1	105884100	53144100	21.16	25	21.16	25	21.16	25	6.76	43506638448.00	490000	729	4900	400
<b>E4</b>	51529	3.42	1	225	1299600	60684100	9	10.24	4.84	16	17.64	17.64	6.76	32920473600.00	409600	576	4900	441
<b>E5</b>	52900	3.42	1	225	129960000	65448100	9	10.24	4.84	16	17.64	17.64	6.76	21892161600.00	108900	576	4900	441
<b>E6</b>	38809	3.24	1	400	1142761	522729	19.36	19.36	16	17.64	7.84	17.64	9	29039738510.25	90751.5625	462.25	5476	441
<b>E7</b>	46656	3.24	1	400	126810121	58049161	19.36	19.36	16	17.64	7.84	17.64	9	37475663291.14	32851.5625	1444	5476	441
<b>E8</b>	35344	2.56	4	100	102616900	48163600	19.36	25	23.04	21.16	12.96	21.16	6.76	36225956557.54	108900	533.61	5476	324
<b>E9</b>	32041	1.96	4	100	100000000	47886400	19.36	25	23.04	21.16	12.96	21.16	6.76	46530225999.00	113906.25	533.61	5476	441
<b>E10</b>	32400	3.24	1	25	115132900	57760000	19.36	11.56	23.04	17.64	10.24	17.64	6.76	25441596197.81	640000	1024	5329	289
<b>E11</b>	28900	3.24	1	25	331494849	205836409	19.36	11.56	23.04	17.64	10.24	17.64	6.76	32383254964.11	102400	900	5041	484
<b>E12</b>	36864	4.41	1	25	135722500	57456400	19.36	11.56	23.04	17.64	10.24	17.64	6.76	29039738510.25	1000000	1024	5329	289
<b>E13</b>	38025	1.96	1	25	114490000	53290000	19.36	11.56	23.04	17.64	10.24	17.64	6.76	39075872139.39	160000	900	5041	484
Sum of squares	494162	38.43	30	1588	1620246456	954454124	228.04	210.28	235.08	240.76	166.4	249.44	89.6	458002111196.11	4675434.375	11046.47	68445	5123
Square roots	702.97	6.20	5.48	39.85	40252.29	30894.24	15.10	14.50	15.33	15.52	12.90	15.79	9.47	676758.53	2162.28	105.10	261.62	71.58

Table 8. Objectives divided by their square roots and ranking of alternatives for the ratio analysis as a part of MOORA

	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$	$X_{11}$	$X_{12}$	$X_{13}$	$X_{14}$	$X_{15}$	$X_{16}$	$X_{17}$	$X_{18}$	$Y_i$	Rank
E1	0.240	0.260	0.183	0.151	0.288	0.215	0.331	0.345	0.326	0.296	0.279	0.317	0.275	0.332	0.347	0.285	0.287	0.251	1.701	5
E2	0.287	0.274	0.365	0.025	0.370	0.460	0.199	0.152	0.196	0.245	0.295	0.253	0.211	0.272	0.428	0.362	0.283	0.251	1.686	6
E3	0.252	0.242	0.548	0.025	0.256	0.236	0.305	0.345	0.300	0.322	0.357	0.317	0.275	0.308	0.324	0.257	0.268	0.279	2.292	1
E4	0.323	0.298	0.183	0.376	0.028	0.252	0.199	0.221	0.143	0.258	0.326	0.266	0.275	0.268	0.296	0.228	0.268	0.293	1.041	13
E5	0.327	0.298	0.183	0.376	0.283	0.262	0.199	0.221	0.143	0.258	0.326	0.266	0.275	0.219	0.153	0.228	0.268	0.293	1.503	10
E6	0.280	0.290	0.183	0.502	0.027	0.023	0.291	0.303	0.261	0.271	0.217	0.266	0.317	0.252	0.139	0.205	0.283	0.293	1.056	12
E7	0.307	0.290	0.183	0.502	0.280	0.247	0.291	0.303	0.261	0.271	0.217	0.266	0.317	0.286	0.084	0.362	0.283	0.293	1.423	11
E8	0.267	0.258	0.365	0.251	0.252	0.225	0.291	0.345	0.313	0.296	0.279	0.291	0.275	0.281	0.153	0.220	0.283	0.251	2.019	3
E9	0.255	0.226	0.365	0.251	0.248	0.224	0.291	0.345	0.313	0.296	0.279	0.291	0.275	0.319	0.156	0.220	0.283	0.293	1.887	4
E10	0.256	0.290	0.183	0.125	0.267	0.246	0.291	0.234	0.313	0.271	0.248	0.266	0.275	0.236	0.370	0.304	0.279	0.238	1.588	8
E11	0.242	0.290	0.183	0.125	0.452	0.464	0.291	0.234	0.313	0.271	0.248	0.266	0.275	0.266	0.148	0.285	0.271	0.307	2.126	2
E12	0.273	0.339	0.183	0.125	0.289	0.245	0.291	0.234	0.313	0.271	0.248	0.266	0.275	0.252	0.462	0.304	0.279	0.238	1.567	9
E13	0.277	0.226	0.183	0.125	0.266	0.236	0.291	0.234	0.313	0.271	0.248	0.266	0.275	0.292	0.185	0.285	0.271	0.307	1.619	7

