Transactions of the Nigerian Association of Mathematical Physics
Volume 8, (January, 2019), **p85 –92**
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MULTI - CRITERIA DECISION MAKING METHODS FOR SUPPLIER SELECTION: A STATE OF THE ARTS REVIEW

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Abstract

This paper presents a state of the arts review of the existing methods for solving the supplier selection problem. The selection of suppliers is a Multi-Criteria Decision Making (MCDM) problem. It requires the evaluation of both qualitative and quantitative factors. This paper examines methods of evaluating the (MCDM) problem and identify gaps and lapses associated with the existing methods. The major contribution of this paper is that it provides timely pieces of information that is expedient to the improvement of contemporary supplier evaluation and selection processes. The paper also proposes new research agenda.

1. INTRODUCTION

Supplier selection is a multi-criteria decision making (MCDM) problem. Every supplier cannot excel in all attributes identified by an organization. The scores of each alternatves with respect to the attributes are not the same. This is the epicentre of supplier selection problem. Therefore, there is need to use scientific and objective method in the evalution and selection of suppliers. To this end this paper review the literature for supplier selection methods with a view of identifying gaps and proposing new research frontiers.

The supplier selection problem can be stated mathematically as follow [1]:

Decision factors	Mathematical formulation
Suppliers or alternative set	$A = \{A_1, A_2, \cdots A_m\}$
(DM) set	$E = \{e_1, e_2, \cdots e_I\}$
Criteria or attributes	$B = \{b_1, b_2, \cdots b_n\}$
(D M) weights	$\Omega = (\omega_1, \omega_2 \cdots \omega_I)$
Criterion weights	$W = \{w_1, w_2, \cdots w_n\}$
Individual decision matrix	$d_{ij} = (\mu_{ij,}\ v_{ij,}\ \tau_{ij})$
Final (weighted) decision matrix	$D = (\mu_{ij,}\ v_{ij,}\ \tau_{ij})$.

Aggregating this variables to select the best supplier is the supplier selection problem.

It is crucial to carryout in-depth study on evaluation and selection of suppliers since they can perform a pivotal role in increasing customer's satisfaction by improving the quality of product, cost reduction and improves competitive ability [2]. It is observed from the literature of this work that there is existence of gaps in the evaluation and selection procedures adopted in the existing models in literature.

To this end, the findings from this work will be beneficial and useful to reseachers, scholars and organization who are working on MCDM problems. It would provide ample opportunities for them to begin their research activities. This work would also be useful to decision makers in industries and organizations who are faced with MCDM problems everyday.

2. SUPPLIER SELECTION METHODS IN THE LITERATURE

Supplier evaluation and selection has been studied extensively [3]. Various decision making approaches have been proposed to tackle the problem. In contemporary supply chain management, the performance of potential suppliers is

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evaluated against multiple criteria rather than considering a single factor –cost [3]. They [3] review 78 articles and literature of the multi-criteria decision making approaches for supplier evaluation and selection from 2000 to 2008. The paper considered the methods that have been used in addressing MCDM problem during this period [3]. The work not only provides evidence that multi-criteria decision making approaches are better than the traditional cost-based approach, but also aids the researchers and decision makers (DM) in applying the approaches effectively [3]. This paper examined 31 methods, 14 pure breed methods and 17 integrated (hybrid) methods. The pure breed methods and the integrated (hybrid) methods and the gaps and limitations associated with the methods are shown in Table 1 and Table 2 respectively.

