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A NEW FRAMEWORK FOR GREEN SELECTION OF MATERIAL HANDLING EQUIPMENT UNDER FUZZY ENVIRONMENT

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Abstract. *In the rapidly changing global circumstances, managements of industrial organizations are making decisions for their survival in business atmosphere in future. Decision makers in industries are steering their respective organizations towards for appropriate decision making satisfying the condition of 'Go green'. Appropriate decision making in fuzzy environment is always a hard task. The current investigation explores a new multi criteria decision making approach for green selection of material handling equipment under fuzzy environment. The proposed technique has the capability of capturing effects of economical, environmental and social factors of benefit, non-benefit and target based criteria under uncertainty and vague information. The proposed method is illustrated with a suitable example on material handling equipment selection under fuzzy environment. The result clearly shows that the proposed technique is useful and effective in the decision making process regarding green material handling selection under fuzzy environment.*

Key words: *MCDM, Green material handling equipment selection, Decision making, Fuzzy sets.*

1. Introduction

In today's highly competitive global market scenario industrial organizations worldwide are facing difficulty and their existence as well as survival is under uncertainty. In this circumstance the industrial organizations are persistently seeking means of resolving the difficulties and trying to attain satisfactory conditions of going green. Selection of material handling equipment under multi criteria decision making environment plays a crucial role for the sustainable development especially for manufacturing organizations. Substantial development needs consideration of economic, environmental and social factors. Green material handling equipment selection procedure gives emphasis on meeting requirements of

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present without compromising the capability of future generations to meet their needs. Therefore for sustainable development the decision makers consciously incorporates social economical or environmental criteria in material handling selection. A wide range of literature on material handling equipment selection shows that the previous search works in this regard have not given enough attention. New research with proper decision-making attitude is still essential to show top level management the ray of hope for their survival and existence in the tough competitive business world.

Selection of material handling equipment for manufacturing applications is essential. Previous researchers' attention is inadequate to select material handling equipment considering green factors. A broad literature survey on material handling equipment selection explores this deficit of research work on the field.

Goswami and Behera (2021) made an investigation for the capability and applicability of two well-known MCDM approaches ARAS and COPRAS for the evaluation and selection of conveyors, AGV and robots as material handling equipment. Soufi et al. (2021) introduced an AHP based MCDM methodology for the evaluation and selection of material handling equipment to be utilized in manufacturing systems. Satyam et al. (2021) applied a multi attribute decision making approach for evaluation and selection of conveyors as material handling equipment. Nguyen et al. (2016) advocated a combined multi criteria decision making model for the evaluation and selection of conveyor as the material handling equipment based on fuzzy analytical hierarchy process and fuzzy ARAS with vague and imprecision information. Mathewa and Sahua (2018) made a comparison among the novel multi-criteria decision-making approaches by solving a problem on material handling equipment selection. None of the above researchers considered green issues in their investigations.

Fonseca et al. (2004) developed a prototype expert system for the purpose of industrial conveyor selection. Poon et al. (2011) addressed selection and allocation of MHE for stocha production material demand problems by using genetic algorithm. Lashkari et al. (2004) proposed an integrated model of operation allocation and material handling equipment selection in cellular manufacturing systems. Sujono and Lashkari (2007) presented a method for determining the operation allocation and material handling equipment. Chan et al. (2001) advocates an intelligent material handling equipment selection advisor (MHESA) composed of three modules. Kulak (2005) proposed a decision support system named fuzzy multi-attribute material handling equipment selection (FUMAHES).

Tuzkaya et al. (2010) developed an integrated fuzzy multi-criteria decision-making methodology combining fuzzy sets, Analytic Network Process and (PROMETHEE) for MHE selection. Chatterjee et al. (2010) gave solution the robot selection problem using two suitable multi-criteria decision-making methods and compared the relative performances. Shih (2008) presented a group TOPSIS to select robots by incremental benefit–cost ratio.

