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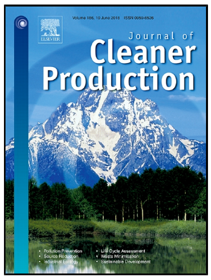


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| PII: | S0959-6526(18)31200-9 |
| DOI: | 10.1016/j.jclepro.2018.04.167 |
| Reference: | JCLP 12748 |
| To appear in: | *Journal of Cleaner Production* |
| Received Date: | 05 October 2017 |
| Revised Date: | 16 April 2018 |
| Accepted Date: | 17 April 2018 |

Please cite this article as: Amir Arabsheybani, Mohammad Mahdi Paydar, Abdul Sattar Safaei, An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk, *Journal of Cleaner Production* (2018), doi: 10.1016/j.jclepro.2018.04.167

# An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk

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## Abstract

Supplier selection is a complex process and plays a signification role in promoting the sustainable supply chain. In this study, a fuzzy multi-objective optimization model based on the ratio analysis (fuzzy MOORA) is applied to evaluate the supplier's overall performance. In reality, suppliers face risks like natural calamity or political variability. Hence, failure mode and effects analysis (FMEA) is implemented to evaluate the risks of a supplier. Moreover, a novel multi-objective mathematical model is developed to consider supplier's sustainability and order allocation simultaneously. The efficiency and applicability of the proposed approach is shown by a case study of the evaporative cooler in the home appliance industry. The current approach can be implemented in many manufacturing industries such as electrical, automotive and chemical. The results show that by employing the proposed model not only potent to increase total profit but also decrease the amount of risks which imposes on the sustainability.

**Keywords:** Sustainability, Supplier selection, Order allocation, FMEA, Quantity discount, Fuzzy MOORA.

## 1. Introduction

In the competitive business environment, companies seek to create competitive advantages by utilizing data management, knowledge management. Supply chain management has an important role in handling this issue. Moreover, in the field of the supply chain (SC), supplier selection is a strategic decision. Supplier selection is a process of taking the best suppliers with right price and quality at the right time and quantity (Ayhan and Kilic 2015). Researchers estimated that more than 60 percent of production costs relates to purchasing raw material from the suppliers (Krajewsld and Ritzman 1996). Supplier selection has great influence on the strategic and operational performance of an organization. Furthermore, good suppliers can reduce the production and inventory costs, improve the quality, flexibility and consequently satisfy customer expectations (Çebi and Otay 2016). Many aspects such as considering qualitative and quantitate criteria for various factors such as globalization of trade, government regulation, and changing customer preferences makes the supplier selection as a complex decision (De Boer et al., 2001).

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Moreover, sustainability was introduced as a widespread concept to integrate environmental, social and economic issues. Sustainability is defined as "satisfy the needs of the current generation without limiting next generation" (Özdemir et al., 2011). Since the first step in production is purchasing raw materials from suppliers, therefore ranking and selecting suppliers based on the sustainability indices is one of the important and strategic decisions on the way of sustainable supply chain. The sustainable concept in the supplier selection problem was introduced in 2010 by Bai and Sarkis. To rank suppliers, researchers considered the sustainability of supplier as a positive score and proposed some multi-criteria decision making (MCDM) methods.

However, risk issue is not considered by most cases in a sustainable supplier selection problem. Suppliers with acceptable performance in sustainability factors may face various risks. For instance, consider a supplier with a fair price in most of the time, however, because of an unstable situation in supply chain, the costs raise 30 percent from the nominal price. In the previous works the overall performance of a supplier is considered and risks such as increasing the selling price is not incorporated in the model. Therefore, considering the risks along with other factors is essential to obtain a widespread view about a supplier. Moreover, FMEA is one of the well-known technique for risk analysis. FMEA usually used as a risk analysis tool to design a process with better product reliability (Anleitner, 2010 and Carlson, 2012).

In the competitive environment, new sales policies encourage the consumer to buy more. A common type of sales policy is quantity discount. To have more realistic model these discounts are considered in the proposed mathematical models in the literature. Mainly, there are three types of price offers from the supplier: all unit discounts, incremental discounts and fixed price. For all units discount, the constant price for an item applies to all units ordered. Fig 1 shows the calculation of total purchasing costs according to all unit discount in which $c_i$ is the price of the product and $Xi$ is the amount of purchased items.