Table 9. The reference point in the normalized the decision matrix

	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$	$X_{11}$	$X_{12}$	$X_{13}$	$X_{14}$	$X_{15}$	$X_{16}$	$X_{17}$	$X_{18}$
$r_i$	0.327	0.339	0.548	0.025	0.452	0.464	0.331	0.345	0.326	0.322	0.357	0.317	0.317	0.219	0.084	0.205	0.268	0.238

Table 10. Deviations from the reference point and ranking of alternatives for the reference point approach as a part of MOORA

	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$	$X_{11}$	$X_{12}$	$X_{13}$	$X_{14}$	$X_{15}$	$X_{16}$	$X_{17}$	$X_{18}$	max	Rank ( $Z_i$ ) min
E1	0.087	0.079	0.365	0.125	0.165	0.249	0.000	0.000	0.000	0.026	0.078	0.000	0.042	0.114	0.263	0.081	0.019	0.014	0.365	5
E2	0.040	0.065	0.183	0.000	0.082	0.004	0.132	0.193	0.130	0.077	0.062	0.063	0.106	0.053	0.344	0.157	0.015	0.014	0.344	4
E3	0.075	0.097	0.000	0.000	0.197	0.228	0.026	0.000	0.026	0.000	0.000	0.000	0.042	0.090	0.240	0.052	0.000	0.042	0.240	2
E4	0.004	0.040	0.365	0.351	0.424	0.212	0.132	0.124	0.183	0.064	0.031	0.051	0.042	0.049	0.212	0.024	0.000	0.056	0.424	11
E5	0.000	0.040	0.365	0.351	0.169	0.203	0.132	0.124	0.183	0.064	0.031	0.051	0.042	0.000	0.069	0.024	0.000	0.056	0.365	9
E6	0.047	0.048	0.365	0.477	0.426	0.441	0.040	0.041	0.065	0.052	0.140	0.051	0.000	0.033	0.055	0.000	0.015	0.056	0.477	12
E7	0.020	0.048	0.365	0.477	0.173	0.218	0.040	0.041	0.065	0.052	0.140	0.051	0.000	0.067	0.000	0.157	0.015	0.056	0.477	13
E8	0.060	0.081	0.183	0.226	0.201	0.240	0.040	0.000	0.013	0.026	0.078	0.025	0.042	0.063	0.069	0.015	0.015	0.014	0.240	1
E9	0.073	0.113	0.183	0.226	0.204	0.240	0.040	0.000	0.013	0.026	0.078	0.025	0.042	0.100	0.072	0.015	0.015	0.056	0.240	3
E10	0.071	0.048	0.365	0.100	0.186	0.218	0.040	0.110	0.013	0.052	0.109	0.051	0.042	0.017	0.286	0.100	0.011	0.000	0.365	8
E11	0.085	0.048	0.365	0.100	0.000	0.000	0.040	0.110	0.013	0.052	0.109	0.051	0.042	0.047	0.064	0.081	0.004	0.070	0.365	6
E12	0.054	0.000	0.365	0.100	0.163	0.219	0.040	0.110	0.013	0.052	0.109	0.051	0.042	0.033	0.379	0.100	0.011	0.000	0.379	10
E13	0.050	0.113	0.365	0.100	0.186	0.228	0.040	0.110	0.013	0.052	0.109	0.051	0.042	0.073	0.101	0.081	0.004	0.070	0.365	7

