Supplier Selection for a Business Operating on a Just-in-Time Production System Using an Integrated DEMATEL and MULTIMOORA Approach

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Abstract

In today's industry, increasing competition and rising customer expectancies are driving businesses to expect some criteria such as cost, quality and fast service from their suppliers at certain levels. Especially for automotive companies working on just-in-time production, it is of utmost importance that these criteria are best achieved by suppliers. While suppliers who meet the criteria at an optimal level are preferred, firms part company with the suppliers who cannot meet these expectations. For this reason, the choice of suppliers for just-in-time companies has become a major problem. In this study, the problem of supplier selection of an automotive subsidiary industry company working with a just-in-time production system was solved using an integrated use of DEMATEL and MULTIMOORA methods. In the study, the MOORA ratio method, the Reference point approach and full multiplicative methods were applied on the supplier selection problem by operating with weights obtained from DEMATEL. The results obtained were assessed using the ordinal dominance theory and the best suppliers were selected.

Keywords: Supplier Selection, DEMATEL, MULTIMOORA, Multi Criteria Decision Making

1. INTRODUCTION

The effect of goods or services received from suppliers on the quality of products or services offered by businesses is undeniable. Particularly, due to the effect of globalization and competition, the proliferation of alternatives in supplier selection has prompted businesses to be more selective. The selection of suppliers for companies operating on a just-in-time (JIT) production system is also of importance. Supplier selection is one of the key components of the JIT philosophy in Fig. 1 [1].

There are several studies conducted regarding the criteria to be considered in the supplier selection process of JIT companies. When the studies conducted by Holmstrom (1998), Lummus et al. (1998) and Schorr (1998) are summarized, it is seen that eight criteria (delivery flexibility, quality and reliability, price, delivery time, location, technological capabilities, financial stability and supplier chain management) affect the JIT supplier selection process in Fig. 2 [2].
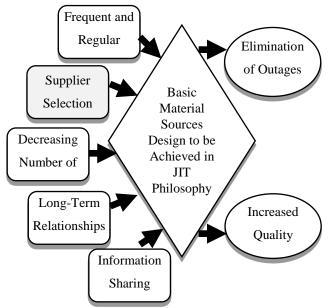

Fig. 1. Elements of JIT Philosophy expressed by Magee D. G.

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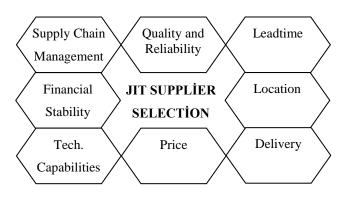
Fig. 2. JIT supplier selection criteria

The first study on supplier selection was conducted by Dickson, G. W. (1966). Dickson listed 23 criteria in his study and ranked them by importance [supplier selection for strategic supplier development] [3]. Due to the large number of criteria, studies conducted in the subsequent years mostly dealt with multi-criteria decision-making techniques. In this context, techniques such as AHP, Electre, Vikor, Promethee, ANP and target programming were found to be used heavily. When the major studies in the literature related to these techniques were examined, it was seen that the use of AHP was suggested for supplier selection in studies conducted by Narasimhan (1983), Partovi (1989), Nydick and Hill (1992) [4]. In 1998, Boer et al. used the Electre method to select suppliers for a business operating on the JIT production system [5]. In a study conducted by Weber and Allrem in 1993, target programming was used when choosing suppliers according to the price, quality and delivery specifications of a company working on the JIT production system [6]. Dulmin and Mininno used the Promethee method in the selection of suppliers of an enterprise operating in the road and rail transport industry in 2003 [7]. In a study conducted by Sarkus and Talluri in 2002, the ANP method was used to select suppliers in a business manufacturing metal-based products [8]. Sanayei et al. (2010) selected suppliers using the Vikor method for components of a new product in an automobile component manufacturing business [9].

When recent studies are examined, it is seen that the MULTIMOORA method developed by Brauers and Zavadskas (2010) has also been included in multi-criteria decision-making techniques [10]. Since then until today, the MULTIMOORA method has been applied in various fields.