Table1: Pure Breed Methods

S/N	METHODS(PURE BREED)	GAPS/LIMITATIONS	AUTHORS(CITATIONS)
1.	Analytical Hierarchy process (AHP)	Inconsistency in results whenever a new alternative is introduced in the selection process.	([4],[5],[6][7],[8]).
2.	Analytical Network Process (ANP)	One of the problems of both the AHP and ANP is their intuitive and compromise nature of the models. This makes the models subjective and may not provide the exact solution to the problem.	[9].
3.	Case-Based Reasoning (CBR)	The CBR model retrieve the past performance of the suppliesr from the data base and select the right supplier base on the specified condition, the limitation for this model is not very clear.	[3].
4.	Mathematical Programming (MP)	The major limitation in using this method to supply selection programme is the complexity of the problem which in many cases may be computationally difficult or intractable.	([10],[11],[12]).
5.	Data Envelopment Analysis (DEA)	Problem may be computationally intractable. Again, the DEA model mainly on input and output analysis which is not sufficient in supplier evaluation and supplier process because in such a situation, many other factors or attributes for contemporary supplier selection will be neglected.	([13],[14],[15]).
6.	Fuzzy Set (FS)	Inacurate or approximate solution.	[16].
7.	Simple Multi-Attribute Rating Technique (SMART)	the problem of chosen the right value function which may be very complex and difficult.	[17].
8.	Genetic Algorithm (GA)	Method cannot be used in isolation and does not guanrantee optimal solution.	([18],[19],[20]).
9	Intuitionistic Fuzzy Set (IFS)	Obtaining precision in membership grades is one of the major drawbacks of this method.	([21],[22],[1],[23],[24],[25],[26]).
10.	Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Different metric functions contradictions may produce contadictory ranking of suppliers.	([24],[25],[26],[27],[28],[29]).
11.	Artificial Neural Network (ANN)	It drawback is lack of expertise and precision to the solutions obtain from the model.	([30],[31]).
12	Bio-Negotiation (BN)	Negotiate on the attributes or factors is done before any deal is contracted. The drawback is not clear in literature.	[3].
13.	Superiority and Inferiority Ranking (SIR)	This method cannot be used in isolation.	[1].
14	Inventory approach	Method is centered on cost minimization without consideration on qualitative factors.	([3],[32]).

Table 2: Integrated(Hybrid) Methods

S/N	METHODS(HYBRID)	GAPS/LIMITATIONS	AUTHORS(CITATIONS)
1.	Integrated Intuitionistic fuzzy TOPSIS	Existence of contradictory ordering with different metric functions	([24], [25],[26],[22],[33]).
2.	Integrated AHP and Bi-negotiation	Same as AHP	[3].
3.	Integrated AHP and DEA	Same as AHP but the more robust than DEA.	([3],[13],[14]).
4.	Integrated AHP, DEA, and ANN	Same as AHP but the more robust than DEA.	[3].
5.	Integrated AHP and GA	Same as AHP	([3],[34],[20]).
.6.	Integrated AHP with Mathematical Programming	Same as AHP but the more computationally tractable.	([12],[35]).
7.	Integrated Fuzzy and AHP	Same as AHP with approximate solutions.	[3].
8.	Fuzzy-AHP-Cluster Analysis	Same as AHP with approximate solutions.	[3].
9.	Integrated Fuzzy and GA	Lack of precision or exact solution	([36],[19],[20]).
10.	Fuzzy-multi-Objective programming	Approximate solution and computational intractable problems.	([12],[35]).
11.	Integrated Fuzzy and SMART		[17].
12.	ANP-andMulti-objective Programming	Same with ANP with computational intratable probems	[35].
13.	Integrated DEA and SMART	Same with DEA	([14],[15]).
14	Integrated GA and Mathematical Programming	computational intractable probems	([12],[14],[15],[35]).
15.	GA and multi-Objective programming	computational intractable probems	([19],[20],35).
16	Integrated ANN and CBR	Same as ANN	([3],[30],[31])
17.	Integrated ANN and GA	Same as ANN	[3].

In section 3 and 4 this paper gives a brief treatment of intuitionistic fuzzy set (IFSs) and intuitionistic fuzzy TOPSIS.

3. Intuitionistic Fuzzy Sets (IFSs)

Intuitionistic Fuzzy Set (IFSs) extends the membership function of fuzzy set by including both non-membership and hesitation functions into the model ([1][16],[21],[22].[23]).