The gap analysis of the above literature review exposes that, despite the fact that previous researchers have attempted to apply MCDM techniques for selection of material handling equipment, still, this effort is inadequate for exhaustive and extensive decision making regarding green selection of proper material handling devices (MHD) from several available alternatives under multiple criteria decision making. The literature survey clearly shows that the previous researchers did not address the problem of green selection of material handling at a satisfactory level.

The objective of the present study is to develop a decision making framework that can be an essential tool in solving problems regarding green selection of material handling equipment for industrial organizations.

The motivation of the research work is our environment. Our planet is changing constantly. Due to rapid global industrialization, our surrounding environment is being constantly harmed from pollutant substance emitted from industries. And its adverse effect is falling on all living creature including human society. We human beings can steer the direction of change towards the welfare of the beautiful planet only by making careful and wise decision in every step of our practical life. We can reduce the harmful effect on the earth caused using different material handling equipment in industry. The lack of suitable decision making framework in the open literature has ignited the motivation to accomplish the current research work.

The rest of the paper is organized as follows. Section 2 presents the proposed algorithm. Section 3 describes an empirical example on green material handling equipment selection. Section 4 is dedicated for essential concluding remarks.

2. Proposed Algorithm

This research work proposes a novel algorithm consisting of 8-steps as follows.

Step 1: Construction of performance rating matrix: A matrix consisting of performance rating of alternatives with respect to criteria is estimated by the experts or decision makers. Since the decision is to be made under uncertainty, linguistic variables are recommended for estimation of performance of alternatives. Seven degrees of linguistic variables with abbreviation and corresponding Triangular Fuzzy Number (TFN) are suggested for performance estimation as presented in Table 1.

Table1. Seven degrees of linguistic variables for assessing performance

Description	Abbreviation	Triangular Fuzzy Numbers
Extremely High	EH	(1,1,1)
Very High	VH	(0.8,0.9,1)
High	H	(0.6,0.7,0.8)
Medium	M	(0.4,0.5,0.6)
Low	L	(0.2,0.3,0.4)
Very Low	VL	(0,0.1,0.2)
Extremely Low	EL	(0,0,0)

The performance rating matrix is denoted by

$$M_{PR} = \left(LV_{ij}\right)_{m\times n} \tag{1}$$

LV_{ij} denotes performance rating of alternative A_i with respect to criterion C_j in linguistic variable. Here, m and n represent the number of alternatives and criteria respectively.

Step 2: *Construction of weight matrix:* In a decision-making process different criteria may have different importance. This importance weight is estimated by the decision makers based on their unanimous decision-making attitude through discussion. Seven degrees of linguistic variables with abbreviation and corresponding Triangular Fuzzy Number (TFN) suggested for weight estimation are presented in Table 2. The weight matrix for measuring criteria importance is formed as follows.

$$M_W = \left(LW_{1j}\right)_{1\times n} \tag{2}$$

LW_{1j} denotes the linguistic weight for criterion *Cj*. Here *n* is a number of criteria.

Table 2. Seven degrees of recommended linguistic weights of criteria

Description	Abbreviation	Triangular Fuzzy Number
Absolutely Important	AI	(1,1,1)
Extremely important	EI	(0.8,0.9,1)
Very important	VI	(0.6,0.7,0.8)
Medium Important	MI	(0.4,0.5,0.6)
Ordinarily Important	OI	(0.2,0.3,0.4)
Slightly Unimportant	S	(0,0.1,0.2)
Unimportant	UI	(0,0,0)

Step 3: *Conversion of rating from linguistic terms to TFN:* Linguistic rating is not suitable for decision making under multiple conflicting criteria. That is why they are required to be transformed into fuzzy numbers. The current approach suggests triangular fuzzy numbers for making calculation simple and straightforward. Table 1 shows the rating and equivalent fuzzy numbers. Performance rating matrix in fuzzy numbers is presented as follows.

$$M_{PRF} = \left(\tilde{r}_{ij}\right)_{m\times n} = \left(r_{ij}^{l},\quad r_{ij}^{m},\quad r_{ij}^{u}\right)_{m\times n} \tag{3}$$

r_{ij}^{l}, r_{ij}^{m}, r_{ij}^{u} stand for lower, middle and upper value of respective TFN respectively.