The main study where the MULTIMOORA method was applied was carried out by Brauers and Zavadskas in the field of project management for transitions in 2010 [11]. Also in 2010, the MULTIMOORA method was used by Kracka, Brauers and Zavadskas in optimizing the heat loss of a building [12]. Baležentis A. et al. (2010) assessed Lithuania's achievement of the Lisbon Strategy's objectives by using the MULTIMOORA method [13]. In 2011, Baležentis A. and Baležentis T. assessed the transport sector by using the MULTIMOORA and DEA methods [14]. Balezentis T. estimated the agricultural productivity of different

agricultural species in 2011 and compared the prosperity levels of the EU countries with Baležentis, A. and Brauers by using the MULTIMOORA method [15, 16]. The bank loan decision for a property to be purchased was given by Brauers and Zavadskas in 2011 using the MULTIMOORA method [17]. Braures and others used the MULTIMOORA method to assess 27 EU countries in terms of the implementation of the Lisbon Strategy in 2012 [18]. Balezentis A. et al. (2012) selected personnel by using MULTIMOORA-FG, the expanded type of MULTIMOORA [19]. The banks registered in Lithuania were ranked by Brauers et al. (2012) using the MULTIMOORA method [20]. Streimikienea et al. (2012) selected sustainable energy sources using the Topsis and MULTIMOORA methods [21]. In a study by Brauers and Zavadskas in 2012, it was shown that the MULTIMOORA method hosted three different methods within itself and that it was a powerful approach that enabled obtaining objective results [22]. Balezentis, T. and Zeng selected personnel using the MULTIMOORA method in 2013 [23]. Balezentiene (2013) used the Fuzzy MULTIMOORA method to prioritize data fusion and energy plants [24]. Between 2008 and 2009, Brauers et al. (2013) evaluated the construction industry using the MULTIMOORA method for 20 European countries [25]. Datta et al. (2013) made a robot selection using the Gray Set Theory combined with the MULTIMOORA method [26]. In a study by Kildiene in 2013, the business development potential of EU countries was assessed using the MULTIMOORA method [27]. Brauers et al. (2014) used the MULTIMOORA method in the assessment of construction sector [28]. In 2014, Stanujkic et al. used the MULTIMOORA method in evaluating the qualities of websites of Serbian hotels in rural areas [29]. Li et al. made software selections in 2014 using MULTIMOORA and Fuzzy Sets [30]. Liu et al. (2014) proposed a risk assessment model using MULTIMOORA and Fuzzy Sets to prevent baby abduction in a health care facility [31].

In 2014, Sahu et al. evaluated the fuzzy multi-criteria decision-making and supply chain performance using the MULTIMOORA method [32]. Stankevičıene et al. (2014) used the MULTIMOORA method to assess the country's risk in the EU Baltic Sea region countries [33]. Lazauskas et al. (2015) evaluated the construction potential of three Baltic capitals (Vilnius, Riga, Tallinn) using the Weightless MOORA and MULTIMOORA methods [34]. The IVIF-MULTIMOORA method (interval-valued intuitionistic fuzzy MULTIMOORA), which was developed by Zavadskas et al. (2015) with the modification of the MULTIMOORA method, solved the group decision problem in uncertain environments, and the advantage of the method was shown by two different applications [35]. The Performance of Turkish Coal Operations was evaluated by Aksoy et al. in 2015 using the AHP-based MULTIMOORA and Copras methods [36]. Excavators were selected by Altuntas et al. (2015) using the Based MULTIMOORA Methods [37]. Hafezalkotob, A. and Hafezalkotob, A. used the MULTIMOORA method in selecting materials for

biomedical applications in 2015 [38] and with Sayadi in selecting power gears in 2016 [39]. Alternatives to health waste treatment technologies were evaluated by Liu et al. in 2015 using the integrated use of 2-tuple DEMATEL and Fuzzy MULTIMOORA methods [40]. The selection of Mechanical Parking System in 2015 by Çiçek et al. was carried out using the Fuzzy MULTIMOORA method [41]. In 2016, Macbeth and MULTIMOORA were used by Kundakcı in the selection of cars for a marble business [42]. The MULTIMOORA, Topsis and Vikor methods and Randomly generated MCDM problems were solved by Ceballos et al. (2016) [43]. In Europe, the housing market situation of the countries was assessed by Gorzen-Mitka et al. (2016) using the MULTIMOORA method [44]. Sahu et al. conducted a study in 2016 for the evaluation of CNC machines using the MULTIMOORA method [45]. Tian et al (2016) brought simplified neutrophilic linguistic problems to a solution using the MULTIMOORA method [46]. In 2016, Aytekin conducted a study on the hospital selection of patients using the MULTIMOORA method [47]. Ömürbek and Özcan used the MULTIMOORA method in 2016 to evaluate the financial performance of insurance companies [48]. A study was conducted by Türe et al. in 2016 using the MULTIMOORA method to evaluate a country's risk [49]. The MULTIMOORA method was used in the performance evaluations of manufacturing sectors in 2017 by Ömürbek and Aksoy [50]. China's five provinces were assessed for whether they provided control in order to prevent atmospheric pollution by using the double hierarchy hesitant fuzzy linguistic MULTIMOORA (DHHFL-MULTIMOORA) method developed by Xunjie et al. (2017). The most appropriate province was selected, and the advantages of the developed method were demonstrated by comparison with the hesitant fuzzy linguistic TOPSIS method [51]. It is observed through these applications that studies on supplier selection is limited in number. Balezentis, A. and Balezentis, T. (2011), extending the MULTIMOORA method with the Two-tuple linguistic representation, applied it in the selection of suppliers [52]. Farzamnia and Babolghani (2014) proposed a fuzzy logic and the MULTIMOORA approach to assessing the group's decisions in the selection of suppliers [53].