Intuitionistic Fuzzy Set A in a finite set U can be written as:

$U = \{u_{1,} u_{2,\dots} u_n\}$ is the universe of discourse

$A = \{u_{i,} \mu_A(u_{i,}), \ v_A(u_{i,}), \tau_A(u_{i,})\}$ is an intuitionistic fuzzy subset

$B = \{u_{i,} \mu_B(u_{i,}), \ v_B(u_{i,}), \tau_B(u_{i,})\}$ is also intuitionistic fuzzy subset

$(i = 1,2, \dots n)$

Where

$\mu_A(u_{i,})$ is a membership function or degree

$v_A(u_{i,})$ is non membership function or degree

$\tau_A(u_{i,})$ is the hesitation degree

But $0 \leq \mu_A(u_i) \leq 1$ (1)

$0 \leq v_A(u_i) \leq 1$ (2)

$0 \leq \mu_A(u_i) + v_A(u_i) \leq 1$ (3)

$\mu_A(u_i) + v_A(u_i) + \tau_A(u_i) = 1$ (4)

Then $\tau_A(u_i) = 1 - \mu_A(u_i) - v_A(u_i)$ (5)

Clearly $0 \leq \tau_A(u_i) \leq 1$ (6)

Some of the authors that use intuitionistic fuzzy set in their studies are ([21], [22], [23], and [23]).

4. Intuitionistic Fuzzy TOPSIS

The TOPSIS method was developed in 1981 by Hwang and Yoon. [27]. Generally, the method is based on the concept of minimum distance from the positive ideal solution and maximum distance from the negative ideal solution. The Negative Ideal Solution (NIS) is the solution that maximizes the cost factor and minimizes the benefit factors, while the Positive Ideal Solution (PIS) is the solution that minimizes the cost factor and maximizes the benefit factors. One of the limitation of TOPSIS method is the problem associated with the use of more than one functions in intuitionistic fuzzy environment. Some of the authors that applied the TOPSIS method are ([27], [28], [29]. [22])

The algorithm for intuitionistic fuzzy TOPSIS as used by [22] is as follows:

Step 1: Determine The Weights Of Decision Makers

Assuming that decision group contains m decision makers (DMs). The importance rating of the DMs are given in linguistic terms which are transformed to intuitionistic fuzzy numbers.

Let $D_k = (\mu_{k,}\ v_k, \tau_k)$ be an intuitionistic fuzzy number for rating k[th] decision maker. Then the weight λ_k of the k[th] decision maker is obtained as:

$$\lambda_k = \frac{\left(\mu_{k,} + \tau_k\left(\frac{\mu_{k,}}{\mu_{k,}+v_k}\right)\right)}{\sum_{k=1}^{m}\left(\mu_{k,}+\tau_k\left(\frac{\mu_{k,}}{\mu_{k,}+v_k}\right)\right)} \qquad (7)$$

And $\sum_{k=1}^{l}\lambda_k = 1 \quad i.e. \lambda_k \epsilon[0,1]$

Where $\lambda = \{\lambda_{1,} \lambda_{2,}\ \lambda_{3,} \dots \lambda_l\}$

Step 2. Construct Aggregate Intuitionistic Fuzzy Decision Matrix based on the Opinions of DMs

In this stage each decision maker has his or her own weight λ_k determined in step 1. Each indiviual decision matrix is combined to obtain aggregate intuitionistic fuzzy decision matrix, $R = r_{ij}$ using equation (8) [22]. To achieve this IFWA operator proposed by [37] is used as given below

$$r_{ij} = IFWA_{\lambda(r_{ij}{}^{(1)}, r_{ij}{}^{(2)}, \dots r_{ij}{}^{(l)})}$$

$$= \lambda_1 r_{ij}{}^{(1)}(+)\lambda_2 r_{ij}{}^{(2)}(+)\lambda_3 r_{ij}{}^{(3)}(+) \dots (+)\lambda_l r_{ij}{}^{(l)}$$

$$= \left[1 - \prod_{k=1}^{m}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k},\ \ \prod_{k=1}^{m}\left(v_{ij}^{(k)}\right)^{\lambda_k},\ \prod_{k=1}^{m}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{m}\left(v_{ij}^{(k)}\right)^{\lambda_k}\right] \quad (8)$$

Here $r_{ij} = (\mu_{Aj}(xi), v_{Aj}(xi), \tau_{Aj}(xi), i = 1,2, \dots n, j = 1,2, \dots m$

The resulting aggregated intuitionistic fuzzy decision matrix is as given.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ r_{m1} & r_{m1} & \cdots & r_{mn} \end{bmatrix} \qquad (9)$$

Step 3. Determine The Weight of The Criteria

Each decison maker (DM) will assign a weight to each criterion. $W_i^{(k)}$ is the weight assigned by the decision maker k to criterion j. Aggregated weight $W_j = \lambda W_i$ as given in equation (10) [22].