Step 4: *Conversion of weight from linguistic terms to TFN:* Linguistic weight is not suitable for decision making under multiple conflicting criteria. That is why these are required to be changed into fuzzy numbers. The present approach suggests triangular fuzzy numbers for making calculation simple and straightforward. Table 2 shows the rating and equivalent fuzzy numbers. Weight matrix in fuzzy numbers is presented as follows.

$$M_{WF} = \left(\tilde{w}_{1j}\right)_{m\times n} = \left(w_{1j}^{l},\quad w_{1j}^{m},\quad w_{1j}^{u}\right)_{m\times n}$$

(4)

w_{ij}^{l}, w_{ij}^{m}, w_{ij}^{u} stand for lower, middle and upper value of respective TFN respectively.

Step 5: *Normalization of fuzzy performance rating:* Based on the desired value, criteria can be divided in 3 different categories, viz. benefit criteria (higher value is desired), non-benefit criteria (lower value is desired) and target-based criteria (Neither higher nor lower value is desired instead a certain target value is desired). Normalization of fuzzy rating is implemented using appropriate formula depending on the nature of criteria. The following formulae are recommended for executing the normalization process.

For benefit criteria:

$$\bar{r}_{ij} = \left(\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}(r_{ij}^{u})},\quad \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}(r_{ij}^{u})},\quad \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}(r_{ij}^{u}}\right) \tag{5}$$

For non-benefit criteria

$$\bar{r}_{ij} = \left(1 - \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}(r_{ij}^{u})},\quad 1 - \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}(r_{ij}^{u})},\quad 1 - \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}(r_{ij}^{u})} \right) \tag{6}$$

For target-based criteria

$$\bar{r}_{ij} = \left(1 - \left| \frac{r_{T}^{u}}{\max\limits_{\forall i,j}(r_{ij}^{u})} - \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}(r_{ij}^{u})} \right|,\ 1 - \left| \frac{r_{T}^{m}}{\max\limits_{\forall i,j}(r_{ij}^{u})} - \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}(r_{ij}^{u})} \right|,\ 1 - \left| \frac{r_{T}^{l}}{\max\limits_{\forall i,j}(r_{ij}^{u})} - \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}(r_{ij}^{u})} \right| \right)$$

(7)

The normalization process is carried out in so as to convert all the fuzzy performance ratings in benefit sense irrespective of nature of criteria.

Step 6: *Weighted normalized rating*: Weighted normalized rating is the rating modified by respective criteria weight. This paper recommends the following nonlinear integration of an alternative rating with each criterion weight.

For benefit criteria Eq. (8) is applied.

$$\tilde{r}_{ij}^{wn} = \left(\int_{0}^{w_{1j}^{l}} \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{l}\right)} dx,\ \int_{0}^{w_{1j}^{m}} \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} dx,\ \int_{0}^{w_{ij}^{u}} \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} dx \right)$$

(8)

For non-benefit criteria Eq. (9) is applied.

$$\tilde{r}_{ij}^{wn} = \left(\int_{0}^{w_{1j}^{u}} \left(1 - \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right) dx,\ \int_{0}^{w_{1j}^{m}} \left(1 - \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right) dx,\ \int_{0}^{w_{ij}^{l}} \left(1 - \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right) dx \right)$$

(9)

For target based criteria Eq. (10) is used.

$$\tilde{r}_{ij}^{wn} = \left(\int_{0}^{w_{1j}^{u}} 1 - \left| \frac{r_{T}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right| dx,\ \int_{0}^{w_{1j}^{m}} 1 - \left| \frac{r_{T}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right| dx,\ \int_{0}^{w_{ij}^{l}} 1 - \left| \frac{r_{T}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} \right| dx \right)$$

(10)

Step 7: Defuzzification of performance rating is accomplished using the following Eq. (11)-Eq. (13)

For benefit criteria used Eq. (11) is employed.

$$\bar{r}_{ij}^{wn} = \frac{1}{6} \left(\int_{0}^{w_{1j}^{l}} \frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} dx + 4 \int_{0}^{w_{1j}^{m}} \frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} dx + \int_{0}^{w_{ij}^{u}} \frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)} dx \right) \tag{11}$$