In this study, an integrated approach consisting of DEMATEL and MULTIMOORA techniques was examined to deal with the problem of supplier selection in an automotive subsidiary company which works on a just in time production system basis. On the same problem, the results of the full multiplicative methods were investigated together with the MOORA ratio method and the Reference point approach methods. The results were evaluated using the ordinal dominance theory, and the best supplier for the company was determined. The reason for choosing MULTIMOORA method in the proposed hybrid method; while generally obtaining a single ranking in other multi-criteria decision making techniques, it is the ability to draw a single result from the three rankings obtained by MULTIMOORA's three sub-methods in its component. However, the MOORA method, which is the main

component of the technique, It was compared with some other multi-purpose decision making techniques(AHP, TOPSIS,VIKOR, ELECTRE and PROMETHEE.) and its superiority was emphasized in terms of computational time, simplicity, mathematical calculations, stability and type of information [54].

2. METODOLOGİES

2.1 DEMATEL

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was first developed by the Geneva Battelle Memorial Institute between the years 1972 and 1976; it is a technique that provides a better understanding of causal relationships [55]. The DEMATEL method, which is based on the graph theory, allows the problem to be better understood and solved by separating the factors as cause and effect [56]. A criterion is a cause criterion if it has a higher effect when compared to other criteria, and it is an effect criterion if it has a lower effect [57]. When studies are examined, it is seen that criteria weights were calculated using DEMATEL, and different techniques were used when ranking the alternatives. The steps for implementing DEMATEL are as follows:

Step 1: Criteria are evaluated using expert opinions by scoring between 0-3 or 0-4 with the help of the determined binary comparison scale in Table 1; and an asymmetric, direct correlation matrix with its diagonals equaling to zero is created ([55], [57])

Table 1. Binary comparison scale

Numerical Value	Definition
0	**Ineffective**
1	**Low Effect**
2	**Intermediate Effect**
3	**High Effect**
4	**Very High Effect**

Step 2: The direct correlation matrix is normalized using the following Eqs. (1) and (2). The maximum values of row and column totals of the direct correlation matrix are found. Each element of the matrix is divided by this value to obtain a normalized direct correlations matrix(C).

$$s = max(max \sum_{k=1}^{n} t_{jk}, max \sum_{j=1}^{n} t_{jk}) \qquad (1)$$
$$C = t_{ij}/s \qquad (2)$$
$$n = number\ of\ criteria$$
$$j = (1,2,3,\dots n)$$
$$k = (1,2,3,\dots n)$$

Step 3: The normalized direct correlation matrix (C) and the unit matrix (I) are transformed into the total correlation matrix (F) using Eq. (3).

$$F = C(I - C)^{-1} \tag{3}$$

Step 4: The row sum of the total correlation matrix is (D), and the column sum is (R). Using these sums, D+R and D-R values are calculated. Here, D + R for each criterion is the total effect sent and received, and D-R is the sum of the effect of the criterion on the system [57].

Step 5: In order to find the criteria weights, the square root of the sum of squares of the values ($D_j + R_j$) and ($D_j - R_j$) calculated in the previous step is calculated on Eq. (4).

$$w_{ja} = \sqrt{(D_j + R_j)^2 + (D_j - R_j)^2} \tag{4}$$

Finally, the weights of the criteria w_j are obtained by dividing each of the found values by the sum of the weights on Eq. (5).

$$w_j = \frac{w_{ja}}{\sum_{j=1}^{n} w_{ja}} \tag{5}$$
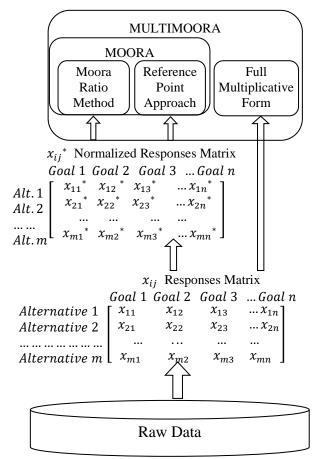
2.2 MULTIMOORA

Fig. 3. The hierarchical structure of the MULTIMOORA method

The basis of the MULTIMOORA method dates back to the introduction of the MOORA method to the literature by Braures and Zavadskas in 2006 [49]. It is a multi-criteria decision-making technique, finalized with the addition of full multiplicative form into the MOORA method in 2010 again by the same authors in Fig. 3 [58]. The theory of dominance was proposed by Braures and Zavadskas to combine the results obtained from the ratio method, the reference point approach and the full multiplicative form [18].

