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Application of Incomplete Analytic Hierarchy Process and Choquet Integral to Select the best Supplier and Order Allocation in Petroleum Industry

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A B S T R A C T

In a powerful industry, supplier selection is one of the complex processes that can increase productivity and competitive advantages. Supplier selection includes different quantitative, qualitative, and also interactive criteria. In addition, the selection process has always faced with inadequate and incomplete data. Multi-criteria decision making (MCDM) is a useful approach that can be applied, for addressing the opting problems of a supplier considering mentioned issues. In this approach, the interaction between criteria can be considered with several methods, such as Choquet integral, which is a practical method for decision ranking. Also, incomplete data can be covered with incomplete analytic hierarchy process (AHP) method. Therefore, in this study, an application of Choquet integral along with incomplete AHP method is provided for supplier selection problem at the petroleum industry. After achieving the ranking rate of suppliers, requested orders are assigned to preferred suppliers by using multi-objective linear programming (MOLP) model and ε-constraint method to generate the Pareto optimal points. As a result, supplier 3 with weight 0.8274 was the most preferred supplier in which 50% of total orders was assigned to this supplier as the best selection.

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1. INTRODUCTION

Reducing production costs in today's highly competitive organizations has always been a concern. Due to the large part of the total manufacturing cost, which is comprised of the cost of raw materials and components cost, selecting the most appropriate suppliers can significantly reduce the purchasing cost and increase the competitiveness of an organization. Companies endeavour to focus on their core business activities, and to outsource other activities. Subsequently, product quality, service delivery, and business performance are affected by the selection of supplier organizations. Increasing competition, market share, and business developments have altered the way of dealing with buyers and suppliers. Under these new circumstances, enhancing sustainable and collaborative relationships with suppliers can reduce costs and increase flexibility against market changes. To increase profits, organizations should select appropriate suppliers, enhance strategic relations, and interact in an effective manner with them.

Selecting appropriate suppliers is necessary for oil and gas refineries and organizations. Supplier selection is a complex operation for engineering, procurement, and construction (EPC) contracts, which are large and critical. Decision-making operation in supplier selection requires multiple criteria [1]. Therefore, this investigation has been directed towards supplier selection that is devised as a Multi-criteria Decision Making (MCDM) method. Besides, organizations should select some of the given suppliers and allocate the best order in conformity with their performance due to considered criteria [2].

MCDM techniques assorted by Ho, et al. [3] and incorporated for selecting suppliers [4]. All these

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methods have the potential to cover different preferences of decision-makers. However, one of MCDM techniques called AHP is employed in many supplier selection researches. In other words, in reality, most criteria and sub-criteria have interaction with each other [5]; while the conventional methods of decision-making consider that the criteria are autonomous and independent from each other. This assumption puts limits on representing the best alternative [6]. As a solution, Choquet Integral has been applied for considering interaction among criteria and sub-criteria; although this method has been used in a few cases with actual applications [7].

Here, incomplete AHP with absolute deviation method and Choquet integral are applied for supplier selection and order allocation model, based on considered refinery experts' opinion. In other words, the purpose of this study is to select suppliers and allocate the best and optimal orders to them through unclear and ill-defined information *via* two complementary MCDM methods that deal with the problem.

The study is organized as follows: section 2, provides an exhaustive literature review on incomplete AHP and Choquet integral, then section 3 introduces preliminaries of these methods. After that, in section 4, some information about the considered case study is given. Additionally, for allocating, the usage of incomplete AHP and Choquet integral for supplier selection and Multi-Objective Linear Programming (MOLP) are presented. In section 5, relates to the model are given. Section 6 ends the study with the conclusion and future work recommendations.

2. LITERATURE REVIEW

Industries have used various methods for supplier selection process in recent years. Selecting the most authentic suppliers and preserving long-run cooperation with them is one of the most crucial decisions for all industries, especially those that relate to the petroleum and refinery plants. Practical methods in selection procedure should be implemented since choosing the right suppliers, which include qualitative and quantitative elements, is an important issue [8]. Some methods try to select the best supplier and some others are look for ranking the suppliers based on the gained rate.

Fuzzy TOPSIS method mixed with AHP method for oil project selection [9], and the combination of SCOR, AHP and TOPSIS approaches for supplier selection in the gas and oil industry are examples in this area [10].

With considering the type of companies and materials, different methods have been used in an integrated supplier selection problem, such as AHP for supplier performance rating in gas and oil exploration and production companies [11-12], SWOT and fuzzy TOPSIS with linear programming for order allocations [13] and entropy weightings method with intuitionistic fuzzy TOPSIS to develop petroleum industry facilities [1].

