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A Fuzzy Multi-Objective Supplier Selection Model with Price and Wastages Considerations

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KEYWORDS

Supplier selection,
Maximal Coverage,
Fuzzy Logic,
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MOICA,
NSGA-II.

ABSTRACT

The present paper aims to propose a fuzzy multi-objective model to allocate order to supplier in uncertainty conditions and for multi-period, multi-source, and multi-product problems at two levels with wastages considerations. The cost including the purchase, transportation, and ordering costs, timely delivering or deference shipment quality or wastages which are amongst major quality aspects, partial coverage of suppliers in respect of distance and finally, suppliers weights which make the products orders more realistic are considered as the measures to evaluate the suppliers in the proposed model. Supplier's weights in the fifth objective function are obtained using fuzzy TOPSIS technique. Coverage and wastes parameters in this model are considered as random triangular fuzzy number. Multi-objective imperial competitive optimization (MOICA) algorithm has been used to solve the model,. To demonstrate applicability of MOICA, we applied non-dominated sorting genetic algorithm (NSGA-II). Taguchi technique is executed to tune the parameters of both algorithms and results are analyzed using quantitative criteria and performing parametric.

1. Interoduction

Supplier selection is as a central problem in supply chain management (SCM). The goals of the SCM models mostly include cost minimization, maximizing a type of utility function, minimizing late delivered items and rejected units and so forth. In this study, a nonlinear multi-objective programming model is developed which objective functions are consisted of cost, delay, wastes, coverage from suppliers' side and supplier's weights. In this model, delay and wastes from supplier side are considered and produced as fuzzy random parameters. Finding the suppliers' weights through fuzzy TOPSIS and using triangular fuzzy numbers for measures weights and evaluation of decision makers for choices are the novelties of objective function in this model. Consideration of coverage by suppliers for selecting and allocating

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the order to suppliers are also among the innovations of present study. Supplier selection is performed according to the distance of customer from suppliers and considering the partial and complete coverage. Moreover, in this model, discount constraint was considered for simplification and to find the product cost according to the order rate and discounts rates from sign function type.To solve the model, a multi-objective meta-heuristic called multi-objective imperialist competitive algorithm (MOICA) is proposed. To demonstrate applicability of MOICA, we applied non-dominated sorting genetic algorithm (NSGA-II).

2. Related Works

Amid and Ghodsypour presented an additive weighted model for fuzzy multi objective supplier selection problem with fuzzy weights[1]. Elahi et al proposed a fuzzy compromise programming was utilized to determine marginal utility function for each criterion. [2]. Nosoohi and Mollaverdi considered a manufacturer in a Make-to-Order production environment who has to outsource a special component from a set of suppliers. [3]. Liang developed a fuzzy multi-objective model in a multi-product, multi period case in two levels. In his model, he considered delivery cost and time as two objective functions and solved his model in a dynamic approach[4]. Faith et al. developed a multi item system to select the suppliers using fuzzy and TOPSIS techniques in a group decision making problem [5].Toraby and Hassini developed a three dimensional model in multi-objective fuzzy case as multi product with fixed demand[6]. Tanweer Ahmad et al proposed a specific dynamic supplier selection problem (DSSP) under a two-echelon supply network (TESN) for the decision maker to allocate optimum order to different levels of suppliers[7]. Nihal et al, extended a model contains relevant calibration service quality parameters as the weight of criteria, cost, calibration time, capability. Their study proposed a fuzzy multi-objective LP model[8]. Anton et al, in their review paper, developed a classification study that contained six parts of research derived from the extensive literature comprising both quantitative and qualitative contents[9]. Christian et al, considered a SCM problem with simultaneous supply chain for multiproduct model where suppliers offer quantity and business volume discounts, and they are subject to failure and the buyer aims at minimizing total costs[10]. Fikri et al, in their case study of automotive industry in the developing country of Pakistan, proposed a support model for supplier evaluation based on AHP and further performed sensitivity analysis[11]. Fang Yu et al, proposed a product transportation distance for a product to record the transportation distance from the raw material stage to finished product, and finally, consumption by the consumers[12]. Sadeque et al, provided a D-M tool to solve a multi-period green supplier selection and order allocation. The tool contains three integrated components. First, fuzzy TOPSIS has used to assign two preference weights to each supplier according to two sets of criteria taken separately: traditional and green[13]. Dragan Simić et al used fuzzy theory, fuzzy decision-making and hybrid solutions based on fuzzy in the various models for supplier selection in a 50 year period[14]. Jafar Rezaei et al proposed a three-phase supplier selection method including pre-selection, selection. Conjunctive screening is used for pre-selection phase[15]. Madjid Tavana, proposed a hybrid ANFIS-ANN model to supplier evaluation process[16]. Francisco et al, combined the fuzzy QFD technique for weighting the criteria with a procedure for assessing the difficulty to obtain information to evaluate the suppliers on each criterion[17]. Jindong et al, extended an acronym in Portuguese of interactive and multi-criteria decision making technique to solve MCGDM problems within the interval type-2 fuzzy sets and applied it in green supplier selection problem[18]. Gülçin et al, proposed an intuitionistic fuzzy MCDM method which has attracted much attention from academics and practitioners in recent years; IF sets are widely used to tackle imprecise and uncertain decision information in decision making due to their capability of accommodating the hesitation in human decision making[19]. Pedro et al presented an integrated framework for deciding about the supplier selection in the food industry under uncertainty[20].