**Appendix B**

Table 11. The Full Multiplicative Form for Multi-Objectives

	1		2		3		4		5		6		7		8							
	max	$X_1$	max	$X_2$	2.1	max	$X_3$	min	$X_4$	4.1=3.1/4	max	$X_5$	5.1=4.1*5	max	$X_6$	6.1=5.1*6	max	$X_7$	7.1=6.1*7	max	$X_8$	8.1=7.1*8
E1	169	1.61	1	272.09	1	272.09	1	272.09	6	45.35	11575	524906.96	3493255807.71	5	6655	3493255807.71	5	17466279038.54	7.1=6.1*7	5	87331395192.71	8.1=7.1*8
E2	202	1.70	2	343.40	2	686.80	1	686.80	1	686.80	14890	10226452.00	145317882920.00	3	14210	145317882920.00	3	435953648760.00	7.1=6.1*7	2.2	959098027272.00	
E3	177	1.50	3	265.50	3	796.50	1	796.50	1	796.50	10290	8195985.00	59748730650.00	4.6	7290	59748730650.00	4.6	274844160990.00	7.1=6.1*7	5	1374220804950.00	
E4	227	1.85	1	419.95	1	419.95	15	28.00	15	28.00	1140	31916.20	248627198.00	3	7790	248627198.00	3	745881594.00	7.1=6.1*7	3.2	2386821100.80	
E5	230	1.85	1	425.50	1	425.50	15	28.37	15	28.37	11400	323380.00	2616144200.00	3	8090	2616144200.00	3	7848432600.00	7.1=6.1*7	3.2	25114984320.00	
E6	197	1.80	1	354.60	1	354.60	20	17.73	20	17.73	1069	18953.37	13703286.51	4.4	723	13703286.51	4.4	60294460.64	7.1=6.1*7	4.4	265295626.83	
E7	216	1.80	1	388.80	1	388.80	20	19.44	20	19.44	11261	218913.84	1667904546.96	4.4	7619	1667904546.96	4.4	7338780006.62	7.1=6.1*7	4.4	32290632029.15	
E8	188	1.60	2	300.80	2	601.60	10	60.16	10	60.16	10130	609420.80	4229380352.00	4.4	6940	4229380352.00	4.4	18609273548.80	7.1=6.1*7	5	93046367744.00	
E9	179	1.40	2	250.60	2	501.20	10	50.12	10	50.12	10000	501200.00	3468304000.00	4.4	6920	3468304000.00	4.4	15260537600.00	7.1=6.1*7	5	76302688000.00	
E10	180	1.80	1	324.00	1	324.00	5	64.80	5	64.80	10730	695304.00	5284310400.00	4.4	7600	5284310400.00	4.4	23250965760.00	7.1=6.1*7	3.4	79053283584.00	
E11	170	1.80	1	306.00	1	306.00	5	61.20	5	61.20	18207	1114268.40	15986408734.80	4.4	14347	15986408734.80	4.4	70340198433.12	7.1=6.1*7	3.4	239156674672.61	
E12	192	2.10	1	403.20	1	403.20	5	80.64	5	80.64	11650	939456.00	7121076480.00	4.4	7580	7121076480.00	4.4	31332736512.00	7.1=6.1*7	3.4	106531304140.80	
E13	195	1.40	1	273.00	1	273.00	5	54.60	5	54.60	10700	584220.00	4264806000.00	4.4	7300	4264806000.00	4.4	18765146400.00	7.1=6.1*7	3.4	63801497760.00	