2.2.1 MOORA ratio method

The Moora-Ratio method was first introduced to the literature in 2006 by Willem Karel M. Brauers and Edmundas Kazimieras Zavadskas [36]. The method starts with an initial matrix that contains the answers of each criterion alternatives. This matrix is normalized by the formula proposed by Van Delft and Nijkamp (1977). A ranking is determined by using obtained values in the formula of the ratio method [26]. The steps of the MOORA-Ratio method are listed below.

Step 1: First, an initial matrix is formed, expressing the performances of the alternatives according to the criteria on Eq. (6). In this matrix, the criteria with the cost effect have the minimum goal, and the criteria with the benefit effect have the maximum goal. They are specified as min and max.

$$X = \begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & ... & x_{2n} \\ ... & ... & ... & ... \\ x_{m1} & x_{m2} & ... & x_{mn} \end{bmatrix} \tag{6}$$

Step 2: By applying Eq. (7) to the initial matrix, a normalized matrix $x_{ij}{}^*$ is obtained.

$$x_{ij}{}^* = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}{}^2}} \tag{7}$$

$i = 1, 2, ..., m; m\ the\ number\ of\ alternatives$
$j = 1, 2, ..., n; n\ the\ number\ of\ objectives$
$x_{ij} = performance\ measurement\ value$
$of\ alternative\ i\ in\ terms\ of\ criterion\ j$

Step 3: Each of the normalized matrix values is multiplied by the weight of the criterion (w_j), and weighted normalized matrix values (v_{ij}) are obtained on Eq. (8).

$$v_{ij} = w_j * x_{ij}{}^* \tag{8}$$
$w_j = criterion\ weight\ of\ j$

Step 4: In the weighted normalized matrix, for each alternative, the sum of the criteria specified as minimum is subtracted from the sum of the criteria specified as the maximum in the row of that alternative, and the value of y_i is obtained on Eq. (9).

$$y_i{}^* = \sum_{j=1}^{g} v_{ij} - \sum_{j=g+1}^{n} v_{ij} \tag{9}$$

$g = maximum\ number\ of\ criteria$

Step 5: The alternatives are sorted according to the calculated value of y_i^* in descending order. Thus, the ranking of the alternatives is determined using the MOORA-ratio method.

2.2.2 MOORA reference point approach

The first work on this approach developed by Braures and Zavadskas dates back to 2009 [58]. It uses the weighted normalized matrix obtained from the ratio method. The ranking of the alternatives is found by sorting the results calculated using the formulations given below in ascending order. The steps of the MOORA- Reference point approach are as follows:

Step 1: In the MOORA-Ratio method, two of the calculated values of the weighted normalized matrix are determined as the reference values (r_j): the minimum value of the criteria specified as the minimum and the maximum value of the criteria specified as the maximum.

Step 2: For each value in the columns, the absolute value of the difference with the reference value is calculated on Eq. (10).

$$\left| w_j r_j - v_{ij} \right| \tag{10}$$

Step 3: The maximum value for each alternative (row) in the resulting matrix is determined. These values are sorted in ascending order to obtain the ranking of the MOORA-Reference point approach on Eq. (11).

$$min_i \{ max_j (\left| w_j r_j - v_{ij} \right|) \} \tag{11}$$

2.2.3 Full multiplicative form

In 2010, Braures and Zavadskas developed the full multiplicative form, the third part of the MULTIMOORA method [59]. This method uses the initial decision matrix without normalizing it. If the decision matrix has zero and negative values in the full multiplicative form, meaningless results can occur. To avoid this, consistent results can be achieved by making the relevant values positive (applying the same procedure throughout the whole column) [60]. The full multiplicative form steps are as follows:

Step 1: The criteria weights x_{ij} of the initial matrix values to the power of w_j are taken as $x_{ij}{}^{w_j}$.