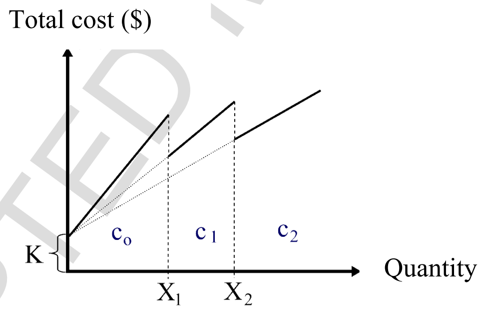


**Figure 1. Total cost calculation when all unit discount is offered**

For the incremental discount, price reduction just applies to quantities greater than the price break quantities. Fig 2 illustrates how to calculate total purchasing costs according to an incremental discount.

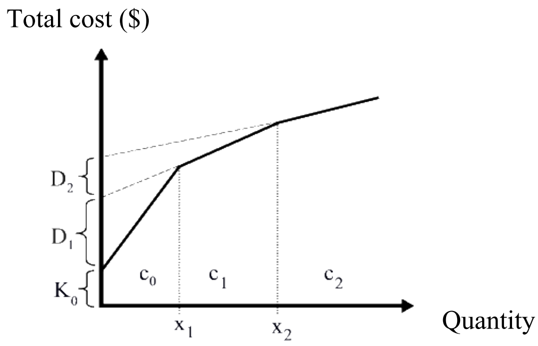


**Figure 2. Total cost calculation when the incremental discount is offered**

As already mentioned, most of the studies utilized different types of MCDM methods to evaluate the suppliers and any research considered the risk of a supplier in a sustainable supplier selection problem. To find the best suppliers, a novel integrated approach including fuzzy MOORA (to determine the supplier's score) and FMEA (to calculate the supplier's risk) is presented in this study. Furthermore, order allocation is incorporated in a multi-objective mathematical model. The proposed model is a multi-item/multi-supplier and multi-period problem. The first objective that relates to the economic aspect of suppliers and maximizes the total profit. Different types of discounts that suppliers may offer are considered in this objective. For situations that companies faced with some troubles and cannot satisfy demand entirely, lost sale is considered. The second objective minimizes the subsequent losses caused by unsatisfied demand. The necessity of this objective function is discussed in detail in Section 3. The third objective considers the sustainability aspects of suppliers by utilizing the results of FMEA and MCDM models.
The rest of this paper is organized as follows. In Section 2, a literature review on sustainable supplier selection and order allocation is presented. The multi-objective mathematical formulation which contains maximization of total profit and minimization of lost sale and total risk is developed in Section 3. Section 4 illustrates the validation of the proposed method by an application to a real-world case study. A discussion presented in section 5. Finally, conclusions and future suggestions are provided in Section 6.

## 2. Literature review

After introducing supplier selection problem by Dickson (1966), various methodologies applied to solve this problem. Some of this approaches listed as follow:

- Multi-criteria decision making-MCDM (Dweiri et al., 2017)
- Multi-objective programming (Hamdan and Cheaitou 2017)
- Total cost of ownership (Visani et al., 2016)
- Statistical analysis (Mummalaneni et al., 1996)
- Data envelopment analysis (Fallahpour et al., 2017)

One of the important steps of the supplier selection problem is defining the criteria. In an admirable research, Govindan et al., (2015) collected popular criteria for supplier evaluation until 2011. Top thirteen popular criteria are selected and shown the number of repetitions in Fig 3.