In this paper, we formulated the problem of multi-objective supplier selection problem in SCM considering coverage from supplier's side and supplier's weights. . Among the major limitations are price discount for products by suppliers which are calculated using signal function. In addition, supplier's weights in the fifth objective function are obtained using fuzzy TOPSIS technique Consideration the coverage by suppliers for selecting and allocating the order to suppliers can also be regarded as the innovations of the present study. In this model, delay and wastes from supplier side are considered as fuzzy parameters and produced as fuzzy random parameters. Tow parameter-tuned Pareto-based algorithm has been presented to solve the presented model.

3. Problem Formulation

There are various criteria to select and allocate the order to suppliers. In this paper, we presented a supply selection problem in SCM in fuzzy environment and the objective of maximizing coverage.

3-1. Fuzzy set theory

Zadeh has introduced Fuzzy set theory, to deal with uncertainty and imprecision associated with information[21]. Some preliminaries of fuzzy set theory used in this paper are defined as follow:

Definition 1: A fuzzy number X is a fuzzy set which is both normal and convex in the universe set U.

Definition 2: Let U be a universe set. A fuzzy set X of U is defined by a membership function $\mu_X(x) \in [0\ 1]$, where $\mu_X(x)$, $\forall x \in U$ indicates the degree of x in X.

Definition 3: A triangular fuzzy number (l, m, u) is defined by the following membership function:

$$\mu_{\tilde{a}}(x) = \begin{cases} 0 & X \leq l \\ \frac{X-l}{m-l} & l \leq X \leq m \\ \frac{u-x}{u-m} & m \leq X \leq u \\ 0 & X \geq u \end{cases} \quad (1)$$

Definition 4: Let $\tilde{N}=(n_1, n2, n3)$ and $\tilde{M}=(m_1, m2, m3)$ be two triangular fuzzy numbers; then, the vertex method is defined to calculate the distance between them as

$$d(M,N) = \sqrt{\frac{1}{3}[(m1-n1)^2+(m2-n2)^2+(m3-n3)^2]} \quad (2)$$

3-2. Fuzzy TOPSIS

TOPSIS (Technique for order performance by similarity to ideal solution) is one of the most classical methods to solve multi-criteria decision making problems (Chen, 2000). [22] [23].The approach to extend the TOPSIS method to fuzzy data used in this study can be outlined as follows:(Taylan et al., 2014)[23]

Step 1: Construct the fuzzy decision matrix

Assume there are m alternatives, A_i (i=1, 2…m) to be evaluated against n selection criteria, C_j (j=1, 2… n). The fuzzy multi-attribute decision making (MADM) can be concisely expressed in pay-off matrix format as Eq. (3).

$$\tilde{D}=\begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (3)$$

$$W=[\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n] \quad (4)$$

where $\tilde{x}_{ij}$ is the performance rating of the i^{th} alternative A_i with respect to j^{th} criterion C_j and $\tilde{w}_j$ represent the weight of the j^{th} criterion C_j. Moreover, $\tilde{x}_{ij}$ and $\tilde{w}_j$, i=1,2,…, m and j=1,2,…., n are triangular fuzzy numbers given as $\tilde{w}=(w_{j1}, w_{j2}, w_{j3})$ and $\tilde{x}_{ij}=(l_{ij}, m_{ij}, u_{ij})$.