Table 11. The Full Multiplicative Form for Multi-Objectives (Continued)

	9	10		11		12		13		14	
		max	$X_{10}$	max	$X_{11}$	max	$X_{12}$	max	$X_{13}$	max	$X_{14}$
		$9.1=8.1*9$	$10.1=9.1*10$	$11.1=10.1*11$	$12.1=11.1*12$	$13.1=12.1*13$	$14.1=13.1*14$				
E1	5	436656975963.54	2008622089432.29	7231039521956.25	36155197609781.30	94003513785431.30	224941.86				
E2	3	2877294081816.00	10933717510900.80	41548126541423.10	4.00	166192506165692.00	184043.34				
E3	4,6	6321415702770.00	31607078513850.00	145392561163710.00	5.00	726962805818550.00	208582.45				
E4	2,2	5251006421.76	21004025687.04	88216907885.57	4.20	370511013119.39	181440.00				
E5	2,2	55252965504.00	221011862016.00	928249820467.20	4.20	3898649245962.24	147960.00				
E6	4	1061182507.33	4456966530.80	12479506286.25	4.20	52413926402.26	170410.50				
E7	4	129162528116.58	542482618089.65	1518951330651.01	4.20	6379595588734.24	193586.32				
E8	4,8	446622565171.20	2054463799787.52	7396069679235.07	4.60	34021920524481.30	190331.18				
E9	4,8	366252902400.00	1684763351040.00	6065148063744.00	4.60	27899681093222.40	215708.66				
E10	4,8	379455761203.20	1593714197053.44	5099885430571.01	4.20	21419518808398.20	159504.22				
E11	4,8	1147952038428.52	4821398561399.78	15428475396479.30	4.20	64799596665213.00	179953.48				
E12	4,8	511350259875.84	2147671091478.53	6872547492731.29	4.20	28864699469471.40	170410.50				
E13	4,8	306247189248.00	1286238194841.60	4115962223493.12	4.20	17287041338671.10	197676.18				

	15	16		17		18		Rank	
		min	$X_{16}$	min	$X_{17}$	min	$X_{18}$		
		$15.1=14.1/15$	$16.1=15.1/16$	$17.1=16.1/17$	$18.1=17.1/18$				
E1	750.00	557201.84	30	18573.39	75	1393004.60	18	77389.14	6
E2	925.00	1952448.53	38	51380.22	74	3802136.61	18	211229.81	4
E3	700.00	12945228.92	27	479452.92	70	33561704.61	20	1678085.23	1
E4	640.00	8295.86	24	345.66	70	24196.26	21	1152.20	12
E5	330.00	207600.91	24	8650.04	70	605502.65	21	28833.46	11
E6	301.25	3062.98	22	142.46	74	10542.36	21	502.02	13
E7	181.25	545458.51	38	14354.17	74	1062208.68	21	50581.37	10
E8	330.00	1408342.56	23	60967.21	74	4511573.56	18	250642.98	3
E9	337.50	996394.29	23	43133.95	74	3191912.44	21	151995.83	5
E10	800.00	436436.33	32	13638.64	73	995620.37	17	58565.90	9
E11	320.00	2925737.93	30	97524.60	71	6924246.45	22	314738.47	2
E12	1000.00	440396.68	32	13762.40	73	1004654.93	17	59097.35	8
E13	400.00	568433.53	30	18947.78	71	1345292.69	22	61149.67	7

**Appendix C**

Table 12. The result of Dominance Directed Graph for the ratio analysis as a part of MOORA method