Few studies in supplier selection through considering interaction between criteria exist. Fuzzy TOPSIS and generalized Choquet integral have been used separately to find a supplier selection problem [14]. In addition, to integrate criteria continuously, a method developed based on fuzzy integral was formulated [15]. Besides, AHP and fuzzy TOPSIS were used to identify the best suppliers, and a multi-period multi-objective optimization model was employed for allocating orders [16]. By taking subjective measures into account, fuzzy MULTIMOORA for selecting suppliers and fuzzy goal programming for deciding about the quantity of order allocation were used [17]. Meanwhile, by considering all-unit quantity discounts and two sets of criteria separately: traditional and green, fuzzy TOPSIS and AHP were implemented in supplier selection problem. Afterward, a single-product bi-objective integer linear programming model was used to allocate orders [18]. On the other hand, based on the mentioned studies, the application of incomplete AHP method was reviewed in this field. Pairwise comparison matrix (PCM) is an essential part of AHP. However, in many cases, it is hard to be completed and this makes incomplete information. Geometric mean, as a basic method, method was proposed by Harker [19]. Many subsequent studies were suggested by Harker's method as different methods to calculate the weights of criteria in incomplete AHP, as discussed in literature [20-21]. To this end, the least square method (LSM) is an effective one. Several studies deal with incomplete information by this method in order to estimate the comparative weight of alternatives [22]. In some of them, the logarithmic form of LSM (LLSM) has been used to solve nonlinear systems of LSM [23-25]. Additionally a homotopy procedure has been introduced [26]. In numerous studies, the LSM method was developed [27-28] in incomplete form by considering limitation on ordinal consistency. This opinion was approved by the equivalent multiplicative and additive form of LLSM. Other studies have been presented an explanation of multiplicative consistent by the LLSM method in an incomplete fuzzy preference relation [29]. By considering all of these applications, one can realize that LLSM is a simple, fine-tunable method for calculating the weight of incomplete AHP. To best of our knowledge and according to previous studies, with incomplete data, combination of incomplete AHP and Choquet integral has not been investigated. Whilst in many real-world case studies, there are always flaws in the received information from decision makers and in other hand, the criteria are not independent, and hence ignoring these facts will cause deviations from right decisions.

Therefore, in this study, we have tried to introduce a combination method of incomplete AHP and Choquet integral by minimizing the percentage error of decisions and considering the interactions between criteria. Then, a novel multi-objective model was introduced for allotting order to suppliers, with considering products guarantees.

3. PRELIMINARIES

3. 1. Analytic Hierarchy Process (AHP)

AHP has been applied in multi-criteria decision-making (MCDM) to identify priority of alternatives. The concept of this method is to illustrate the problem by using a hierarchy process that is, in fact, a presentation of the entire problem [30].

Based on this hierarchy process, the preference of alternatives can be obtained from the comparison operation by the decision-maker (DM) [31]. These preferences are presented as pairwise comparison matrix (PCM) by a 1 to 9 ratio scales as Table 1.

Definition 1. A matrix M is called pairwise comparison if it complies the condition $a_{ij} = \frac{1}{a_{ji}}$ for all $i\ ,j$.

Definition 2. A matrix M is called consistent if it complies with the condition $a_{ij}.a_{jk} = a_{ik}$ for all i, j, k.

Preferences of decision-makers are declared subjectively; as a result, it is sensible for the existence of inconsistency in the decision matrix. To measure the degree of this inconsistency, the consistency index (CI) is presented by Saati [32].

If λ_{max} gives the eigenvalues of matrix M as follow:

$$M.W = \lambda_{max}.W \quad (1)$$

Then CI and consistency ratio (CR) is calculated in the following order:

$$CI = \frac{\lambda_{max}-n}{n-1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

TABLE 1. Saati's scales

Explanation	Definition	Score
Two criteria are of equal importance	equal importance	1
The importance of i is a little more than j	a little more importance	3
The importance of i is more than j	more important	5
The importance of i much more than j	much more importance	7
i is of absolute importance than j	absolute importance	9
When there are intermediate modes	intermediate modes	2,4,6,8

IfCR <0.1, the comparison matrix is accepted; otherwise, the preferences of the DMs are adjusted until CR <0.1 [32].

Definition 3. Random index (RI) depends on the dimension of the comparison matrix that is given as Table 2 [32].

Definition 4. An incomplete pairwise comparisons matrix M is like as below, where the * mark indicates unknown elements:

$$\boldsymbol{M}=\begin{bmatrix} 1 & * & a_{13} \\ * & 1 & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix}$$

3. 1. 1. Least Square Method for Incomplete AHP

It is necessary to assess the incomplete information for determining the weights [33]. Therefore, LSM can be used in incomplete AHP to calculate the ratings as follows. The objective function is sum of the square of errors and the constraints represent the weighting conditions:

$$\begin{aligned} & min \sum_{i=1}^{n}\sum_{j=1}^{n} \delta_{ij}\,(a_{ij}w_j - w_i)^2 \\ & s.t\ \ \sum_{i=1}^{n} w_i = 1 \\ & w_i \geq 0, i = 1,2,\dots,n \end{aligned} \quad (4)$$

Where $\delta_{ij}=\begin{cases}0 & a_{ij}\ is\ missing \\ 1 & otherwise\end{cases}$

3. 2. Choquet Technique

By considering monotonous property, which can substitute additive property with a monotony property, and taking into account the potential interplay between criteria on computation, the importance of criterion and their coalitions are implied by fuzzy measurement theory method to the model [33].