Step 2: Normalize the fuzzy decision matrix

The raw data are normalized in several MCDM problems to eliminate anomalies with different measurement units and scales. However, the purpose of linear scales transform normalization function used in this study is to preserve the property which ranges of normalized triangular fuzzy numbers to be included in [0,1]. If $\tilde{R}$ denotes the normalized fuzzy decision matrix, then

$\tilde{R}_{ij} = [\tilde{r}_{ij}]_{m*n}$ $i = 1, 2... m$ and $j = 1,2,...,n$

Where the normalized values for benefit related criteria (B) and cost related criteria (C) are calculated as follows for fuzzy data denoted by triangular fuzzy number as (l_{ij}, m_{ij}, u_{ij}),:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u_{ij}}{u_j^*}\right) \quad u_j^* = max_i\, u_{ij} \quad J \in B \quad (5)$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right) \quad l_j^- = min_i\, l_{ij} \quad J \in C \quad (6)$$

Step 3: Construct weighted normalized fuzzy decision matrix

The weighted normalized decision matrix $\tilde{V}$ is defined as

$$\tilde{V}=\begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix} i=1, 2... m;\ j=1,2,...,n \quad (7)$$

$\tilde{v}_{ij} = \tilde{r}_{ij}. \tilde{w}_j$

Where $\tilde{w}_{ij}$ is the fuzzy weight of the criterion C_j.

Step 4: Determine PIS and NIS

Since the positive triangular fuzzy numbers are included in the interval [0,1], the fuzzy positive ideal reference point (FPIRP) denoted by A^* and fuzzy negative ideal reference point (FNIRP) denoted by A^-, can be defined as

$$A^*=\{\tilde{v}1^*, \tilde{v}2^* \ldots \tilde{v}n^*\} \quad (8)$$

$$A^-=\{\tilde{v}1^-, \tilde{v}2^- \ldots \tilde{v}n^-\} \quad (9)$$

$$\tilde{v}_j^*=Max\{\tilde{v}_{ij}\}; i=1,2,\ldots,m;\ j=1,2,\ldots,n \quad (10)$$

$$\tilde{v}j^-=Min\{\tilde{v}_{ij}\};\ i=1,2,\ldots,m;\ j=1,2,\ldots.n \quad (11)$$

where $\tilde{v}_j^*$=(1,1,1) and $\tilde{v}j^-$=(0,0,0), j=1,2,…,n

Step 5: Calculate the distances of each initial alternative from FPIRP and FNIRP.

The distance of each alternative from fuzzy positive ideal reference point and fuzzy negative ideal reference point can be derived as follows:

$$s_i^* = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^*); \quad i=1,\ldots,m \tag{12}$$

$$s_i^- = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^-); \quad i=1,\ldots,m \tag{13}$$

Where d $(\tilde{v}_{ij}, \tilde{v}_j^*)$ denotes the distance between two fuzzy numbers and is calculated using Eq. (2). Moreover, s_i^* represents the distance of alternative A_i from FPIRP and s_i^- is the distance of alternative A_i from FNIRP.

Step 6: Obtain the closeness coefficient and rank the alternatives

Calculate the closeness coefficient (CC_i) of each alternative as

$$CC_i = \frac{s_i^-}{s_i^- + s_i^*} \quad ; i=1, 2\ldots m \tag{14}$$

An alternative with CC_i =1 indicates that the closeness to FPIRP and farness from FNIRP. The alternative with the highest value is the best choice.

Step 7: Calculate the supplier weight

$$W_i = \frac{cci}{\sum_{i=1}^{m} cci} \quad ; i=1, 2,\ldots,m \tag{15}$$

3-3. Maximal Covering Location Problem (MCLP)

Maximal covering location problem (MCLP) maximizes the number of demand points covered within a specified critical distance or time by a fixed number of facilities. This method does not require that all demand points be covered Figure 1 represents the possible solutions for MCLP.

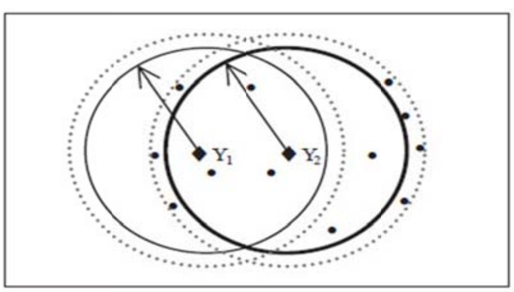

Fig. 1. A possible situation for a MCLP

Suppose that there are two potential facilities and we want to choose one with the maximal covering. The solid line shows the minimum critical distance and dotted line shows the maximum critical distance. Location Y_1 can cover six demand points and location Y_2 can cover five demand points within the full coverage range. Thus, a classical MCLP solution chooses location Y_1 as the location of maximal coverage. If we apply the partial coverage idea, we may select location Y_2 instead of location Y_1 ; because location Y_2 covers five demand points fully and an additional seven demand points partially; while location Y_1 covers only six demand points fully (Karasakal and Karasakal, 2004).[24] Coverage is calculated as follows:

$$\mu_{\tilde{a}}(x) = \begin{cases} 1 & w_{ij} \le S_j \\ L(w_{ij}) & S_j < w_{ij} < R_j \\ 0 & w_{ij} \ge R_j \end{cases} \tag{16}$$

$$L(w_{ij}) = \frac{R_j - w_{ij}}{R_j - S_j} \quad 0 < L < 1 \tag{17}$$

3-4. Indices and parameters

i customers Index (*i* = 1, 2, …, *I*)

j suppliers Index (*j* = 1, 2, …, *J*)

k products Index(*k* = 1, 2, …, *K*)

t periods Index(*t* = 1, 2, …, *T*)

r discount level index (*r* = 1, 2, …, *R*).