For non-benefit criteria

$$\bar{r}_{ij}^{nw}=\frac{1}{6}\left(\int_{0}^{w_{1j}^{u}}\left(1-\frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{l}\right)}\right)dx+4\int_{0}^{w_{1j}^{m}}\left(1-\frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right)dx+\int_{0}^{w_{ij}^{l}}\left(1-\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right)dx\right)$$

(12)

For target based criteria

$$\frac{1}{6}\left(\int_{0}^{w_{1j}^{u}}1-\left|\frac{r_{T}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx+4\int_{0}^{w_{1j}^{m}}1-\left|\frac{r_{T}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx+\int_{0}^{w_{ij}^{l}}1-\left|\frac{r_{T}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx\right)$$

(13)

Step 8: *Performance Index:* Performance index indicates responsible for measuring performance, ranking and selection. The current investigation advocates the following technique in calculation performance indicator (PI) by integrating individual contribution of each criterion towards the evaluation of alternatives.

$$\begin{aligned}PI_i=&\frac{1}{6}\sum_{j\in BC}\left(\int_{0}^{w_{1j}^{l}}\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{l}\right)}dx+4\int_{0}^{w_{1j}^{m}}\frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}dx+\int_{0}^{w_{ij}^{u}}\frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}dx\right)\\&+\frac{1}{6}\sum_{j\in NBC}\left(\int_{0}^{w_{1j}^{u}}\left(1-\frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{l}\right)}\right)dx+4\int_{0}^{w_{1j}^{m}}\left(1-\frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right)dx+\int_{0}^{w_{ij}^{l}}\left(1-\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right)dx\right),\\&+\frac{1}{6}\sum_{j\in TBC}\left(\int_{0}^{w_{1j}^{u}}1-\left|\frac{r_{T}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{u}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx+4\int_{0}^{w_{1j}^{m}}1-\left|\frac{r_{T}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{m}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx+\int_{0}^{w_{ij}^{l}}1-\left|\frac{r_{T}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}-\frac{r_{ij}^{l}}{\max\limits_{\forall i,j}\left(r_{ij}^{u}\right)}\right|dx\right)\end{aligned}$$

(14)

Hence PI_i denotes performance index of *i*th alternative. Performance index has its beneficial sense, that is higher value is desirable. Thus alternatives are arranged in the descending order of their respective PI value. The alternative with the highest value of performance index is considered the best alternative. The alternative with the least value of performance index is considered as the worst alternative and so on.

3. Illustrative Example

A South-East Asian manufacturing organization plans to select material handling equipment including the factors related to green. A selection committee comprising of managers, experts and decision makers is formed. The committee chooses seven selection criteria keeping green selection in view under fuzzy environment. Safety (C1), operating friendliness (C2), environment friendliness (C3), robustness (C4), cost (C5), repeatability (C6), and human-interaction (C7) are the six selection criteria for material handling equipment. Safety and operating friendliness are social factors, cost is economical and environment friendliness is environmental factors. These factors are selected keeping green factors in view. Safety, operating friendliness, environment friendliness, and robustness are benefit criteria; cost and repeatability are non-benefit or cost criteria, whereas human-interaction is target based criteria.

Four alternative material handling equipment designated by A1, A2, A3 and A4 are preliminarily selected after initial screening for further evaluation.

3.1 Estimation of linguistic rating

A detailed question-answer interview is conducted for the decision-making committee to construct a performance rating matrix in terms of linguistic variable as furnished in Table 3. It is observed that Criteria C1, C2, C3 and C4 are benefit criteria, C5 and C6 are non-benefit criteria and C7 is target based criteria (TBC). Table 4 represents performance rating matrix in terms of linguistic variables. The alternative material handling equipment A1 is awarded linguistic performance rating viz. EH, VH, M, EH, M, VH, and L with respect to criteria C1, C2, C3, C4, C5, C6 and C7. EH (extremely high rating is better and desirable) under benefit criteria. M and VH are provided under non-benefit or cost criteria. Comparatively, M (medium) is better than VH (very high). For C7, L (low) is the expected value.