Definition 5. Where $F(X)$ is power set for the finite set of criteria x =$\{x_1, x_2\ \dots x_n\}$. So, μ can be defined on $F(X)$ as non-additive fuzzy capacity with following properties [34].

- Boundary condition: $\mu(\varphi)$ =0& $\mu(x) = 1$
- Monotonicity condition: $If\ A_1, A_2\ \epsilon\ F(x) \& A_1 \subseteq A_2, then\ \mu(A_1) \leq \mu(A_2)$

3. 2. 1. Calculating λ_Fuzzy Measure

Definition 6. The λ_fuzzy measure presents the interaction between each paired set like A_1 and A_2, according to the following equation:

$$\mu(x) = \begin{cases} -\frac{1}{\lambda}[\prod_{i=1}^{n}\left(1+\lambda\mu(x_i)\right)-1] & \text{if } \lambda \neq 0 \\ \sum_{i=1}^{n}\mu(x_i) & \text{if } \lambda = 1 \end{cases} \quad (5)$$

TABLE 2. Random index

N	3	4	5	6	7	8	9	10
R$_i$	0.58	0.9	1.12	1.1	1.3	1.41	1.45	1.49

The λ parameter can be implied by boundary condition $\mu(x) = 1$, which is resulted by the following equation.

$$\lambda + 1 = \prod_{i=1}^{n}(1 + \lambda\mu(x_i)) \quad (6)$$

where μ is the fuzzy capacity on power set $F(X)$, and $A_1 \cap A_2 = \emptyset$. Thus, the following equation is demonstrated [33]:

$$\mu(A_1 \cup A_2) = \mu(A_1) + \mu(A_2) + \lambda\mu(A_1)\mu(A_2)$$
$$\text{Of which } \lambda \epsilon [-1, \infty] \ \forall A_1, A_2 \in F(x) \quad (7)$$

3. 2. 2. Ranking Alternatives through the Choquet Fuzzy Integral

Definition 7. Let f be a measurable function on the set x $=\{x_1, x_2, ..., x_n\}$, and μ be a fuzzy capacity on x then:

$$\int f d\mu = \sum_{i=1}^{n} \mu(x_i)[\, h\,(x_i) - h\,(x_{i-1})] \quad (8)$$

And also the following equation is considerable [3].

$$\int f d\mu = f(x_n).[\, \mu\,(H_n) - \mu\,(H_{n-1})] + f(x_{n-1})$$
$$.\, [\, \mu\,(H_{n-1}) - \mu\,(H_{n-2})] + ... + f(x_1).\, \mu\,(H_1) \quad (9)$$

Where $H_1 = \{x_1\}$, $H_2 = \{x_1, x_2\}$... $H_3 = \{x_1, x_2, ..., x_n\}$
Total weight of each supplier can be calculated with the fuzzy integral, which is determined in Equation (9) by addressing the Choquet integral. As mentioned, by using of the fuzzy integral, the interactions between criteria and sub-criteria have also been considered.

3. 3. Multi-objective Order Allocation Model

Assumption:

i. Demand is constant
ii. For any suppliers, shortage of the supplied product is not allowed
iii. Transportation cost, holding cost and ordering cost is including in purchasing price
iv. Single-Product is ordered from supplier with any quantity.

Index	
i	Index for suppliers = 1, 2... *n*.
Variable	
x_i	product order quantity from supplier i.
Parameters	
c_i	The product supply capacity of supplier i.
p_i	Purchasing price of products from supplier i.
Q	Maximum allowed defect value of the products.
q_i	Average defect percentage of the products from supplier i.
L	Maximum allowed late delivery value of products.
d_i	Percentage of products delivered late by supplier i.
D	Demand for the products
W_i	Overall weight of supplier i obtained by Choquet integral
g_i	Percentage of the products that use guarantees by the supplier i.
G	Maximum allowed value of the products that need to be guaranteed

Objective Function:

$$\text{Min } Z_1 = \sum_{i=1}^{n} P_i\, x_i \quad (10)$$

$$\text{Max } Z_2 = \sum_{i=1}^{n} W_i\, x_i \quad (11)$$

Here, two objective functions are explained: cost and total efficiency.

Equation (10) minimizes the total cost, and Equation (11) represents the applicable aim to maximize the organizational efficiency by the received results from Choquet.

The constraints are presented as below:

$$\sum_{i=1}^{n} x_i = D \quad (12)$$

$$x_i \leq C_i \quad (13)$$

$$\sum_{i=1}^{n} q_i\, x_i \leq Q \quad (14)$$

$$\sum_{i=1}^{n} d_i\, x_i \leq L \quad (15)$$

$$\sum_{i=1}^{n} g_i\, x_i \leq G \quad (16)$$

$$x_i \geq 0 \quad (17)$$

They include demand satisfaction, the capacity of suppliers, banned admissible amount of quality rejection, the allowed value of late delivery quantities, allowed value of products that need to be guaranteed, and non-negativity constraint, respectively.