Step 2: The maximum and minimum column values for each alternative in the resulting matrix are multiplied among themselves on Eq. (12).

$$A_i = \prod_{j=1}^{g} x_{ij}{}^{w_j} \qquad B_i = \prod_{j=g+1}^{n} x_{ij}{}^{w_j} \tag{12}$$

$A_i = multiplication\ of\ maximum\ colum$
$values\ for\ each\ alternative$
$B_i = multiplication\ of\ minimum\ column$

$values\ for\ each\ alternative$

Step 3: The resulting A_i and B_i values are proportioned to each other to obtain the U_i values on Eq. (13). These values are sorted in descending order to obtain the ranking of the full multiplicative form.

$$U_i = A_i / B_i \tag{13}$$

$U_i = overall\ utility\ of\ alternative\ i$

2.2.4 Ordinal dominance theory

Brauers and Zavadskas (2011) have developed the dominance theory to obtain a single ranking from the MOORA-Ratio method, the MOORA-Reference point approach, and the full multiplicative form rankings, which are the components of the MULTIMOORA method. The basis of the theory is about the determination of the predominance among the results of different approaches. The theory consists of Dominance, being Dominated, Transivitiy and Equability [17, 60].

Absolute Dominance: If an alternative's sorting values, obtained from three different technique are respectively (1-1-1), it is definitely dominant.
Dominance: $(x < y < z < t)$ sorting values given, generally $(t - x - x)$ dominates $(z - y - y)$, $(x - t - x)$ dominates $(y - z - y)$ and $(x - x - t)$ dominates $(y - y - z)$.
Transitiveness: If x dominates y and y dominates z than also x will dominate z.
Being Dominated: For instance $(x - x - x)$ is overally dominating $(y - y - y)$ which is overally being dominated.
Equability: For instance; 2 alternatives have $(u - u - u)$ absolute equability, If $(2 - u - 9)$ and $(4 - u - 5)$ exist in 2 of 3, it is called partial equability.

Contradictory situations other than those listed above may also occur. For example, generally, Alternative A (1-9-3) dominates Alternative B (3-5-4), Alternative B (3-5-4) dominates Alternative C (4-8-2) and Alternative C (4-8-2) dominates Alternative A (1-9-3). In such a case the same ranking is given to the 3 alternatives which is also called circular reasoning.

3. APPLICATION

The application was carried out in an automotive subsidiary industry company aiming to operate on the basis of the JIT system. The study used criteria for delivery flexibility, quality and reliability, price, delivery time, location, technological capabilities, financial stability, and supplier chain management which were summarized by Schniederjans (2002) and which are effective in the JIT supplier selection process [1]. The data were obtained by the expert decision-maker in the company accompanied by an academic expert. In the problem that was dealt with, 8 suppliers were evaluated in terms of a part commonly used in the automobile production. The hierarchical structure of the problem is as shown in Fig. 4.
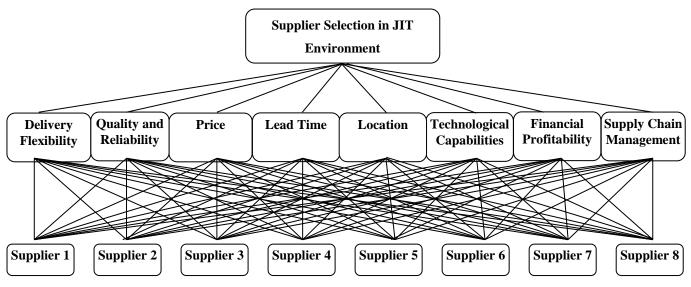
Supplier Selection in JIT Environment

Delivery Flexibility | Quality and Reliability | Price | Lead Time | Location | Technological Capabilities | Financial Profitability | Supply Chain Management

Supplier 1 | Supplier 2 | Supplier 3 | Supplier 4 | Supplier 5 | Supplier 6 | Supplier 7 | Supplier 8

Fig. 4. Hierarchical structure of the research proble

An integrated approach consisting of the DEMATEL method and the MULTIMOORA method was proposed for use in the solution phase (Fig. 5). In this proposed approach, evaluation were transformed into a direct correlation matrix t_{jk} and used as an input to the DEMATEL method. As a result of applying the DEMATEL method, the weight of each criterion w_j was obtained. In the next step, the alternatives were evaluated by the same experts using six of the eight quantitative JIT criteria (Delivery Flexibility, Quality and Reliability, Location, Technological Capability, Financial Profitability, and Supply Chain Management) with scores from 0 to 5. For the other two JIT criteria, which were Price and Delivery Time, qualitative data from the firm regarding the alternatives were used. The responses matrix x_{ij} in which the criteria were compared

the JIT supplier selection criteria were scored from 0 to 4 in the presence of experts, and their effects were evaluated. The results of the
with the alternatives was created using these data. The MULTIMOORA method was applied using the criteria weights w_j determined by the x_{ij} matrix and the DEMATEL method. Three different rankings were obtained for the alternatives by applying the steps of the MULTIMOORA method in the following order: the ratio method, the reference point approach and the full multiplicative form. These rankings were compared using the ordinal dominance theory, and thus, the MULTIMOORA ranking of the alternatives was obtained.