P_{ijkt} Unitary purchasing cost of product *k* by customer *m* in the period *t* from supplier *j*

$\tilde{t}_{jkt}$ Price of the product *k* in period *t* by supplier *j*

$\tilde{B}_{jkt}$ Price of defective goods of product *k* from supplier *j* in period *t*

b_{ij} Coverage rate of center *j* for customer *i*

D_{ikt} Customer *i* 's demand for the product *i* in period *t*

$\widetilde{W}_j$ The weight of supplier *j*

f_{jkt} Fixed cost of ordering for supplier *j* in period *t* for product *k*

P_{ktjr} Price of each unit product *k* offered by supplier *j* in period *t* in dicscount level *r*

C_{jkt} Capacity of supplier *j* for product *k* in period *t*

n_{ikt} Maximum number of suppliers for customer *i* and product *k* in period *t*

Q_{ij} Maximum price of reception of the defectives purchased by buyer i from supplier *j*

T_{ij} Maximum rate of delayed delivery for purchased goods by buyer i from supplier *j*

S_j Maximum distance for complete coverage by supplier *j*

R_i Maximum distance for partial coverage by supplier *j*

V_{ijk} Cost of shipment per unit product *k* from supplier *j* to customer *i* in distance unit

w_{ij} Distance of supplier *j* to customer *i*

H_j Minimum ordering to each supplier *j*

O_{it} Maximum capital of customer *i* in period *t*

3-5. Decision variables

X_{ijkt} Purchasing quantity of product k by buyer i from supplier j in period t

y_{ijkt} 1 if customer i buys product k in period t from supplier j; zero, otherwise.

3-6. Assumptions

- Demand is depends on price.

$a(i, j,k,t,r)$ corresponding to each discount rate is activated according to the order rate and x as well as other ranges are zero and become inactivated. By this way, price of each product is found

- Shortage is not permissible.

in order not to face any shortage, ordering rate of each customer for each product in each period from suppliers must be greater than or equal to the customer demand for that product in the desired period

- Discount is universal and a function of the sign.

price of each product offered by the suppliers has a discount of sign function type in which $a(i, j,k,t,r)$ are positive variables so that their total value is one

3-7. Proposed mathematical modeling

The final proposed mathematical model for supplier selection is formulated as:

$$MinZ_1=\sum_{i,j,k,t}P_{ijkt}x_{ijkt}+\sum_{i,j,k,t}w_{ij}v_{ijk}x_{ijkt}y_{ijkt}+\sum_{i,j,k,t}f_{jkt}y_{ijkt} \quad (18)$$

$$Min\ Z_2=\sum_{i,j,k,t}\tilde{t}_{jkt}x_{ijkt} \quad (19)$$

$$Min\ Z3=\sum_{i,j,k,t}\tilde{W}_j x_{ijkt} \quad (20)$$

$$Max\ Z_4=\sum_{i,j,k,t}b_{ij}D_{ikt}y_{ijkt} \quad (21)$$

$$Max\ Z5=\sum_{i,j,k,t}\tilde{W}_j x_{ijkt} \quad (22)$$

Subject to:

$$\sum_j x_{ijkt}\geq D_{ikt} \quad ;\forall i,k,t \quad (23)$$

$$\sum_j x_{ijkt}\leq\sum_j b_{ij}D_{ikt} \quad ;\forall i,k,t \quad (24)$$

$$\sum_i x_{ijkt}\ \leq c_{jkt} \quad ;\forall i,k,t \quad (25)$$

$$1\leq\sum_j y_{ijkt}\ \leq n_{ikt} \quad ;\forall i,k,t \quad (26)$$

$$\sum_{i,j,k,t}\tilde{B}_{jkt}\mathrm{x}_{ijkt}\leq\sum_{i,j,k,t}Q_{ij}b_{ij}D_{ikt} \quad ;\forall i,j,k,t \quad (27)$$