3. 3. 1. The Augmented ε-Constraint Method

The ε-constraint method is a well-known method for solving MOLP models to find a set of Pareto solutions. One of the ε-constraint methods that has been developed by Equation (18) is AUGMECON [35]. In this method, one objective function is optimized and the other objective functions act as constraints.

$$Max(z_1(x) + \varepsilon \times (s_2/r_2 + s_3/r_3 + ... + (s_p/(r_p)) \quad (18)$$

where ε is a sufficient slight number (generally between 10^{-3} and 10^{-6}), r_i is the variable range of ith objective function, and s_i is surplus or slack variable.

$$r_i = PIS_{\text{fi}} - NIS_{\text{fi}} \quad (19)$$

In Equation (19) PIS_{fi} and NIS_{fi} are ideal positive and negative solutions for ith objective function that are resulted from solving the model, only through this objective function.

Therefore, the linear programming model of order allocation problem, which includes two objectives and five sets of constraints, is calculated by the AUGMECON method with the help of GAMS (General Algebraic Modeling System) software.

4. CASE STUDY

In this section, application of the developed model based on a real-world case is explained to show its utility. The actual production demand data was provided by a case company for developing a new combination model of incomplete AHP, Choquet Integral, and MOLP to select suppliers and find an order plan.

4. 1. Explanation of the Subject and Recognition of Criteria

Heretofore, for supplier selection and order allocation problem, several MCDM techniques have been developed, however, the present combined model in this study was unnoticed. In addition, each main issue has been analyzed separately, and supplier selection and order allocation problems are discussed in two parts. An oil refinery is the case study, which plays a strategic role in the country's economy. Over the past few years, with the increase in foreign sanctions on Iran, oil companies were excluded from the oil and gas projects, and hence, the projects have been outsourced to domestic startups. Therefore, selecting appropriate suppliers and allocating the best orders is a vital issue for refinery's managers and has a significant and critical impact on the country's economy. In addition, if suppliers can encounter a refinery's requirements though right order allocation, the refinery can work in an efficient manner and raise benefits.

Through the numerous deliberation and discussions with refinery's experts, based on desired products, reputation, history, competitive market advantage, and current strategies and by reviewing the pertinent studies, the criteria and sub-criteria for supplier selection problem were procured, so that 10 criteria were selected as shown in Table 3. Additionally, based on the supplier's product capacity, proposed price, location and delivery time, 5 potential alternatives (suppliers A1 to A5) were considered. Accordingly, the procedure of this study and the hierarchical process were developed and depicted in Figures 1 and 2, respectively.

TABLE 3. The criteria and sub-criteria for supplier selection

Criteria			Sub criteria	References
D_1	Cost	c_{11}	Material costs	[2] [10] [13] [36]
		c_{12}	Transportation costs	[2] [10] [37]
D_2	Delivery	c_{21}	On-time delivery	[11] [37]
		c_{22}	Delivery time	[11] [36]
		c_{23}	Delivery capability	[37] [38]
D_3	Quality	c_{31}	Quality of product	[11] [17]
		c_{32}	Quality control & standards	[2] [11] [13]
		c_{33}	Quality certification	[1] [10] [11]
D_4	Service	c_{41}	after-sales services	[13] [37]
		c_{42}	guarantees	[1] [37]