Table 3. Performance rating matrix in terms of linguistic variables

Estimated by Decision making committee		Criteria						
		Benefit Criteria				Non-benefit Criteria		TBC*
	Ai	C1	C2	C3	C4	C5	C6	C7
Alternative	A1	EH	VH	M	EH	M	VH	L
	A2	VH	H	EH	M	VH	M	EH
	A3	M	VL	EH	VH	H	L	VH
	A4	EH	M	VH	MI	VL	EH	M

*TBC stands for Target Based Criteria; Target value for TBC is set to M (medium).

The importance weights of Criteria, C1, C2, C3, C4, C5, C6 and C7 are estimated as AI, EI, MI, OI, MI, EI, and AI in linguistic abbreviation. It implies that criteria C2 and criteria C6 are jointly given the highest importance. Criterion robustness (C4) is assumed relatively less important.

Table 4. Weight matrix in terms of linguistic variables

Estimated by Decision making committee	Criteria						
	Benefit Criteria				Non-benefit Criteria		TBC*
	C1	C2	C3	C4	C5	C6	C7
Weight	AI	EI	MI	OI	MI	EI	AI

*TBC stands for Target Based Criteria; Target value for TBC is set to M (medium).

3.2 Calculation and Illustration

Since the decision is to make in fuzzy environment, therefore performance rating of alternative and the importance weights of selection criteria have been extracted in the form of linguistic variables. These linguistic variables are not directly suitable for decision making. So conversion of linguistic variables into corresponding fuzzy number is an essential step. The conversion scale for the performance rating are as follows: Extremely High (1,1,1), Very High (0.8,0.9,1), High (0.6,0.7,0.8), Medium (0.4,0.5,0.6), Low (0.2,0.3,0.4), Very Low (0,0.1,0.2) and Extremely Low (0,0,0). Conversion of linguistic terms to TFN is performed and shown in Table 5.

Table 5. Fuzzy performance rating in terms of TFN

	Benefit Criteria				Non-benefit Criteria		TBC*
Ai	C1	C2	C3	C4	C5	C6	C7
A1	(1,1,1)	(0.8,0.9,1)	(0.4,0.5,0.6)	(0.2,0.3,0.4)	(0.4,0.5,0.6)	(0.8,0.9,1)	(0.2,0.3,0.4)
A2	(0.8,0.9,1)	(0.6,0.7,0.8)	(0.2,0.3,0.4)	(0.4,0.5,0.6)	(0.8,0.9,1)	(0.4,0.5,0.6)	(1,1,1)
A3	(0.4,0.5,0.6)	(0,0.1,0.2)	(1,1,1)	(0.8,0.9,1)	(0.6,0.7,0.8)	(0.2,0.3,0.4)	(0.8,0.9,1)
A4	(0.2,0.3,0.4)	(0.4,0.5,0.6)	(0.8,0.9,1)	0.4,0.5,0.6)	(0,0.1,0.2)	(1,1,1)	(0.4,0.5,0.6)

*TBC stands for Target Based Criteria

The conversion scale for the linguistic weight of criteria into triangular fuzzy number are as follows: Absolutely Important (1,1,1), Extremely important (0.8,0.9,1), Very important (0.6,0.7,0.8), Medium Important (0.4,0.5,0.6), Ordinarily Important (0.2,0.3,0.4), Slightly Unimportant, (0,0.1,0.2) and Unimportant (0,0,0). Conversion of weight from linguistic terms to triangular fuzzy number is presented in Table 6.