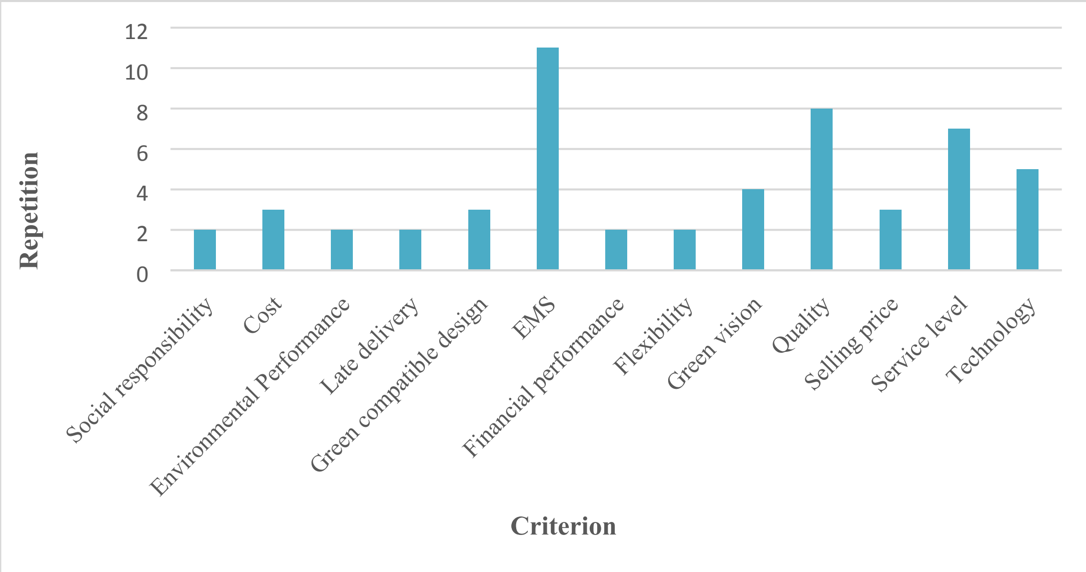


**Figure 3. Popular criteria for evaluating suppliers and number of repetition in the literature**

Some of the recent models dealt with supplier selection problem are presented in follow. Rao et al., (2017b) focused on supplier selection for divisible goods. They used supply chain risk management and multi-attribute auction in their two-stage approach. In the first stage, shortlist among all qualified suppliers determined by using multi-auction mechanism. In the second stage, to select final winner, seven risk attributes against the shortlisted suppliers are considered. To show the efficiency and applicability of the proposed approach, they used a case study in the electricity coal.

The supply chain is a complex process with different kind of parameters that faced various risks. The risk can range from natural calamity and political variability to the labor strikes and fluctuation of currency. The issue of risk widely considered in the supplier selection in view of five failures as follows: risk in delivery, cost, quality, general confidence and flexibility (Li and Zeng 2014 and Kull and Talluri, 2008). Wu et al., (2010) developed two risk objectives that contain the economic and vendor rating.

One of the best methods for assessing risks is FMEA. The basis of FMEA can be found in the US Military (revised in 1980 as MIL-STD-1629A). Furthermore, this technique used by NASA for Apollo mission and plays an important role in the six sigma methodology (Raisinghani et al., 2005). Li and Zeng (2014) applied this technique for evaluating the supplier's economic criteria without considering sustainability issue.

As mentioned in Section 1, the sustainable supplier must perform in three main aspects: economic, environmental and social. Table 1 gives a detailed review of criteria and the MCDM methods implemented for solving supplier selection problem by random search.

**Table 1. Literature classification of sustainable criteria and MCDM method in the supplier selection problem**

| Researcher | Economic | Environmental | Social | Fuzzy | Mathematical model | MCDM | Other approaches |
|---|---|---|---|---|---|---|---|
| Lima Junior et al., 2014 | ✓ | | | ✓ | | Fuzzy AHP<br>Fuzzy TOPSIS | |
| Guo and Li, 2014 | ✓ | | | ✓ | ✓ | | |
| Rao et al., 2017c | ✓ | ✓ | | ✓ | | Extended VIKOR | |
| Sarkis and Dhavale, 2015 | ✓ | ✓ | ✓ | ✓ | | | Montecarlo simulation for Markov chain |
| Akman, 2015 | ✓ | ✓ | | ✓ | | VIKOR | Fuzzy c mean |
| Orji and Wei, 2015 | ✓ | ✓ | ✓ | | | TOPSIS | System dynamic |
| Govindan and Sivakumar, 2016 | ✓ | ✓ | | ✓ | ✓ | Fuzzy TOPSIS | |
| Zhou et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | | Data envelopment analysis |
| Trapp and Sarkis, 2016 | | ✓ | | | ✓ | | Heuristic method |
| Keshavarz Ghorabaee et al., 2016 | | ✓ | | ✓ | | | Interval type 2 fuzzy sets |
| Yu et al., 2016 | | ✓ | | | ✓ | | |
| Dweiri et al., 2016 | ✓ | | | | | AHP | |
| Rao et al., 2017a | ✓ | ✓ | ✓ | | | | Linguistic 2-tuple grey correlation degree |
| Banaeian et al., 2018 | ✓ | ✓ | | ✓ | | Fuzzy TOPSIS<br>Fuzzy VIKOR<br>Fuzzy GRA | |
| Vahidi et al., 2018 | ✓ | ✓ | ✓ | | ✓ | | Hybrid SWOT-QFD |
| Awasthi et al., 2018 | ✓ | ✓ | ✓ | ✓ | | Fuzzy AHP<br>Fuzzy VIKOR | |
| This study | ✓ | ✓ | ✓ | ✓ | ✓ | Fuzzy MOORA | FMEA |