$$\sum_{i,j,k,t}\tilde{t}_{jkt}\mathrm{x}_{ijkt}\leq\sum_{i,j,k,t}T_{ij}b_{ij}D_{ikt} \quad ;\forall i,j,k,t \quad (28)$$

$$a(i,j,k,t,r)=sign\left[sign\left(x_{ijkt}-q_{jkt,r-1}\right)+sign(q_{jktr}-x_{ijkt})\right] \quad ;\forall i,j,k,t,r \quad (29)$$

$$P_{ijkt}=\sum_r P_{jktr}\times a(i,j,k,t,r) \quad ;\forall i,j,k,t \quad (30)$$

$$\sum_{i,j,k,t}y_{ijkt}\left[P_{ijkt}+\left(W_{ij}V_{ijk}\right)+f_{jkt}\right]\leq O_{it} \quad ;\forall i,j,k,t \quad (31)$$

$$x_{ijkt}y_{ijkt}\geq H_j \quad ;\forall i,j,k,t \quad (32)$$

$$x_{ijkt}\geq 0 \quad ;\forall i,j,k,t \quad (33)$$

$$y_{ijkt}\in\{0,1\} \quad ;\forall i,j,k,t \quad (34)$$

The first objective, namely cost function, is composed of three parts including purchase cost, shipment cost, and fixed cost of ordering. The second objective function presents to minimize the delay from supplier's side. The third objective is the ordering amount of each product from suppliers which is also defined based on percentage of wastes produced for each product by suppliers in each period. This parameter is also represented as random triangular fuzzy numbers. The fourth objective function is to maximize the coverage of customer's suppliers. The fifth objective, in this objective function, is the product ordering rate which is defined according to the supplier's weights. Supplier's weight is obtained through fuzzy TOPSIS technique in order to make suppliers evaluation more realistic and to select the best suppliers,Constraint (23) represents the fact that in order not to face any shortage, ordering rate of each customer for each product in each period from suppliers must be greater than or equal to the customer demand for that product in the desired period. Constraint (24) indicates that the ordering rate must be less than or equal to the coverage rate of supplier for the desired customer. This constraint is provided for the coverage objective function; accordingly, the supplier with more coverage is selected. On the other hand, this constraint defines the ordering rate after selecting the supplier. Constraint (25) shows supplier's capacity constraint to explain that ordering rate for each product by the customers in each period must be according to the capacity of each supplier. Constraint (26) explains the fact that amount of applying the suppliers for each product in each period by the customer must be according to the amount defined by the managers. In addition, each customer in each period must purchase the product at least from one supplier. Constraint (27) ensures that amount of accepting the wastes for each product by each customer in each period from each supplier must be corresponded to the rate defined by decision makers. Constraint (28) assures that delays reception rate for each product by each customer in each period for each supplier must be as what is defined by decision makers. Constraint (29-30) shows that price of each product offered by the suppliers has a discount of sign function type in which $a(i, j,k,t,r)$ are positive variables so that their total value is one. When in sign function, x is positive, one is returned, if x is zero, 0 is returned, when x is negative, -1 is returned. Therefore, $a(i, j,k,t,r)$ corresponding to each discount rate is activated according to the order rate and x as well as other ranges are zero and become inactivated. By this way, price of each product is found. Constraint (31) represents the amount of fund belonging to each customer in each period, where expenditure rate in supply chain must be equal to this fund. Constraint (32) ensures that order rate for each customer must be at least equal to the amount defined by the supplier. Otherwise, if the order rate to the supplier is lower than permitted amount, it will not be performed and purchasing from that supplier is not applicable. Constraints (33-34) give the range of decision variables.

3.6 In this section, for application hn real world and verification of the proposed model a numerical example is given to illustrate the proposed model. In this example, we assume that there exist two suppliers for each product and six customers within two time periods. The customers intend to buy two different types of products from the best suppliers and allocate the optimal order quantities to each supplier**.**The above instant supplier selection problem is solved by the epsilon-constraint method with GAMS software and the obtained results are analyzed. Supposing $f_1(x)$ as the main objective function, the model is solved by using the different amounts of epsilons (dividing the interval between the maximum and minimum amount of the subsidiary objective function in three equal intervals) and then the Pareto solutions are reported in Table 1.