Table 6. Weight matrix in terms of linguistic variables

	Criteria						
	Benefit Criteria				Non-benefit Criteria		TBC*
	C1	C2	C3	C4	C5	C6	C7
Weight	(1,1,1)	(.8,0.9,1)	(.4,0.5,0.6)	(.2,0.3,0.4)	(.4,0.5,0.6)	(.8,0.9,1)	(1,1,1)

*TBC stands for Target Based Criteria

Normalization of fuzzy performance rating is accomplished, and the normalized performance fuzzy ratings are calculated by using respective Eq. (5) - Eq. (7). For example, normalized fuzzy performance rating for the alternative A1, with respect to criteria C1 is carried out as follows. The criterion Safety (C1) is benefit criterion. Therefore, Eq. (5) has been used. The highest grade under criterion C1 is (1,1,1). The upper point of the TFN is 1. Then the normalized performance rating for this case is obtained by dividing each of the point, lower, middle, upper with 1(maximum upper point under the criterion). The computed normalized performance rating is (1,1,1). Similarly, the rest of the normalized performance ratings are calculated. To take account of the variation, different importance weights have been integrated with the already calculated normalized performance ratings. For this purpose, a new equation is introduced in the current proposed algorithm. Weighted normalized rating is computed by using Eq. (8) -Eq. (10) and shown in Table 7.

Table 7. Weighted normalized fuzzy performance ratings

	Benefit Criteria				Non-benefit Criteria		TBC*
Ai	C1	C2	C3	C4	C5	C6	C7
A1	(1,1,1)	(.64,0.81, 1)	(0.16,0.25,.36)	(0.04,.09,0.16)	(0.16,0.25,0.36)	(0,0.09,0.2)	(0.6,0.8, 1)
A2	(0.8,0.9,1)	(.48,0.63,.8)	(0.08, .15,.24)	(0.08,0.15,.24)	(0.0,0.05,0.12)	(0.32,0.45,0.6)	(0.4,0.5,0.6)
A3	(0.4,0.5,0.6)	(0,0.09,0.2)	(0.16, 0.5 ,0.6)	(0.16,0.27,0.4)	(0.08,0.15,0.24)	(0.48,0.63,0.8)	(0.6,0.6,0.6)
A4	(0.2,0.3,0.4)	(.32,0.45,.6)	(0.32,.45, 0.6)	(0.08,.15,0.24)	(0.16,0.45,0.6)	(0,0,0)	(1,1,1)

*TBC stands for Target Based Criteria

Weighted normalized performance ratings have been expressed in terms of triangular fuzzy number. TFN is not suitable for making final decision regarding the performance evaluation of the alternative material handling equipment. Therefore, it is essential to convert the fuzzy number into quantified corresponding crisp number. The process of converting the fuzzy number into crisp number is termed as defuzzification. Conversely, the conversion process of crisp number into corresponding fuzzy number is termed as fuzzification. In the current study the defuzzification process is completed through the application of three different newly introduced appropriate equations. Eq. (11) has been implemented for benefit criteria, Eq. (12) has been used for cost or non-benefit criteria, Eq. (13) has been applied for target-oriented criterion C7. Table 8 shows defuzzified weighted normalized ratings as calculated by using Eq. (11)- Eq. (13). Performance index is the index of an alternative material handling equipment that expresses extent of benefit over the cost as well as non-beneficial performance. For the purpose of estimation of performance index of each of the alternative material handling equipment a new, integration oriented technique has been proposed in the investigation as presented in Eq.(14). The performance index for each individual alternative has been shown in Table 8.

Table 8. Defuzzified weighted normalized rating, performance index and rank

	Defuzzified Weighted Normalized Rating							Performance Index	
	Benefit Criteria				Non-Benefit Criteria		TBC*		Rank
Ai	C1	C2	C3	C4	C5	C6	C7	PI	
A1	1	0.816	0.256	0.096	0.256	0.096	0.8	3.32	1
A2	0.9,	0.636	0.156	0.156	0.056	0.456	0.5	1.96	4
A3	0.5	0.096	0.560	0.276	0.156	0.636	0.6	2.28	3
A4	0.3	0.456	0.456	0.156	0.456	0	1	2.82	2

*TBC stands for Target Based Criteria

Theoretically, the lower limit and the upper limit of performance index associated with any alternative can be 0 (zero) and n (where n is the number of criteria) respectively. In other words, the range of the performance index may vary from 0 to *n*, that is zero is the lower limit and n (number of criteria) is the upper limit of the result (performance index).