		M												
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	
E1	0	1	0	1	1	1	1	0	0	1	0	1	1	
E2	0	0	0	1	1	1	1	0	0	1	0	1	1	
E3	1	1	0	1	1	1	1	1	1	1	1	1	1	
E4	0	0	0	0	0	0	0	0	0	0	0	0	0	
E5	0	0	0	1	0	1	1	0	0	0	0	0	0	
E6	0	0	0	1	0	0	0	0	0	0	0	0	0	
E7	0	0	0	1	0	1	0	0	0	0	0	0	0	
E8	1	1	0	1	1	1	1	1	1	1	0	1	1	
E9	1	1	0	1	1	1	1	0	1	1	0	1	1	
E10	0	0	0	1	1	1	1	0	0	0	0	1	0	
E11	1	1	0	1	1	1	1	1	1	1	0	1	1	
E12	0	0	0	1	1	1	1	0	0	0	0	0	0	
E13	0	0	0	1	1	1	1	0	0	1	0	1	0	

		M2												
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	
E1	0	0	0	7	4	6	5	0	0	2	0	3	1	
E2	0	0	0	6	3	5	4	0	0	1	0	2	0	
E3	3	4	0	11	8	10	9	2	3	6	0	7	5	
E4	0	0	0	0	0	0	0	0	0	0	0	0	0	
E5	0	0	0	2	0	1	0	0	0	0	0	0	0	
E6	0	0	0	0	0	0	0	0	0	0	0	0	0	
E7	0	0	0	1	0	0	0	0	0	0	0	0	0	
E8	2	3	0	10	7	9	8	1	2	5	0	6	4	
E9	1	2	0	9	6	8	7	0	1	4	0	5	3	
E10	0	0	0	4	1	3	2	0	0	0	0	0	0	
E11	2	3	0	10	7	9	8	1	2	5	0	6	4	
E12	0	0	0	3	0	2	1	0	0	0	0	0	0	
E13	0	0	0	5	2	4	3	0	0	0	0	1	0	

		A = M + M2												
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	Sum
E1	0	1	0	8	5	7	6	0	0	3	0	4	2	36
E2	0	0	0	7	4	6	5	0	0	2	0	3	1	28
E3	4	5	0	12	9	11	10	3	4	7	1	8	6	80
E4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	3	0	2	1	0	0	0	0	0	0	6
E6	0	0	0	1	0	0	0	0	0	0	0	0	0	1
E7	0	0	0	2	0	1	0	0	0	0	0	0	0	3
E8	3	4	0	11	8	10	9	2	3	6	0	7	5	68
E9	2	3	0	10	7	9	8	0	2	5	0	6	4	56
E10	0	0	0	5	2	4	3	0	0	0	0	1	0	15
E11	3	4	0	11	8	10	9	2	3	6	0	7	5	68
E12	0	0	0	4	1	3	2	0	0	0	0	0	0	10
E13	0	0	0	6	3	5	4	0	0	1	0	2	0	21

Table 13. The result of Dominance Directed Graph for the reference point approach as a part of MOORA method

M													
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0	0	0	1	1	1	1	0	0	1	1	1	1
E2	1	0	0	1	1	1	1	0	0	1	1	1	1
E3	1	1	0	1	1	1	1	0	1	1	1	1	1
E4	0	0	0	0	0	1	1	0	0	0	0	0	0
E5	0	0	0	1	0	1	1	0	0	0	0	1	0
E6	0	0	0	0	0	0	1	0	0	0	0	0	0
E7	0	0	0	0	0	0	0	0	0	0	0	0	0
E8	1	1	1	1	1	1	1	0	1	1	1	1	1
E9	1	1	0	1	1	1	1	0	0	1	1	1	1
E10	0	0	0	1	1	1	1	0	0	0	0	1	0
E11	0	0	0	1	1	1	1	0	0	1	0	1	1
E12	0	0	0	1	0	1	1	0	0	0	0	0	0
E13	0	0	0	1	1	1	1	0	0	1	0	1	0