Jain et al., (2015) applied incremental and all unit discounts. They developed a non-linear model and proposed three different meta-heuristic algorithms of genetic algorithm (GA), artificial bee colony (ABC) and chaotic bee colony (CBC) to solve the model. An integration of MCDM and a mathematical model developed by (Çebi and Otay 2016). They proposed an approach with two-stage: in the first stage supplier evaluation is performed by applying fuzzy MULTIMOORA with triangular fuzzy numbers. Further, in the second stage, they proposed a multi-objective model to minimize purchasing cost (considering discount), late deliveries, defective items and maximize the total score of a supplier that obtained from the previous stage. They reformulated the model as a fuzzy multi-objective linear programming. The fuzzy model change to a single objective model by using a max-min technique which has been expanded by Arikan (2013).

Table 2 reviews the supplier selection works with mathematical model and discount consideration. As it stands, after the researcher's name, the first column including two different discounts (all unit, incremental) and one situation that a seller does not offer any discount. The second column shows criteria that used for evaluating suppliers. The last column implies solution method that used to solve the proposed model.

**Table 2. Classification of literature on mathematical model, sustainable criteria and quantity discounts which considered by the researchers**

| Researcher | Discount | | | Criterion | | | Risk | Multi-product | Solution approach |
|---|---|---|---|---|---|---|---|---|---|
| | Not discount | All-unit | Incremental | Environmental | Social | Economic | | | |
| Ayhan and Kilic, 2015 | | ✓ | | ✓ | | ✓ | | ✓ | Fuzzy AHP |
| Mohammaditabar et al 2014 | ✓ | | | | | ✓ | | ✓ | Game theory |
| Chen and Baddam, 2015 | ✓ | | | | ✓ | | ✓ | ✓ | Heuristic |
| Chai and Ngai, 2015 | ✓ | | | | | ✓ | | ✓ | Hesitant Fuzzy sets |
| Moghaddam, 2015 | ✓ | | | | | ✓ | | ✓ | Fuzzy goal programming |
| Torabi et al., 2015 | ✓ | | | | | ✓ | | ✓ | ε- constraint |
| Kırılmaz and Erol 2016 | ✓ | | | ✓ | ✓ | ✓ | | ✓ | Heuristic |
| Jain et al., 2015 | | ✓ | ✓ | | | ✓ | | ✓ | GA<br>Artificial Bee Colony<br>Chaotic Bee Colony |
| Çebi and Otay, 2016 | | ✓ | ✓ | | | ✓ | | ✓ | Fuzzy MOORA |
| Rezaei et al., 2016 | ✓ | | | ✓ | | ✓ | | ✓ | Best-Worst |
| Meena and Sarmah, 2016 | | ✓ | ✓ | | | ✓ | | ✓ | Heuristic |
| Nourmohamadi Shalke et al., 2017 | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | Revised multi-choice goal programming |
| This study | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Fuzzy MOORA<br>FMEA<br>Fuzzy goal programming based on MINMAX method |

## 3. The proposed approach

A diagram for representing the proposed methodology is shown in Fig 4. This approach illustrates how sustainability issues can be integrated into the problem of multi-product, multi-supplier, multi-period, multi-item along with considering the different type of discounts. The first step to select appropriate suppliers is gathering correct and complete information about the product and its requirements. Step 2 is generating a list of potential suppliers, according to the product requirements. Afterward, the proposed approach divides into two parts. Left side in Fig 4, consider qualitative criteria to evaluate the sustainability of suppliers. The right side of the proposed framework relates to the quantitative economic factors. To consider all the important aspects of suppliers, a non-linear multi-objective model is developed. In order to reduce solution time, the model is reformed to a linear programming by adding a few constraints. Finally, to demonstrate the capability of new approach a real-world case study and sensitivity analysis are presented.