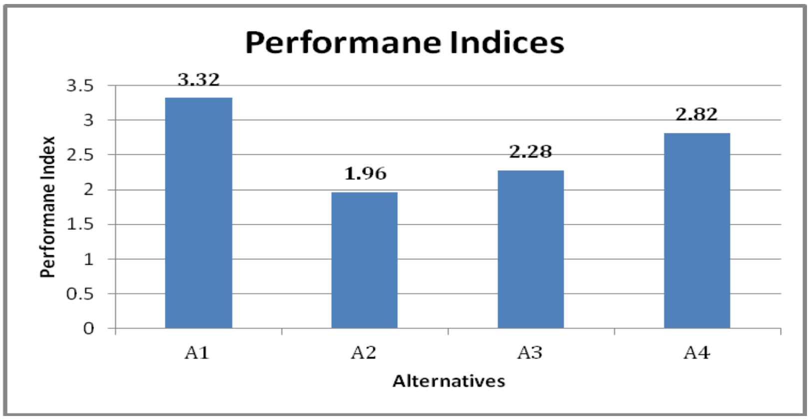

Figure 1. Performance indices of alternatives

The performance indices of the alternative material handling equipment are diagrammatically represented in Figure1, for improved visualization, enhanced clarification, and better comparison. Different alternatives are plotted along the horizontal axis, and the respective performance indices are depicted along the vertical axis. It is clearly observed from Figure 1 that alternative material handling equipment A1 attains the highest performance index. A4 has the second highest performance index, A3 possesses the next higher performance index, lastly A2 has the lowest performance index. The alternatives of material handling equipment are ranked accordingly.

The performance indices of the alternatives Al, A2, A3 and A4 are 3.32, 1.96, 2.28, and 2.82 respectively. The alternatives are arranged as per the descending order of their performance indices. Therefore, the ranking order of the alternatives are arranged as A1>A4>A3>A2. It is seen that the alternative A1 has the highest performance index. Hence A1 is considered the best alternative and A2 is the worst one and so on. The ranking order is depicted in Figure 2.

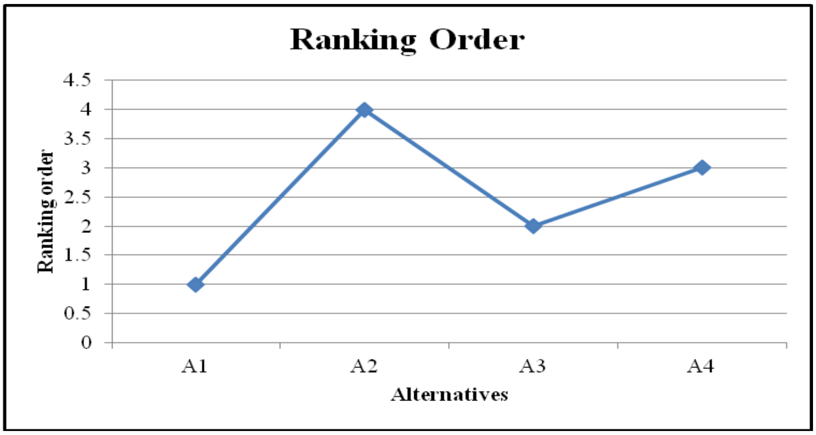

Figure 2. Ranking order of the alternatives

3.2 Comparison of the Results

The results obtained by the proposed method have been compared with and validated by two well-known tools viz. Technique of Order Preference by Similarity to Ideal Solutions (TOPSIS) and Multi Objective Optimization based on Ratio Analysis (MOORA). For making comparison and validation, the same ranking problem on material handling equipment selection is once again solved by the methods separately. In TOPSIS method, the closeness coefficient (CC) for each of the alternative is calculated. In MOORA method, net score is computed for each alternative material handling equipment. The relevant information is provided in the Table 9. It is observed that the closeness coefficient or relative closeness of the alternative A1, A2, A3 and A4 are 0.60, 0.42, 0.41 and 0.45 respectively. Therefore, the ranking orders of the alternatives are A1>A4>A2>A3. It is obvious that TOPSIS method selects alternative A1 as the best alternative, A4 as the second best alternatives as the proposed methods. Though, the ranking orders of the A2 and A3 do not match. In MOORA method, alternative A1 is ranked 1 and regarded as the best method. The graphical representation of the ranking orders obtained by the proposed method and the two well-known existing methods TOPSIS and MOORA is portrayed in Figure 3. The alternatives are plotted along horizontal axis and the ranking orders are plotted along vertical axis. It is found that alternative A1 has been selected as the best alternative by all the three multi-criteria decision-making techniques. These results verify and validate the novel framework in decision making under fuzzy environment.