M2													
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0	0	0	5	3	6	7	0	0	2	0	4	1
E2	0	0	0	6	4	7	8	0	0	3	1	5	2
E3	2	1	0	8	6	9	10	0	0	5	3	7	4
E4	0	0	0	0	0	0	1	0	0	0	0	0	0
E5	0	0	0	1	0	2	3	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	0	0	0	0	0	0	0	0	0	0
E8	3	2	0	9	7	10	11	0	1	6	4	8	5
E9	1	0	0	7	5	8	9	0	0	4	2	6	3
E10	0	0	0	2	0	3	4	0	0	0	0	1	0
E11	0	0	0	4	2	5	6	0	0	1	0	3	0
E12	0	0	0	0	0	1	2	0	0	0	0	0	0
E13	0	0	0	3	1	4	5	0	0	0	0	2	0

A = M + M2														
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	Sum
E1	0	0	0	6	4	7	8	0	0	3	1	5	2	36
E2	1	0	0	7	5	8	9	0	0	4	2	6	3	45
E3	3	2	0	9	7	10	11	0	1	6	4	8	5	66
E4	0	0	0	0	0	1	2	0	0	0	0	0	0	3
E5	0	0	0	2	0	3	4	0	0	0	0	1	0	10
E6	0	0	0	0	0	0	1	0	0	0	0	0	0	1
E7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E8	4	3	1	10	8	11	12	0	2	7	5	9	6	78
E9	2	1	0	8	6	9	10	0	0	5	3	7	4	55
E10	0	0	0	3	1	4	5	0	0	0	0	2	0	15
E11	0	0	0	5	3	6	7	0	0	2	0	4	1	28
E12	0	0	0	1	0	2	3	0	0	0	0	0	0	6
E13	0	0	0	4	2	5	6	0	0	1	0	3	0	21

Table 14. The result of Dominance Directed Graph for the full multiplicative form for multi-objective

M													
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0	0	0	1	1	1	1	0	0	1	0	1	1
E2	1	0	0	1	1	1	1	0	1	1	0	1	1
E3	1	1	0	1	1	1	1	1	1	1	1	1	1
E4	0	0	0	0	0	1	0	0	0	0	0	0	0
E5	0	0	0	1	0	1	0	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	1	1	1	0	0	0	0	0	0	0
E8	1	1	0	1	1	1	1	0	1	1	0	1	1
E9	1	0	0	1	1	1	1	0	0	1	0	1	1
E10	0	0	0	1	1	1	1	0	0	0	0	0	0
E11	1	1	0	1	1	1	1	1	1	1	0	1	1
E12	0	0	0	1	1	1	1	0	0	1	0	0	0
E13	0	0	0	1	1	1	1	0	0	1	0	1	0

M2													
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0	0	0	5	4	6	3	0	0	2	0	1	0
E2	1	0	0	7	6	8	5	0	0	4	0	3	2
E3	4	2	0	10	9	11	8	1	3	7	0	6	5
E4	0	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	1	0	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	1	0	2	0	0	0	0	0	0	0
E8	2	0	0	8	7	9	6	0	1	5	0	4	3
E9	0	0	0	6	5	7	4	0	0	3	0	2	1
E10	0	0	0	2	1	3	0	0	0	0	0	0	0
E11	3	1	0	9	8	10	7	0	2	6	0	5	4
E12	0	0	0	3	2	4	1	0	0	0	0	0	0
E13	0	0	0	4	3	5	2	0	0	1	0	0	0

A = M + M2														
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	Sum
E1	0	0	0	6	5	7	4	0	0	3	0	2	1	28
E2	2	0	0	8	7	9	6	0	1	5	0	4	3	45
E3	5	3	0	11	10	12	9	2	4	8	1	7	6	78
E4	0	0	0	0	0	1	0	0	0	0	0	0	0	1
E5	0	0	0	1	0	2	0	0	0	0	0	0	0	3
E6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	2	1	3	0	0	0	0	0	0	0	6
E8	3	1	0	9	8	10	7	0	2	6	0	5	4	55
E9	1	0	0	7	6	8	5	0	0	4	0	3	2	36
E10	0	0	0	3	2	4	1	0	0	0	0	0	0	10
E11	4	2	0	10	9	11	8	1	3	7	0	6	5	66
E12	0	0	0	4	3	5	2	0	0	1	0	0	0	15
E13	0	0	0	5	4	6	3	0	0	2	0	1	0	21

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