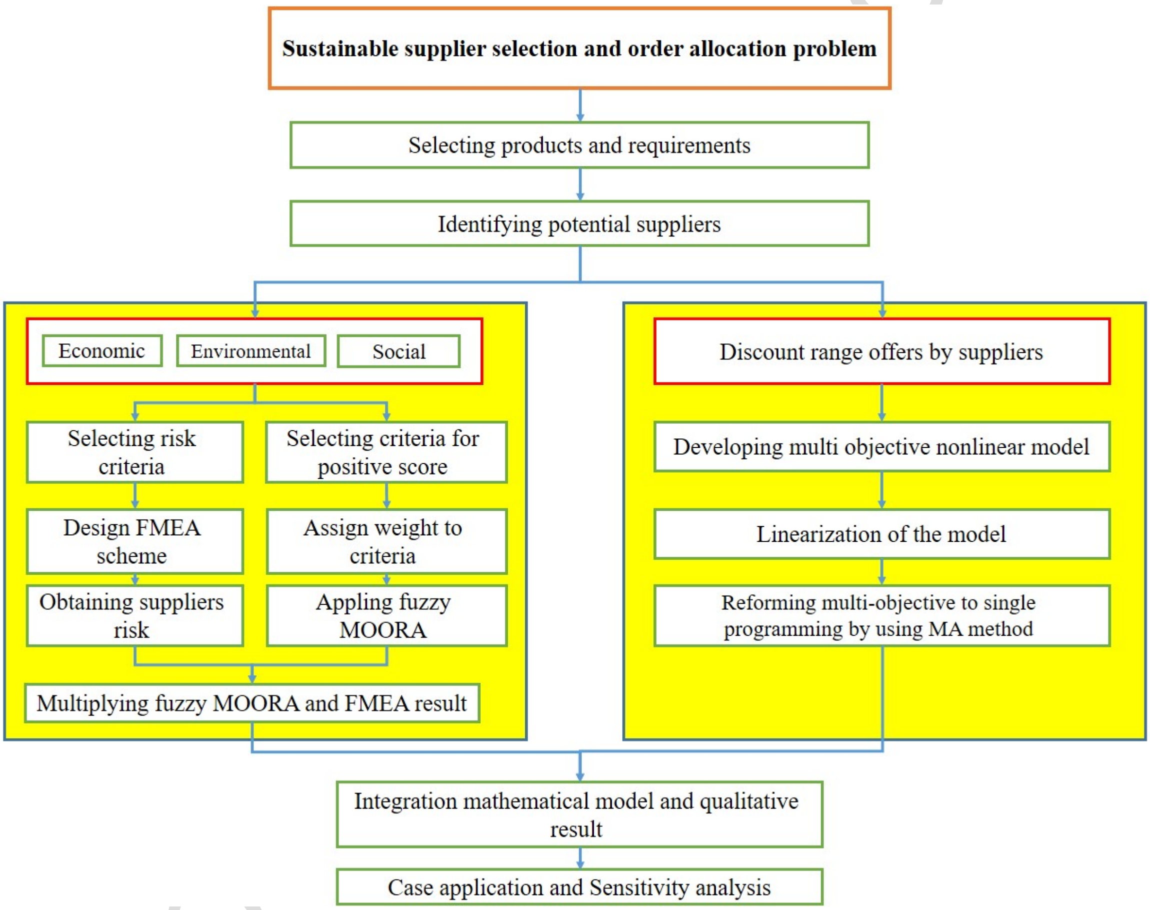


**Figure 4. The proposed framework**

### 3.1. Problem definition

As illustrated in Fig 5, this research systematically analyzes sustainable supplier selection and order allocation problem with a single plant, multi-supplier, multi-item, multi-product and multi-period under quantity discount by developing a non-linear programming model. In other word, the model deals with suppliers that offer quantity discounts and different price levels for each type of items in each period.