$W_i^{(k)} = [\mu_i^{(k)},\ v_i^{(k)},\ \tau_i^{(k)}]$ is the weight assigned to criterion x_j by the K^{th} decision maker (DM). Then the weights of the criteria are calculated by using IFWA operation [37]

$$W = IFWA_{\lambda(W_i{}^{(1)}, W_i{}^{(2)}, \dots W_i{}^{(l)})} = \lambda_1 w_i{}^{(1)}(+)\lambda_2 w_i{}^{(2)}(+)\lambda_3 w_i{}^{(3)}(+) \dots (+)\lambda_l w_i{}^{(l)}$$

(10)

Where $w_i = [\mu_i, v_j, \tau_i, \dots w_n,]\ i = 1,2, \dots n$

Step 4. Construct Final (Aggregated Weighted) Intuitionistic Fuzzy Decision Matrix

The aggregated weight intuitionistic fuzzy is determined by using the following definition [38].

$$D \otimes W = \{x, \mu_{Aj}(x)\ \mu_w(x), v_{Aj}(x) + v_w(x) - v_{Aj}(x)\ v_w(x) / x \epsilon X\} \qquad (11)$$

and

$$\tau_{Ajw^{(x)}} = 1 - V_{Aj}(x) - v_w(x) - \mu_{Aj}(x)\ \mu_w(x) + v_{Aj}(x)\ v_w(x) \qquad (12)$$

The final intuitionistic fuzzy decision matrix is given as follows:

$$D = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1j} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2j} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & x_{i3} & \cdots & x_{ij} \end{bmatrix} \qquad (13)$$

$where\ x_{ij} = (\mu_{ij,} v_{ij,} \tau_{ij}) = (\mu_{Ajw}(x_i), v_{Ajw}(x_i), \tau_{Ajw}(x_i))$

is an element of the final score of intuitionistic fuzzy decision matrix.

Step 5. Obtain the positive ideal solution (PIS) and negative ideal solution (NIS)

Let I^B and I^c be the benefit and cost criteria respectively. B^+ is intuitionistic fuzzy positive ideal solution and B^- is intuitionistic fuzzy negative ideal solution. The B^+ and B^- is obtained as follows:

$$B^+ = (\mu_{B^+w}(x_i), v_{B^+w}(x_i))and\ B^-(\mu_{B^-w}(x_i), v_{B^-w}(x_i)) \qquad (14)$$

Where

$\mu_{B^+w}(x) = \left(max\ \mu_{B_jw}(x_i)/I\epsilon I^B\right), \left(min\ \mu_{B_jw}(x_i)/I\epsilon I^C)\right)$ (15)

$v_{B^+w}(x_i) = \left((min\ v_{B_jw}(x_i)/I\epsilon I^B\right), \left(max\ v_{B_jw}(x_i)/I\epsilon I^C)\right)$ (16)

$\mu_{B^-w}(u_i) = \left((min\ \mu_{B_jw}(x_i)/I\epsilon I^B\right), \left(max\ \mu_{B_jw}(x_i)/I\epsilon I^C)\right)$ (17)

$vB^-w(u_i) = \left((max\ v_{Bjw}(x_i)/I\epsilon I^B\right), \left(min\ v_{Bjw}(x_i)/I\epsilon I^C)\right)$ (18)

Step 6: Construct the separation measures (distance from PIS and distance from NIS) for each supplier. The computation of separation measure is obtained using the metric functions. Three metric functions Hamming (H), Euclidean(E) and Spherical(S) were recently adopted in literature, with a novel application of Spherical metric function[39] to supplier selection([24], [25], [26])

Step 7: Calculate the closeness coefficients for each supplier. The calculation for closeness coefficient is given below.

$CC = s^-/(s^- + s^+)$, where $0 \leq CC \leq 1$. (19)

Where eq. 19 is applicable to the Hamming (H), Euclidean(E)[33] and Spherical(S)[39] metric functions for calculating the similarity measures or closeness coefficients of the suppliers.