Creation of the Direct Correlation Matrix, X → Creation of the Normalized Direct Correlation Matrix, C → Creation of the Total Direct Correlation Matrix, F → Calculation of the w_i weights through the w_{ia} values

Responses Matrix, x_{ij} → w_i → Ratio | Reference Point | Full Multiplicative → Ordinal Dominance Theory → Selection of Best Supplier
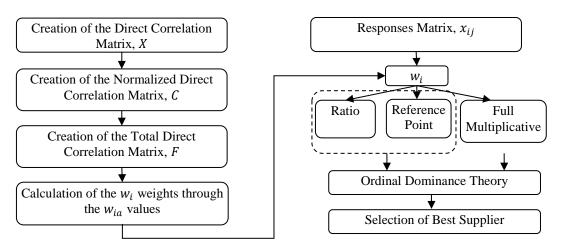
Fig. 5. Proposed DEMATEL – MULTIMOORA integrated approach procedures

A five-point linguistic scale was used to assess the effects of the criteria on each other (Table 2). Experts assessed the effects of the criteria between 0-4 by using the numerical equivalents of the linguistic expressions.

Table 2. Numeric equivalents of linguistic expressions and criteria codes

Linguistic expressions	Numeric equivalence
Ineffective	0
Low effect	1
Intermediate Effect	2
High Effect	3
Very High Effect	4

Criteria	Criterion Codes
Delivery Flexibility	C_1
Quality and Reliability	C_2
Price	C_3
Delivery Time	C_4
Location	C_5
Technological Capability	C_6
Financial Profitability	C_7
Supply Chain Management	C_8

Table 3 shows the numerical expressions resulting from the evaluation of the relationship between the criteria by the expert. These values form the direct correlation matrix t_{jk}.

Table 3. Direct relationship matrix t_{jk}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0	2	2	4	4	3	3	3
C_2	4	0	4	4	4	4	4	4
C_3	4	4	0	0	1	4	4	3
C_4	2	2	0	0	3	2	2	1
C_5	3	2	2	3	0	2	2	2
C_6	3	4	4	2	2	0	3	3
C_7	4	4	3	1	3	3	0	3
C_8	3	3	3	1	2	3	3	0

The normalization process was accomplished by applying Eq. (1) and Eq. (2) to the direct correlation matrix data. The normalized direct correlation matrix C was obtained as a result of the normalization process (Table 4).

Table 4. Normalized direct correlation matrix (C)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.00	0.07	0.07	0.14	0.14	0.10	0.10	0.10
C_2	0.14	0.00	0.14	0.14	0.14	0.14	0.14	0.14
C_3	0.14	0.14	0.00	0.00	0.03	0.14	0.14	0.10
C_4	0.07	0.07	0.00	0.00	0.10	0.07	0.07	0.03
C_5	0.10	0.07	0.07	0.10	0.00	0.07	0.07	0.07
C_6	0.10	0.14	0.14	0.07	0.07	0.00	0.10	0.10
C_7	0.14	0.14	0.10	0.03	0.10	0.10	0.00	0.10
C_8	0.10	0.10	0.10	0.03	0.07	0.10	0.10	0.00

The Total Relation Matrix (F) was obtained by applying Eq. (3) using the normalized direct correlation matrix (C) data (Table 5).

Table 5. Creation of the total correlation matrix (C)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.26	0.30	0.27	0.30	0.34	0.33	0.33	0.31
C_2	0.47	0.32	0.41	0.36	0.42	0.44	0.44	0.42
C_3	0.40	0.38	0.23	0.19	0.27	0.38	0.38	0.34
C_4	0.22	0.21	0.13	0.11	0.23	0.21	0.21	0.17
C_5	0.30	0.25	0.23	0.24	0.17	0.25	0.25	0.24
C_6	0.37	0.38	0.35	0.25	0.30	0.26	0.35	0.33
C_7	0.40	0.38	0.33	0.23	0.33	0.35	0.26	0.34
C_8	0.34	0.32	0.30	0.20	0.27	0.32	0.32	0.21

The row sum (D) and the column sum (R) of the total correlation matrix were calculated. For each criterion, the $D + R$ and $D - R$ values were obtained using the D and R values. By applying Eq. (4) and Eq. (5) to these values, weights of each criterion w_j were calculated. The results of the calculations are shown in Table 6.