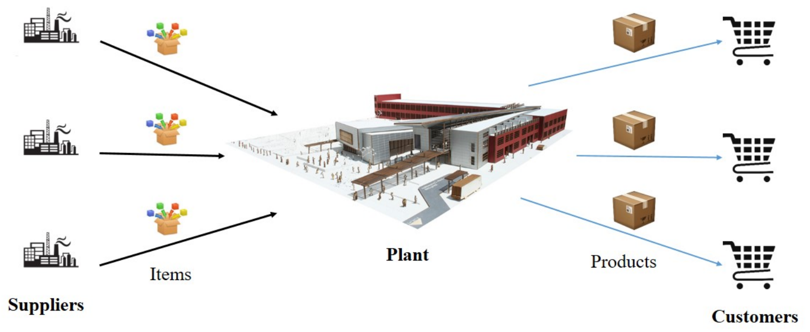


**Figure 5. The structure of the proposed network**

### 3.2. Fuzzy MOORA

An MCDM method is utilized to consider multiple qualitative criteria for supplier assessment. The fuzzy MOORA is implemented in the current study because of three main reasons (Akkaya et al., 2015):

1. MOORA is one of the latest MCDM methods that covers the weakness of other older methods.
2. The result is stable nature and setup time is low.
3. The computational time for MOORA is about MCDM point out.

Application of Fuzzy MOORA has five steps which completely explained in Paydar et al., (2017a)

### 3.3. FMEA

During the implementation of fuzzy MOORA method, there is no consideration to the failure of suppliers and ranking based on their overall performance. However, in the real world, suppliers may face some failure. Therefore, the risk notion is proposed in the current research. In this section, risk of suppliers obtained using FMEA technique.

Preparing a team of experts to determine risk criteria is the first step of FMEA. The expert team can select risk criteria by exploring the company's historical data and reviewing the previous literature. After determining risk criteria, the planner should examine three aspects of risks: severity, occurrence and detection. Then, FMEA scheme should be designed for each criterion. To design scheme, this paper uses 1-10 point scale introduced by Carlson, (2012) that the larger point illustrates the higher risk. The schemes contain a rank and a brief description of each FMEA aspects that help decision maker to select rank.

After scheme designing, decision maker needs to select 3 ranks (rank in severity, occurrence, and detection) for all criteria. Changing FMEA results to numbers is the next step of FMEA, therefore the RPN concept arises. Let define $L$ as equation (1) and $ep$ as equation (2). The RPN formula is shown in equation (3).

$$L=S*O \tag{1}$$

$$ep = -0.1*D+1.55 \tag{2}$$

$$R = \left(\frac{(L-1)}{99}\right)^{ep} *100 \tag{3}$$

Justification of $ep$ equation and how to design risk scheme explained in Paydar et al., (2017a).

Finally, the integration of FMEA and fuzzy MOORA which obtained by the equation (4) will be used for ranking suppliers. It should be noticed that fuzzy MOORA reveals the desirable aspect and the risk factor shows the negative points for each supplier. Hence, direct multiplication is not reasonable, therefore the equation 4 is used to integrate the result of fuzzy MOORA and FMEA.

$$\text{Risk discount} = \text{risk} * (1- \text{fuzzy MOORA}) \quad (4)$$

### 3.4. Mathematical model

As mentioned in Section 3.1, to have a comprehensive look in the supplier selection problem, it seems essential to develop a mathematical model for integrating the FMEA results and total supplier's score reported by fuzzy MOORA with other important quantitative economic factors. The proposed model has three objective functions which maximize total profit, minimize the lost sale unbalancing and minimize the total discount risk imposed on the sustainability of supply chain. The model is based on the following assumptions:

- A supply chain with multi-product, multi-supplier, multi-item and multi-period is considered.
- Each supplier can choose only one of the three possible pricing strategy. In other words, $Nd_{si}+ Ad_{si}+ Id_{si}=1$.
- Purchasing price from the supplier is incessant simply put $Ub_{si(k_s-1)t} = Lb_{sik_st}$ for all $s$ and $k_s$.