Recent development in Multi-Criteria Decision Making (MCDM) problems on multiple sourcing shown most of the literatures have either used the fuzzy set theory, AHP, ANP, TOPSIS, DEA or a combination of these methods or with other methods ([7],[23],[28],[7] [3]).

However, there some other literature that applied other methods to solving multiple criteria decision making for supplier selection problem. A paper [40] suggested a method based on third generation prospect theory (PT3) for selecting green suppliers in a dynamic environment. Another work [41] proposed the Multi-criteria optimization (MCO) with compromised solution method combined to information entropy weight method in solving MCDM problem for supplier selection. However, this model [41] is subjective because of its compromise nature.

5. FINDINGS

In the view of the above, the following gaps and lapses were identified from the literature:

(i) The objective criteria used in the literature for supplier selection problem are: cost, lead time and production capability. The intangible criteria like honesty, faithfulness and integrity and flexibility are mostly ignored. These qualitative (intangible) criteria are indispensible for healthy business relationship and growth.

(ii) Some of the methods focuses on cost minimization, for example, inventory approach and mathematical programming. These methods are not sufficient for addressing contemporary supplier selection problems [3]..

(iii) Attempts to include intangible criteria in the supplier selection process in the literature are based to DMs subjective ranking. This may lead to imprecision or inconsistency in the methods. Methods incorporating these criteria include: fuzzy set theory, intuitionistic fuzzy set [1], DEA, AHP, ANP, SIR and so on

(iv) Some of the methods may be complex or computationally intractable or may not guarantee optimal solution. For example, mathematical programming, GA [20].

(v) Business objective is ignored by all methods.

(vi) It is not clear when to use specific methods. For example cost is both input and output in DEA [3].

(vii) Inconsistency in TOPSIS ordering when different metric functions are adopted. ([24], [25],[26],[33]).

6. RESEARCH FRONTIERS

In today's highly competitive environment, an effective supplier selection from multiple sourcing processes in the presence of many alternatives is very important since it is almost impossible to find a supplier that excel in all of the possible criteria identify by an organization. It is important to develop an easy to use method for selecting the supplier that will meet the needs of the organization. The multiple sourcing problems usually are very complicated because of variety of factors which may be uncontrollable and unpredictable affect the evaluation of supplier decision making process [13]. The objective of supplier selection is to identify suppliers with highest potential for meeting the firm's requirement consistently. Therefore, the tasks before decision makers in any organization are:

(i) Stating in clear terms objective criteria for evaluating and selecting the right supplier

(ii) Develop a criteria weighting method that is devoid of subjective judgment but comprehensively objective and robust in approach.

(iii) How to choose the best supplier that will promote the goals of the organization?

A review of the existing models in literature shows that various approaches have been used in solving the supplier selection problem. It is obvious from the literature review that objective and subjective criteria have not been effectively combined. It is also not clear from the literature when to apply each method. Indeed, the task of "helping a purchaser to find an adequate decision method in a particular situation as a specific set of criteria may be accommodated by more than one method[42]". This task has not been adequately addressed in the literature. To this end, comparison of several methods and suggestions for the methods taxonomy is very expidient. The task therefore, is to address some of these limitations or gaps, by developing a robust and objective model capable of solving some of these problems identified in this paper. Other critical areas for research proposal are to:

(i) Examine critically AHP-SIR with a view to eliminate the inconsistency in DMs assignment of weights to evaluate criteria.
(ii) Develop decision method that will accommodate both subjective (qualitative) and objective criteria will be developed.
(iii) Develop methods that will take into consideration business objective (voice of company) is paramount importance to the evaluation and selection processes.
(iv) Model agent system for MCDM problems, this lacking in literature. However, a framework of an abridged version of intuitionistic fuzzy TOPSIS for supplier selection was developed [24], but the full implementation is a viable area for further research.

7. CONCLUSION

The need for an effecient supplier to meet the goal of any organization cannot be over-emphasized. Therefore a proper review of the methods to identify the gaps and limitations in the methods of selection is crucial. To this end this paper reviewed 31 methods of supplier selection and identified gaps in literature to set new research agenda for researchers and practioneers in industries. The main contribution of this paper is that it provides timely pieces of information that would be expedient for the improvement of MCDM problems. It obvious from this paper that there many problems to be addressed in this area of research to improve the selection process.

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