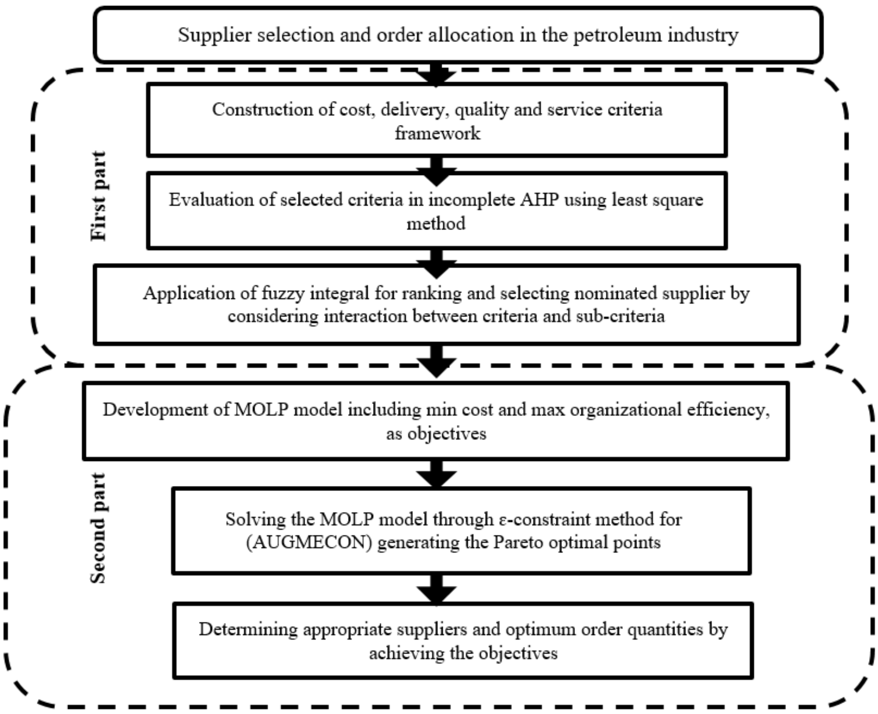

Figure 1. The procedure of this study

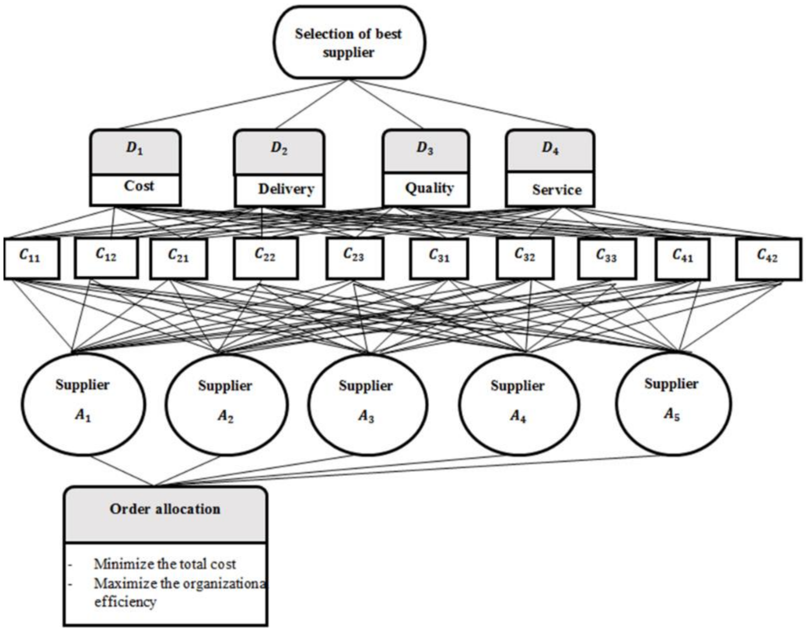

Figure 2. The hierarchical process of this study

4. 2. Matrix Collection and Processing The mathematical computation in the AHP is simple, however, when dealing with incomplete information, this computation becomes more challenging. In this study, 16 primary $PCMs$ were provided by 20 experts based on the criteria. Finally, several $PCMs$, as shown in Tables 4 (as an example) and 5 (as conclusion), were incomplete based on the following reasons:

- Lack of experts' knowledge
- Lack of experts' time

According to below incomplete $PCM(iPCM)$, for instance, regarding SC2 based on M = $(m_{ij})_{5\times5}$ $(i,j = 1,2,\dots,5)$, m_{24} and m_{35} are two pairs of missing values.

$$\begin{bmatrix} 1 & 6.09 & 14.65 & 2.40 & 7.94 \\ 0.16 & 1 & 1.64 & * & 1.51 \\ 0.20 & 0.60 & 1 & 2.55 & * \\ 0.41 & * & 0.39 & 1 & 1.64 \\ 0.12 & 0.65 & * & 0.60 & 1 \end{bmatrix}$$

The issue is that what the method should be used in $iPCMs$ for calculating the weight of criteria. In this section, the least square method (LSM) is applied by Equation (4) for calculating the weights (in both complete and incomplete $PCMs$) and the results are shown in Table 5, and local and global weights of alternative A_1 (as a sample) are summarized in Table 6. After calculating all the pairwise comparison matrices, the next step is to calculate the consistency of $PCMs$ by Equation (3). Since CR is less than 10%, the $PCMs$ can be considered consistent. Therefore, as a result of the Table 5, all $PCMs$ and total hierarchical processes are consistent.

4. 3. Implementing Choquet Technique Although the petroleum industry is a sensitive and tense industry and plays a very strategic role in the country's economy so, the right and accurate measurement can be very effective. However, surprisingly, the interaction between criteria and sub-criteria is often overlooked in its evaluations, analyses and decisions. Choquet Integral is able to consider certain types of interaction between criteria, and it makes Choquet Integral a powerful and necessary tool in petroleum industry decision making. In this section, the interaction among criteria is assessed by implementing the Choquet integral technique.

Mono and multi-members of fuzzy capacity sets, are extracted from the result of AHP as summarized in Table 7. To illustrate the calculations of Choquet integral, the calculation of D_2 for A_1 is presented as an example in Figure 3.

Finally, Table 8 represents the rate of each alternative, which is obtained from computing by Equation (9). The rank of each alternative is specified as $A_3 > A_1 > A_5 > A_4 > A_2$.

TABLE 4. Incomplete PCM for c_{12}

Transportation costs	A_1	A_2	A_3	A_4	A_5
A_1	1	6.093	4.959	2.408	7.949
A_2	0.164	1	1.643	*	1.515
A_3	0.201	0.608	1	2.550	*
A_4	0.415	*	0.392	1	1.643
A_5	0.125	0.659	*	0.608	1

TABLE 5. λ_{max} and consistency rate (CR)