Tab. 1. Pareto solution

Pareto solutions	The amounts of the objective functions				
	Z_1	Z_2	Z_3	Z_4	Z_5
1	125322.5	417.6	3034	1749.9	16.8
2	800852.4	417.6	5011.7	1749.9	26.4
3	872900	417.6	3031.5	1749.9	16.4
4	2404116.6	417.6	9015	1820	49.4
5	906332.4	417.6	7011.7	1749.9	37.42
6	1204396.9	648.6	3002.7	3308	16.1
7	2499835.3	468.6	8793.7	1856.1	52.11

3-8. Handling random fuzzy numbers

Using uniform distribution, 100 numbers are generated for each parameter matrix solution based on the desired range of the parameter. Then, the final fuzzy number is found through minimizing the numbers of first triangular fuzzy number, from mean numbers of middle number and through the maximizing of the numbers. Finally, utilizing the mean distribution β, triangular fuzzy numbers are converted to crisp. This is done for all the results of the desired parameter matrix. Moreover, Beta mean distribution formulation is applied for defuzzification of random triangular fuzzy numbers in the objective functions of delays, wastes, and weight (Timothy et al., 2005)[25].

$$\tilde{B} = (\boldsymbol{B^p}, \boldsymbol{Bm}, \boldsymbol{B^0}) \; ; \; B = \frac{\mathbf{B^p+4Bm+B^0}}{\mathbf{6}} \qquad (35)$$

4. Two Preto-Based Meta-Heuristics

Since the proposed mathematical model is NP-hard to solve it, two strong Pareto-based meta-heuristic algorithms called Non-dominate Sorting Genetic Algorithm (NSGA-II) in which has a fast and capable sorting procedure is accompanied by an elitism operation and Multi-objective imperialist competitive algorithm (MOICA) have been applied. NSGA-II applied to demonstrate applicability of MOICA. Fast non-dominated sorting and the Sigma method are employed for ranking the solutions in MOICA. Enayatifar et al(2013).

4-1. NSGA-II

Due to the drawbacks of NSGA (or NSGA-I) such as computational complexity, non-elitist operation, and the necessity of sharing parameter which can be quite preventable, NSGA-II was proposed by Deb et al. (2002)[26] as a class of multi-objective evolutionary algorithms.

The solution structure of the problem (chromosome) is consisted of two parts. The first part of chromosome indicates the order rate for each product by the customer in each period. The second part of chromosome is also considered as a binary variable to select the supplier.

4-2. MOICA (Multi-objective imperialist competitive algorithm)

A novel multi-objective evolutionary algorithm (MOEA) is developed based on imperialist competitive algorithm (ICA), a newly introduced evolutionary algorithm (EA). Fast non-dominated sorting and the Sigma method are employed for ranking the solutions. The algorithm is tested on six well-known test functions each of them incorporate a particular feature that may cause difficulty to MOEAs. Enayatifar et al.(2013)[27].

There are two fundamental issues to be taken into account when a MOEA is developed: 1) Determining the merit of each individual based on all objectives; 2) Maintaining the diversity of the final solutions.

4-3. Parameters calibration

Taguchi approach is executed by three levels of defined parameters in order to set the algorithm parameters. The calibration test is executed by Taguchi technique L27 (3**5); i.e. 27 tests are designed using five parameters and three levels. Signal-to-noise (SN) function is also defined as follows (Montgometry, 2000)[28]:

$$F(Y) = -10*\text{Log10}\ (\text{Sum}(Y**2)/n) \quad (36)$$

Tab. 2. The levels defined for parameters of NSGA-II and MOICA

Algorithm	Parameters	Parameters levels		
		Level 1	Level 2	Level 3
NSGA-II	Maximum Number of Iterations	10	15	20
	Population Size	50	75	100
	Crossover Percentage	0.3	0.5	0.7
	Mutation Percentage	0.1	0.3	0.5
	Mutation Rate	0.01	0.03	0.05
MOICA	Number of Maximum solutions	10	15	20
	Population Size	50	75	100
	Repository Size	0.3	0.5	0.7
	Mutation Percentage	0.1	0.3	0.5
	Mutation Rate	0.01	0.03	0.05

In this regard, three problems for supplier selection are defined for each suggested test by implementing the algorithm for each test; then, goal function value are computed. Table 2 reports the outputs of these three test problems.

Tab. 3. Generated test problems

Problem No.	1	2	3
Number of Customer	2	3	5
Number of Suppliers	3	4	6
Number of Products	2	4	7
Number of Period	2	3	3

For each test problem, separate objective functions are found and the mean of each objective function is obtained from three problems. the value of each objective function obtained for each problem is converted to an objective function through weighted-sum approach (Szidarovszky et al., 1985)[29].

$$TotalZ= w_1*Z_1+w2*Z_2+w_3*Z_3+w_4*Z_4+w_5*Z_5 \quad (37)$$

Parameter w indicates that if the weight or significance functions are of equal impotance for decision maker, w is set on 0.2. Figures 5-6 represent the SN ratio of Taguchi execution for NSGA-II and MOICA.