Table 9: Comparison and validation of the results

	Proposed Method		TOPSIS		MOORA	
Ai	Performance Index	Rank	CC	Rank	Net Score	Rank
A1	3.32	1	0.60	1	0.79	1
A2	1.96	4	0.42	3	-0.07	2
A3	2.28	3	0.41	4	-0.16	4
A4	2.82	2	0.45	2	-0.1	3

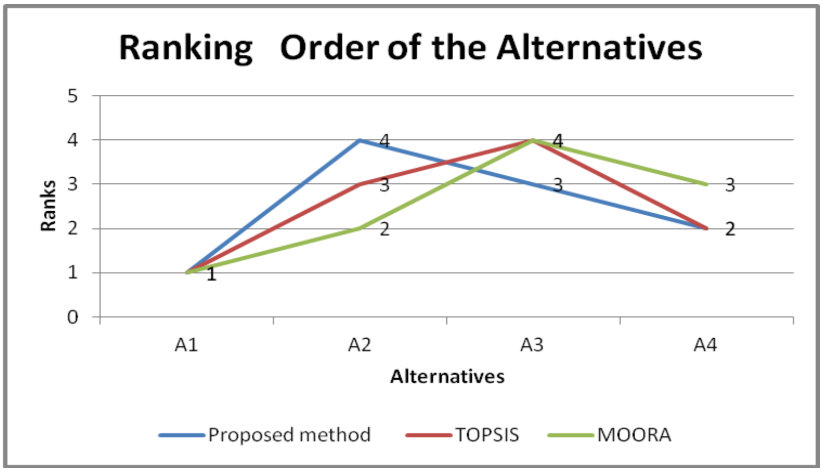

Figure 3. Comparision of ranking orders

4. Conclusions

The current investigation explores a new fuzzy MCDM framework in green selection of material handling equipment for industrial purpose considering multiple conflicting criteria. The novel framework is able to integrate economical, environmental and social factors with vague information to meet the necessary requirements for green selection. The application of the proposed framework in solving the material handling evaluation problem clearly shows the way of implementation and the ability of the framework to make proper decision considering multiple criteria under fuzzy environment. The framework clearly selects the alternative material handling equipment A1 as the best one with the highest performance index 3.32. Therefore, it can be concluded that the proposed technique introduced in the current research work might be a useful and essential aid to managerial decision makers of manufacturing industry in solving problem on green selection of material handling equipment. The result of the proposed method is supported and validated by two exiting well-known multi-criteria methods. The novelty of the current study can be highlighted as follows:

- Introduction of a novel mathematical model for fuzzy decision making.
- Incorporation of green factors in evaluation of material handling equipment.
- Consideration of benefit, non-benefit and target value-based criteria.
- Application of integration in fuzzy decision-making environment.

There are some limitations of the present approach though it has many advantages. This method cannot be used for objective factors or a mixture of objective and subjective factors. It has not addressed the consideration of heterogeneous group decision making. The current investigation is limited to independent criteria and decision making under fuzzy environment.

An insight of the research exposes that a new paradigm has been explored in the current investigation. In this research work, performance rating and weights of criteria are estimated in the prescribed degrees of linguistic form. These are efficiently integrated for calculating the performance indices for proper decision making in the specific domain.

The proposed model can be used for solving similar multi criteria decision making problems where decision is to make under fuzzy environment. The appropriate implementation of the technique can be a useful managerial tool in solving industrial decision-making problem.

Consideration of interdependent factors, incorporation of heterogeneous group decision making process and decision making with both subjective and objective factors, in green selection of material handling equipment for industrial purpose might be some important directions of future research.

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