Pairwise Comparison Matrix	Complete	Incomplete	LSM	Weight	λ_{max}	CR	CR<0.1
PCMs for criteria		✓	✓		4.03	0.01	✓
PCMs for sub criteria	✓		✓		11.27	0.09	✓
PCMs for alternatives to SC1	✓		✓	0.32	5.44	0.09	✓
PCMs for alternatives to SC2		✓	✓	0.08	5.33	0.08	✓
PCMs for alternatives to SC3		✓	✓	0.17	5.29	0.03	✓
PCMs for alternatives to SC4	✓		✓	0.18	5.43	0.09	✓
PCMs for alternatives to SC5		✓	✓	0.06	5.40	0.08	✓
PCMs for alternatives to SC6	✓		✓	0.07	5.49	0.10	✓
PCMs for alternatives to SC7		✓	✓	0.05	5.45	0.10	✓
PCMs for alternatives to SC8	✓		✓	0.026	5.36	0.08	✓
PCMs for alternatives to SC9	✓		✓	0.004	5.41	0.09	✓
PCMs for alternatives to SC10		✓	✓	0.003	5.35	0.07	✓
PCMs for alternatives to C1	✓		✓	0.304	5.20	0.04	✓
PCMs for alternatives to C2	✓		✓	0.387	5.14	0.03	✓
PCMs for alternatives to C3	✓		✓	0.262	5.41	0.09	✓
PCMs for alternatives to C4	✓		✓	0.047	5.29	0.06	✓
Total hierarchical process						0.07	✓

TABLE 6. Local and global weights of alternative A_1

A_1		Local	Global			Local	Global			Local	Global			Local	Global
D_1		0.119		D_2		0.109		D_3		0.368		D_4		0.305	
	c_{11}	0.319	0.037		c_{21}	0.28	0.03		c_{31}	0.32	0.117		c_{41}	0.297	0.09
	c_{12}	0.1	0.011		c_{22}	0.227	0.024		c_{32}	0.109	0.04		c_{42}	0.103	0.031
					c_{23}	0.216	0.023		c_{33}	0.119	0.043				

TABLE 7. Criteria and sub criteria of fuzzy measures

Mono fuzzy measures		Multi fuzzy measures		
$\mu(D_1)$	0.301	$\mu(D_1, D_2)$	0.537	$\mu(D_1, D_2, D_3)$
$\mu(D_2)$	0.278	$\mu(D_1, D_3)$	0.533	$\mu(D_1, D_2, D_4)$
$\mu(D_3)$	0.273	$\mu(D_1, D_4)$	0.534	$\mu(D_2, D_3, D_4)$
$\mu(D_4)$	0.146	$\mu(D_2, D_3)$	0.513	
		$\mu(D_2, D_4)$	0.404	
		$\mu(D_3, D_4)$	0.4	
		$\mu(D_1, D_2, D_3, D_4)$		1
$\mu(c_{11})$	0.32	$\mu(c_{11}, c_{12})$	1	
$\mu(c_{12})$	0.08			
$\mu(c_{21})$	0.17	$\mu(c_{21}, c_{22})$	0.389	
$\mu(c_{22})$	0.18	$\mu(c_{21}, c_{23})$	0.34	$\mu(c_{21}, c_{22}, c_{23})$
$\mu(c_{23})$	0.06	$\mu(c_{22}, c_{23})$	0.349	
$\mu(c_{31})$	0.07	$\mu(c_{31}, c_{32})$	0.395	
$\mu(c_{32})$	0.05	$\mu(c_{31}, c_{33})$	0.216	$\mu(c_{31}, c_{32}, c_{33})$
$\mu(c_{34})$	0.026	$\mu(c_{32}, c_{33})$	0.147	
$\mu(c_{41})$	0.004	$\mu(c_{41}, c_{42})$	1	
$\mu(c_{42})$	0.003			

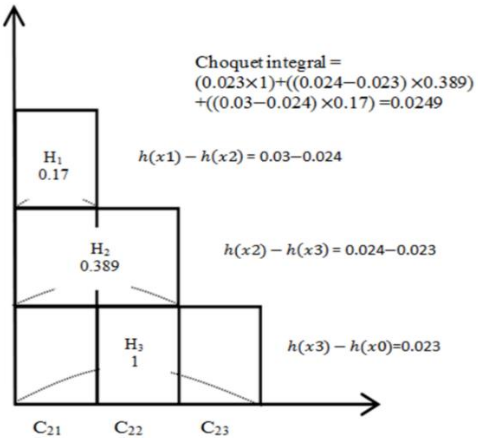

Figure 3. Choquet integral calculation for criteria D2

TABLE 8. The rate of alternatives

Suppliers	Rate	Rank
A_1	0.1089	2
A_2	0.0137	5
A_3	0.8274	1
A_4	0.0139	4
A_5	0.0137	3

4. 4. Order Allocation Problem In this part, the order allocation problem for five potential suppliers is presented. The objective functions and constraints of the considered model were described in earlier sections. The extent of the best and optimal order for suppliers is calculated by Equations (10) to (17). Due to the suppliers' ability and capability, and refinery's demands, the following quantities are afforded: (Q = 0.22 %; L = 0.39 %; G = 0.305**%;** D=5000 (Ton)), the capacity values and other information of each supplier are presented in Table 9.

In Table 9, capacity and purchasing price of each supplier are adapted by refinery's experts and average percentage of defect products (q_i), products delivered late (d_i), and products that use guarantees (g_i) are obtained from pairwise comparison matrices (PCM) in previous sections.