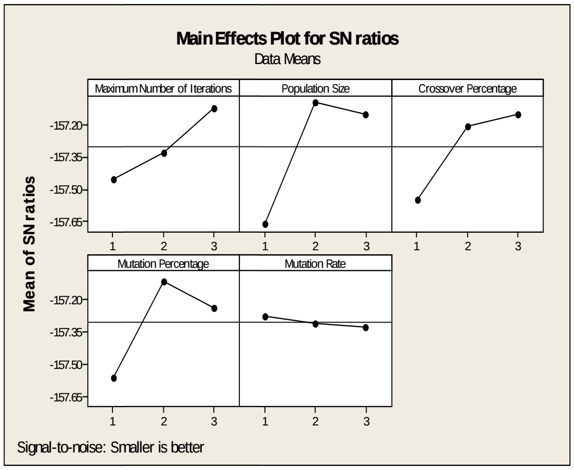

Fig. 2. Main effects plot for SN ratios of NSGA-II

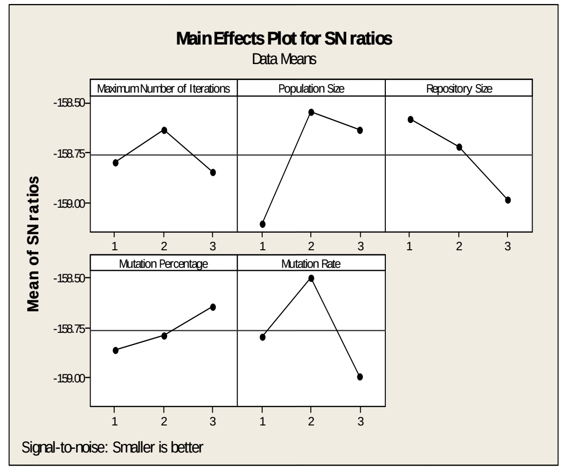

Fig. 3. Main effects plot for SN ratio of MOICA

The best values of algorithm parameters determined by Taguchi method are shown in Table 3.

Tab. 4. The best rations of NSGA – II and MOICA algorithm parameters:

Algorithm	Parameters	Optimal Value
NSGA-II	Maximum Number of Iterations	20
	Population Size	75
	Crossover Percentage	0.7
	Mutation Percentage	0.3
	Mutation Rate	0.01
MOICA	Number of Maximum solutions	15
	Population Size	75
	Repository Size	25
	Mutation Percentage	0.5
	Mutation Rate	0.03

5. Results Analysis

Five numerical illustrations are considered in this study to evaluate the efficiency of two meta-heuristics. Then, ratios of each measure for each function of each sample example from model are obtained and finally, mean amount of each measure is defined among the objective function in each sample example. We firstly introduce considered performance measures for evaluating and comparing the algorithms; then, the results are statistically analyzed. Table 4 indicates the input parameters of five test examples.

Tab. 5. Input parameters of five numerical illustrations

Problem No.	1	2	3	4	5
Number of Customer	2	3	5	8	10
Number of Suppliers	3	4	6	8	9
Number of Products	2	4	7	9	10
Number of Period	2	3	3	4	4

5-1. Performance measures

We consider three following measures to analyze Pareto solutions in multi-objective optimization:

5-1-1. Mean ideal solution distance (MID)

One of the measures to evaluate the algorithms is the distance from the ideal point which calculates the distance of all points from the best population size. This equation indicates how to calculate this measure (Boloori et al., 2001)[30]:

$$MID = \frac{\sum_{i=1}^{n} c_i}{n} \qquad (38)$$

Where c_i is the distance from the ideal solution i and n is the number of Pareto solutions in the final front.

5-1-2. Spacing

Based on the spacing measure, the algorithm covers all the solution spaces points. This measure calculates the relative distance of subsequent solutions. (Boloori et al., 2001).

$$S = \sqrt{\mathbf{1/n}\sum_{\mathbf{i=1}}^{\mathbf{n}}(\mathbf{d}_i - \bar{\mathbf{d}})^{\mathbf{2}}} \quad (39)$$

where $\bar{d} = \sum_{i=1}^{n}\frac{di}{|n|}$ and $d_i = min_{\{k\epsilon N\&k\neq 1\}}\sum_{m=1}^{2}\left|fm^i - fm^k\right|$

5-1-3. Algorithm time-to-solution

The final measure is computational time of algorithm. Algorithms are programed using MATLAB 7.14.0.739 (R2012a) and implemented on a PC under windows 7, 2.40 GHz, RAM 4 GB. Figures 4 to 6 are the outputs of executing NSGA-II and MOICA by concentrating on algorithm comparison in terms of MID, Spacing, and computational time metrics.