Table 6. Calculation of the weights of criteria

D_j	R_j	$D_j + R_j$	$D_j - R_j$	W_{ja}	Criteria		w_j
2.48	2.80	5.29	-0.32	5.30	C_1	→	0.1356
3.31	2.57	5.88	0.73	5.93	C_2	→	0.1517
2.61	2.28	4.89	0.33	4.90	C_3	→	0.1255
1.51	1.92	3.43	-0.40	3.45	C_4	→	0.0884
1.96	2.36	4.33	-0.39	4.35	C_5	→	0.1113
2.64	2.58	5.22	0.06	5.22	C_6	→	0.1336
2.65	2.58	5.23	0.07	5.23	C_7	→	0.1339
2.30	2.38	4.68	-0.07	4.68	C_8	→	0.1199

In the next step, the results of the alternatives ($A_1,A_2,..,A_8$) were prepared in terms of 8 JIT criteria by experts, and the initial matrix of the MULTIMOORA method x_{ij} was created. Of the 8 criteria that affect the JIT supplier selection process, the criteria with positive effects on the business (Delivery Flexibility, Quality and Reliability, Location, Technological Capability, Financial Profitability and Supply Chain Management) were determined as the maximum, and the criteria with negative effects (Price and Delivery Time) as the minimum (Table 7).

Table 7. Initial matrix x_{ij}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX
A_1	4	5	3.85	1	4	5	5	5
A_2	3	5	4	2	4	5	5	5
A_3	3	5	4.1	3	3	5	5	4
A_4	3	4	4.1	2	4	4	4	4
A_5	4	4	4	2	4	5	5	4
A_6	3	4	4.1	2	4	4	4	4
A_7	3	4	4.05	2	5	3	4	3
A_8	4	4	4	2	5	4	4	3

The normalized matrix x_{ij}^* is obtained by proportioning

each of the values in the initial matrix to the square root of the sum of the squares of the column values on Eq. (7) (Table 8).

Table 8. Normalized matrix x_{ij}^*

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX
A_1	0.41	0.51	0.39	0.10	0.41	0.51	0.51	0.51
A_2	0.31	0.51	0.41	0.20	0.41	0.51	0.51	0.51
A_3	0.31	0.515	0.42	0.31	0.31	0.51	0.51	0.41
A_4	0.31	0.41	0.42	0.20	0.41	0.41	0.41	0.41
A_5	0.41	0.41	0.41	0.20	0.41	0.51	0.51	0.41
A_6	0.31	0.41	0.42	0.20	0.41	0.41	0.41	0.41
A_7	0.31	0.41	0.42	0.20	0.51	0.31	0.41	0.31
A_8	0.41	0.41	0.41	0.20	0.51	0.41	0.41	0.31

Each value in the normalized matrix is multiplied by the criterion weight on Eq. (8) to obtain the weighted normalized matrix v_{ij} (Table 9).

Table 9. Weighted normalized matrix v_{ij}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX
A_1	0.05	0.07	0.05	0.00	0.04	0.06	0.06	0.06
A_2	0.04	0.07	0.05	0.01	0.04	0.06	0.06	0.06
A_3	0.04	0.07	0.05	0.02	0.03	0.06	0.06	0.04
A_4	0.04	0.06	0.05	0.01	0.04	0.05	0.05	0.04
A_5	0.05	0.06	0.05	0.01	0.04	0.06	0.06	0.04
A_6	0.04	0.06	0.05	0.01	0.04	0.05	0.05	0.04
A_7	0.04	0.06	0.05	0.01	0.05	0.04	0.05	0.03
A_8	0.05	0.06	0.05	0.01	0.05	0.05	0.05	0.03

Using Eq. (9), the ratio method score was obtained for each alternative supplier by subtracting the sum of the minimum values from the sum of the obtained maximum values. The ranking of the MOORA-Ratio method was obtained by ranking the scores in descending order in Table 10.

Table 10. Ranking of suppliers according to the MOORA-RATIO method

$\sum Max - \sum Min$	MOORA-Ratio Rank
0.3227	1
0.2975	2
0.2630	4
0.2403	6/7
0.2834	3
0.2403	6/7
0.2262	8
0.2547	5

The first step of the reference point approach begins with the use of the weighted normalized matrix in Table 9. In this matrix, the maximum value of the columns specified as the maximum and the minimum value of the columns specified as the minimum are set as the reference points (Table 11).

Table 11. Reference points r_j

r_j	0.056	0.078	0.050	0.009	0.057	0.069	0.069	0.062

Each value in the weighted normalized matrix is transformed using Eq. (10) (Table 12).