Objective function

MinZ_1 = 540 x_1+570x_2+580x_3+570x_4+550x_5

Max Z_2 = 0.1089x_1+0.0137x_2+0.8274x_3+ 0.0139x_4 +0.0362x_5

Subject to

$x_1+x_2+x_3+x_4+x_5=5000$

$x_1 \leq 1500$

$x_2 \leq 1000$

$x_3 \leq 2500$

$x_4 \leq 2000$

$x_5 \leq 1500$

$$\sum_{i=1}^{n} q_i\, x_i \leq 1100$$

$$\sum_{i=1}^{n} d_i\, x_i \leq 1950$$

$$\sum_{i=1}^{n} g_i\, x_i \leq 1525$$

$x_i \geq 0$, i=1…5

5. THE RESULT, SENSITIVITY ANALYSIS AND DISCUSSIONS

The augmented ε-constraint method produced 6 optimal Pareto solutions for order allocation calculation, as shown in Table 10. The augmented ε-constraint method determined the same number of interval solutions, by using grid points with equal distances. To get the preferable solution, each pair of optimal objective functions were depicted in Figure 4, which compares Pareto solution of objectives $z_1$and z_2; and also product order quantity of each Pareto solution were shown in Figure 5. Finally, decision makers of the company selected solution number 6 as the most efficient solution. The optimal total cost, and the organizational efficiency based on this solution were z_1=27535.98, z_2=1408.45, and order allocation were x_1= 1500, x_2=340, x_3= 2500 x_4= 0, x_5 =660. Furthermore, in this solution, supplier A_3 gained the most weight and A_1 and A_5 were in the next, respectively; it is obvious that supplier A_3 was assigned 50%, supplier A_1 30% and supplier A_5 13.2% of total orders. It demonstrated that the weight of the criteria had relative importance, in the solution of objective functions.

The validation of proposed approach has been considered in two parts:

The first part relates to the assessment of pair-wise comparison matrices that has been done by calculating the amount of CR according to the Equation (3) and controlling of them (CR < 0.1).

In second part, at first, incomplete PCMs obtained were completed by Harker and LSM methods, and then global weights of criteria and total rank of alternatives have been obtained by TOPSIS and SAW as benchmark methods. The results of the comparison and ranking of suppliers were reported in Table 11.

TABLE 9. Capacity values of suppliers

Suppliers	A_1	A_2	A_3	A_4	A_5
C_i(Ton)	1500	1000	2500	2000	1500
p_i ($/Ton)	540	570	580	570	550
q_i (%)	0.368	0.04	0.444	0.077	0.071
d_i (%)	0.109	0.088	0.614	0.074	0.115
g_i (%)	0.305	0.057	0.421	0.042	0.176

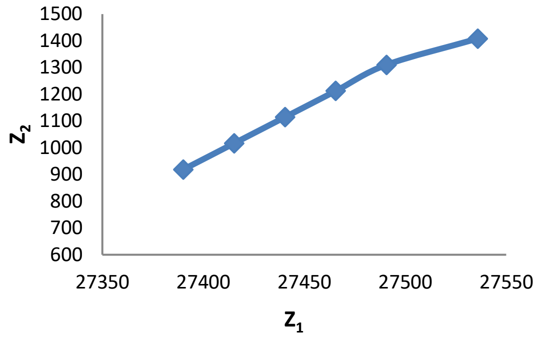

Figure 4. Pareto solution of objectives

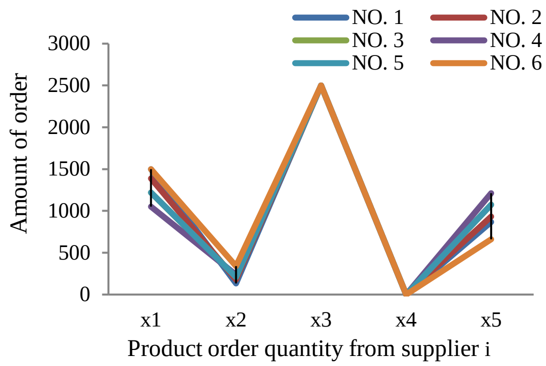

Figure 5. Optimal pareto solution of product order quantities

Clearly, the ranking of suppliers A_3>A_5> A_1>A_4>A_2 is approximately similar to the results of current study. The differences can be justified by interaction between criteria because of applying the Choquet technique, and the comparison confirms authentic results in the selected case.

TABLE 10. Optimal Pareto solution produced by the augmented ε-constraint method

NO	Z_1	Z_2	x_1	x_2	x_3	x_4	x_5
1	27390.05	918.59	1500	133	2500	0	867
2	27415.24	1016.56	1387	180	2500	0	933
3	27440.43	1114.54	1219	208	2500	0	1073
4	27465.61	1212.51	1051	236	2500	0	1213
5	27490.8	1310.48	1219	208	2500	0	1073
6	27535.98	1408.45	1500	340	2500	0	660

In addition, the sensitivity analysis was conducted for the MOLP model. At first, by replacing the weights of alternatives obtained from the combination techniques with the coefficient of the second objective function that shown organizational efficiency, and then by assessing coefficient of parameters (q_i), (d_i) (g_i) obtained from LSM or Harker method, MOLP model have been solved with augmented ε-constraint method. It is noteworthy that in all benchmark methods, the same Pareto solutions were obtained. The optimum results were summarized in Table 12. The obtained weights from Choquet method had significantly effect on MOLP model and order allocation problem. Moreover, the results shown that, similar to the presented results of the first part supplier A3 gained the greatest order.