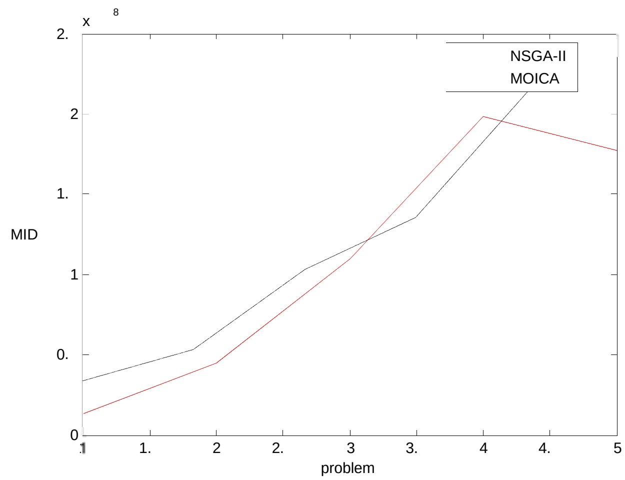

Fig. 4. Comparing MOICA and NSGA-II in terms of MID metric

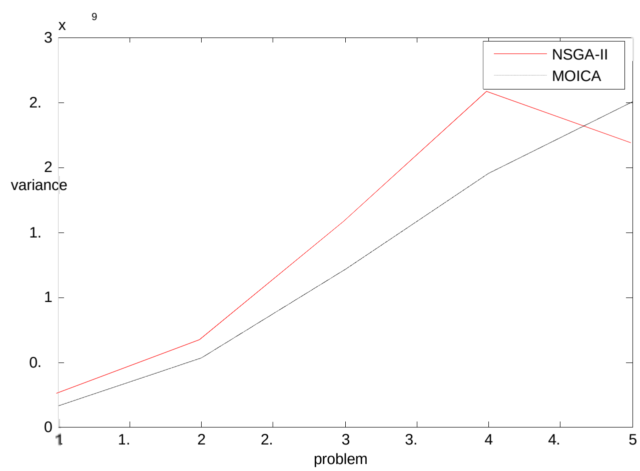

Fig. 5. Comparing MOICA and NSGA-II in terms of Spacing metric.

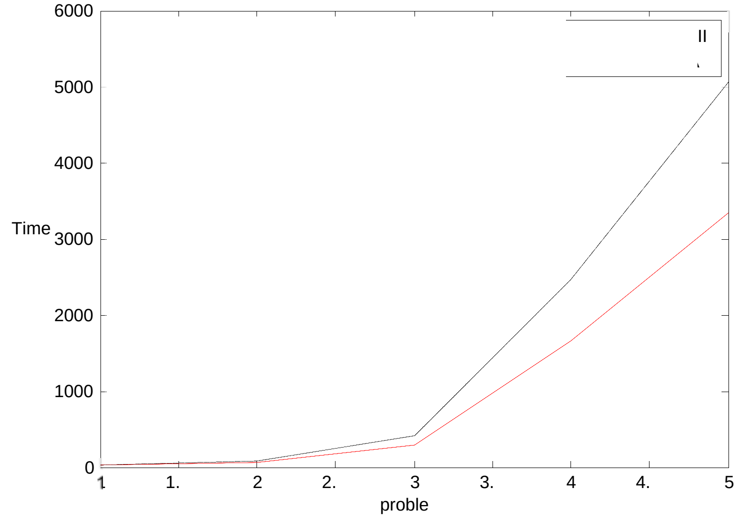

Fig. 6. Comparing MOICA and NSGA-II in terms of computational time metric.

6. Conclusion

In this paper, Deference and wastes parameters are considered as uncertain and random triangular fuzzy number. Since the proposed mathematical model is NP-hard, MOICA and NSGA-II are applied to solve the multi-objective model. After performing the tests and evaluating the solutions of two algorithms by three measures including MID, spacing, and computational time (CPUT) metrics, it was concluded that NSGA-II is superior on the measures of CPUT and spacing; however, MOICA has a better performance in MID metric. We concluded that both algorithms are completely comparable. In addition, it is possible to solve the model for selecting and allocating the orders to the supplier in the wide spread case, that is, in multi objective, multiple customer, multi product and multi period and in the multi objective case, NSGA-II and MOICA are capable to find and manage Pareto solutions. Taguchi technique is executed to tune the parameters of both algorithms. The results are analyzed using quantitative criteria, performing parametric, and non-parametric statistical analysis. However, it is worth considering that in case that the time and spacing is important for decision maker, NSGA-II can be better choice; while, in MID desire, MOICA algorithm is preferred.

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