Table 12. Converted criterion values

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX
A_1	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000
A_2	0.014	0.000	0.002	0.009	0.011	0.000	0.000	0.000
A_3	0.014	0.000	0.003	0.018	0.023	0.000	0.000	0.012
A_4	0.014	0.015	0.003	0.009	0.011	0.013	0.013	0.012
A_5	0.000	0.015	0.002	0.009	0.011	0.000	0.000	0.012
A_6	0.014	0.015	0.003	0.009	0.011	0.013	0.013	0.012
A_7	0.014	0.015	0.002	0.009	0.000	0.027	0.013	0.024
A_8	0.000	0.015	0.002	0.009	0.000	0.013	0.013	0.024

The results are sorted in ascending order to obtain the

Reference Point Approach ranking of the alternatives (Table 13).

Table 13. Ranking of suppliers according to the MOORA-REFERENCE method

$max_j(|w_j r_j - v_{ij}|)$	Reference Point Approach Rank
0.0115	1
0.0141	2
0.0231	6
0.0157	3/4/5
0.0157	3/4/5
0.0157	3/4/5
0.0277	7
0.0249	8

The steps of the full multiplicative form start with the use of the initial matrix. Each value in the initial matrix to the power of the weight value of the criterion $x_{ij}{}^{w_j}$ is calculated. Using Eq. (12), the multiplications of the maximum value and the minimum value in each row of the weighted matrix is calculated separately. By proportioning these values to each other, the U values of the full multiplicative form are obtained (Table 14).

Table 14. A_i, B_i and U_i values of the full multiplicative form

A_i	B_i	U
3.3535	1.1844	2.8314
3.2252	1.2653	2.5490
3.0412	1.3156	2.3117
2.8596	1.2692	2.2530
3.1563	1.2653	2.4945
2.8596	1.2692	2.2530
2.7253	1.2673	2.1505
2.9447	1.2653	2.3273

By ordering the obtained U values in descending order, a Full Multiplicative Form ranking of the suppliers is obtained (Table 15).

Table 15. Ranking of the suppliers according to the full multiplicative form.

U	Full Multiplicative Form Rank
2.8314	1
2.5490	2
2.3117	5
2.2530	6/7
2.4945	3
2.2530	6/7
2.1505	8
2.3273	4

The final MULTIMOORA method rank is obtained using the ordinal dominance theory through the rankings obtained by the MOORA-ratio method, the reference point approach, and the full multiplicative form (Table 16).

Table 16. Obtaining MULTIMOORA ranking

	MOORA-Ratio	Reference Point Approach	Full Multiplicative Form	MULTIMOORA
A_1	1	1	1	1
A_2	2	2	2	2
A_3	4	6	5	4
A_4	6/7	3/4/5	6/7	6/7
A_5	3	3/4/5	3	3
A_6	6/7	3/4/5	6/7	6/7
A_7	8	7	8	8
A_8	5	8	4	5

When the results in Table 16 are examined, it is seen that the 1st supplier is the best choice for the business according to the MULTIMOORA ranking obtained by considering the JIT supplier selection criteria. The Alternative 2 is the best choice as the second candidate. According to the results, the Alternative 7 emerged to be the last supplier to be preferred. It was observed that the Alternative 4 and the Alternative 6 shared the 6th and 7th ranks of preference together. According to these results, two alternative rankings were obtained: $A_1>A_2>A_5>A_3>A_8>A_4>A_6>A_7$ and $A_1>A_2>A_5>A_3>A_8>A_6>A_4>A_7$.

5. CONCLUSIONS

From the point of businesses, suppliers are critical stakeholders directly affecting the quality of products or services produced. Therefore, the selection and evaluation of suppliers is important for businesses. For firms that operate on a just-in-time basis, this importance is even greater. Especially in the automotive industry, suppliers are expected to pay extra attention to issues such as time, quality, flexibility, and so forth. In this study, the problem of supplier selection of a company operating in the automotive subsidiary industry and on a just-in-time production system was discussed. The supplier selection problem is a complex problem because of the need to assess together the subjective and objective information with different goals. For this reason, an integrated approach using the DEMATEL and MULTIMOORA methods was proposed in the study. The weights of the criteria determined and evaluated based on expert opinions were calculated by using the DEMATEL method, followed by the application of MULTIMOORA. The results obtained by applying the MOORA-Ratio Method, the MOORA-Reference Point Approach and the Full Multiplicative Form methods were combined using the ordinal dominance theory to determine the appropriate supplier.

The MULTIMOORA method is a method that has been contributed to the literature in recent years and provides rapid results. In future studies, the area of use of the technique can be further improved by applying it in combination with different methods in different multi-criteria decision-making problems.

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