In a real case, the opinions' inconsistency of experts, lack of experts' time, interconnection between criteria, to name but a few, can lead to the incomplete data and incorrect results. As a result, managers should use specific and appropriate solution methods to deal with this incomplete and inaccurate information. The proposed solution method can help experts to make better decisions.

TABLE 11. Comparative results with different benchmark techniques

	Topsis & Harker	Rank	Topsis & LSM	Rank	Saw & LSM	Rank	Choquet & LSM	Rank
A_1	0.1797	3	0.7989	3	0.1088	2	0.1089	2
A_2	0.00032	5	0.2008	5	0.0137	5	0.0137	5
A_3	0.8859	1	0.983	1	0.8271	1	0.8274	1
A_4	0.0108	4	0.7978	4	0.0139	4	0.0139	4
A_5	0.5323	2	0.8012	2	0.0362	3	0.0137	3

TABLE 12. Sensitivity analysis with different weights

	Z_1	Z_2	x_1	x_2	x_3	x_4	x_5
Topsis & Harker	27575.53	2760.58	561	439	2500	0	1500
Topsis & LSM	27419.99	1810.54	780	453	2323	0	1414
Saw & LSM	27535.98	1407.62	1500	620	1449	0	1431
Choquet & LSM	27535.98	1408.45	1500	340	2500	0	660

Applying the presented method can provide appropriate orientation for achieving important decision goals. These results shows that this method can be a promising method to decide precisely in order to attain more organized performance in the state of incomplete and inaccurate data, especially in petroleum industry.

For future researches, this study can be extended by considering the role of some essential parameters such as quantity discount and lead time. Green supplier selection with sustainable criteria will be attended as another recommendation; additionally, uncertain parameters can be added to the robust or stochastic MOLP model.

6. CONCLUSION

In recent years, by handing over oil and gas projects to domestic startups, selecting appropriate suppliers and allocating suitable orders to them are basic problems for petroleum companies, which have significant and critical impacts on the country's economy.

This study discusses the supplier selection via two complementary MCDM methods; AHP with the least square method for unclear and incomplete information, and Choquet technique for considering the existing interaction between criteria. Furthermore, the order allocation problem was applied by developing the MOLP model to minimize the total cost and maximize the organizational efficiency by the Choquet technique, and then it was solved by the augmented ε-constraint method. At result, some optimal Pareto solutions were produced that one of them was selected from the reported solutions by the managers. The numerical results and sensitivity analysis were used to examine the weights resulted from the first part through the comparison with some benchmark methods. The results showed the similarity of the presented results with the gained previous results in benchmark methods.

Likewise, the sensitivity analysis of coefficient was preformed to check the effects of parameter and objective weights in the order allocation model (second part) through the same benchmark methods. It was obvious that second objective plays an important role and simultaneously, it confirms the impact of Choquet integral technique by considering interaction between criteria in order allocation problem.

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Persian Abstract

چکیده

انتخاب تأمین کننده از فرآیندهای پیچیده ای است که می تواند بهره وری و مزیت رقابتی را در یک صنعت قدرتمند افزایش دهد. انتخاب تامین کننده دارای معیارهای مختلف، از قبیل معیارهای کمی، کیفی و معیارهایی است که برهم کنش، بین آنها وجود دارد. به علاوه فرایند انتخاب، همواره با داده های ناکافی و ناکامل مواجه است. تصمیم گیری چند معیاره (MCDM) رویکرد مفیدی است که می تواند در مسئله انتخاب یک تامین کننده با در نظر گیری چالشهای مورد اشاره بکار گرفته شود. در این رویکرد، برهم کنش بین معیارها را می توان با روش هایی مانند انتگرال چوکوئت ، که روشی کاربردی برای رتبه بندی در فرایند تصمیم گیری است، در نظر گرفت. همچنین ناکافی بودن داده ها توسط روش AHP ناقص می تواند پوشش داده می شود. بنابراین، در این مطالعه به منظور انتخاب تأمین کننده در صنعت نفت ، از انتگرال چوکوئت همراه با روش AHP ناقص استفاده شده است. تخصیص سفارشات درخواستی با استفاده از مدل برنامه ریزی خطی چند هدفه (MOLP) و روش اپسیلون محدودیت برای تولید نقاط بهینه پارتو ، پس از دستیابی به رتبه بندی تأمین کنندگان انجام شده است. نتایج نشان می دهد که ، تامین کننده ی سوم با وزن ۰.۸۲۷٤ ارجح ترین تامین کننده است که بر این اساس ۵۰٪ از کل سفارشات به این تامین کننده به عنوان بهترین انتخاب، تخصیص داده شده است.