**Indices:**

| | |
|---|---|
| $s$ | Index of the supplier ($s=1,2,3,\ldots,S$) |
| $i$ | Index of the item ($i=1,2,\ldots,I$) |
| $p$ | Index of the product ($p=1,2,\ldots,P$) |
| $m$ | Index of the market ($m=1,2,\ldots,M$) |
| $k_s$ | Index of the discount range of supplier $s$ ($k_s=1,2,\ldots,K_S$) |
| $t$ | Index of the time period ($t=1,2,3,\ldots,T$) |

**Parameters:**

| | |
|---|---|
| $sell_{pt}$ | Unit selling price of product $p$ in period $t$ |
| $cost_{pt}$ | Unit production cost of product $p$ in period $t$ |
| $d_{pmt}$ | Demand of market $m$ for product $p$ in period $t$ |
| $Capacity_t$ | Production capacity of period $t$ |
| $support_{si}$ | Supply capacity of supplier $s$ to provide item $i$ |
| $time_p$ | Production time of product $p$ |
| $\lambda_{ip}$ | Required amount of item $i$ for producing product $p$ |
| $BC_{pm}$ | Cost of lost sale for product $p$ in market $m$ |
| $fc_{st}$ | Fixed ordering cost of supplier $s$ in period $t$ |
| $Ship_{si}$ | Transportation cost of item $i$ from supplier $s$ |
| $Ship_{pm}$ | Transportation cost of product $p$ to market $m$ |
| $hci_i$ | Holding cost per unit of item $i$ |
| $hcp_p$ | Holding cost per unit of product $p$ |
| $Nd_{si}$ | Equals 1 if supplier $s$ does not consider any discounts for item $i$, 0 otherwise |
| $Ad_{si}$ | Equals 1 if supplier $s$ consider an all-unit quantity discounts for item $i$, 0 otherwise; |
| $Id_{si}$ | Equals 1 if supplier $s$ consider an incremental quantity discounts for item $i$, 0 otherwise |
| $u_{si}$ | Unit purchase price of item $i$ from supplier $s$ |
| $Lb_{sik_st}$ | Lower bound of the discount range $k_s$ of supplier $s$ for item $i$ in period $t$ |
| $Ub_{sik_st}$ | Upper bound of the discount range $k_s$ of supplier $s$ for item $i$ in period $t$ |
| $AP_{sik_s}$ | Buying price paid for the entire purchase order in range $k_s$ of supplier $s$ for item $i$ (all-unit quantity discount) |

| | |
|---|---|
| $IP_{sik_s}$ | Buying price paid per unit between the respective bounds of range $k_s$ of supplier *s* for item *i* (incremental quantity discount) |
| $RMAX_i$ | Maximum available discount risk for item *i* |
| $M$ | Big number (Positive) |

**Decision Variables:**

| | |
|---|---|
| $Y_{pt}$ | Production quantity of product *p* for period *t* |
| $X_{sit}$ | Order quantity of item *i* from supplier *s* in period *t* |
| $T_{pmt}$ | Transport of product *p* to market m in period *t* |
| $II_{it}$ | Inventory of item *i* in period *t* |
| $XP_{pt}$ | Inventory of product *p* in period *t* |
| $B_{pmt}$ | Lost sale of product *p* in market *m* for period *t* |
| $VFC_{st}$ | 1 if an order is placed with supplier *s* in period *t*, 0 otherwise |
| $VAP_{sik_st}$ | 1 if discount range $k_s$ of supplier *s* for item *i* is elected in period *t*, 0 otherwise (all-unit quantity discount) |
| $VIP_{sik_st}$ | 1 if discount range $k_s$ of supplier *s* for item *i* is selected in period *t*, 0 otherwise (incremental quantity discount) |

**Objective functions:**

**Total profit**

A non-linear objective function that maximizes the total profit during the planning horizon is proposed as follow:

*Max* $OB_1=$

$$\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{t=1}^{T} sell_{pt}T_{pmt} \tag{5}$$

$$-\sum_{p=1}^{P}\sum_{t=1}^{T} cost_{pt}Y_{pt} \tag{6}$$

$$-\sum_{s=1}^{S}\sum_{t=1}^{T} fc_{st}VFC_{st} \tag{7}$$

$$-\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T} ship_{si}X_{sit} - \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{t=1}^{T} ship_{pm}T_{pmt} \tag{8}$$

$$-\sum_{i=1}^{I}\sum_{t=1}^{T} hci_i II_{it} - \sum_{p=1}^{P}\sum_{t=1}^{T} hcp_p XP_{pt} \tag{9}$$

$$-\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T} X_{sit}u_{si}Nd_{si} \tag{10}$$

$$-\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{k_s=1}^{K_S}\sum_{t=1}^{T} AP_{sik_s}X_{sit}VAP_{sik_st}Ad_{si} \tag{11}$$

$$-\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{k_s=1}^{K_s}\sum_{t=1}^{T}\left(\left(X_{sit}VIP_{sik_st} - Ub_{si(k_s-1)t}VIP_{si\hat{k}_st}\right)IP_{sik_s}Id_{si} + \sum_{\hat{k}_s=0}^{K_s-1}\left(Ub_{si\hat{k}_st} - Lo_{si\hat{k}_st}\right)IP_{si\hat{k}_s}Id_{si}VIP_{si\hat{k}_st}\right) \tag{12}$$

Equation (5) represents the total sale. Equation (6) shows the operation cost for manufacturing product. Equation (7) is the fixed ordering cost for each supplier. Term (8) is transportation cost from suppliers to plant and from plant to markets, respectively and Term (9) is holding cost for inventory of items and products. The last three terms represent purchasing items from suppliers. The model uses equation (10) when a supplier does not offer discount for an item.Term (11) is used when supplier offer all-unit discount and finally equation (12) is used to consider the incremental discount in the model.

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In the first objective, $X_{sit}VAP_{sik_st}$ and $X_{sit}VIP_{sik_st}$ are nonlinear parts. In these terms that a multiplication of integer and binary variables is visible. variables of $L_{sik_st}$ and $F_{sik_st}$ as auxiliary variables are added in the following constraints to the model:

$$L_{sik_st} = X_{sit}VAP_{sik_st} \qquad \forall s,i,k_s,t \qquad (13)$$

$$L_{sik_st} \geq X_{sit} - M(1 - VAP_{sik_st}) \qquad \forall s,i,k_s,t \qquad (14)$$

$$L_{sik_st} \leq X_{sit} + M(1 - VAP_{sik_st}) \qquad \forall s,i,k_s,t \qquad (15)$$

$$L_{sik_st} \leq M \times VAP_{sik_st} \qquad \forall s,i,k_s,t \qquad (16)$$

$$F_{sik_st} = X_{sit}VIP_{sik_s} \qquad \forall s,i,k_s,t \qquad (17)$$

$$F_{sik_st} \geq X_{sit} - M(1 - VIP_{sik_st}) \qquad \forall s,i,k_s,t \qquad (18)$$

$$F_{sik_st} \leq X_{sit} + M(1 - VIP_{sik_st}) \qquad \forall s,i,k_s,t \qquad (19)$$

$$F_{sik_st} \leq M \times VIP_{sik_st} \qquad \forall s,i,k_s,t \qquad (20)$$

$$F_{sik_st}, L_{sik_st} \geq 0, \text{and Integer} \qquad (21)$$

**Lost sale balance**

This objective function makes a balance between lack of product and satisfied demand of each market. The objective expresses that market with higher demand must have more lack of product.

$$Min\ OB_2 = \sum_{p=1}^{P}\sum_{t=1}^{T} \underset{m}{Max} \frac{d_{pmt} - T_{pmt}}{d_{pmt}}$$

To reduce the solution time, the second objective is rearranged as a linear objective by adding an auxiliary variable and new constraint. Auxiliary variable is $W_{pt}$ and constraint (22) is added to linearize the second objective function as follow:

$$Min\ OB_2 = \sum_{p=1}^{P}\sum_{t=1}^{T} W_{pt}$$

$$W_{pt} \geq \frac{d_{pmt} - T_{pmt}}{d_{pmt}} \qquad \forall p,m,t \qquad (22)$$

**Total discount risk**

The total discount risk of suppliers is minimized by introducing the equation (23). The supplier's discount risk which is obtained by the FMEA and fuzzy MOORA is used as a coefficient for $X_{sit}$ as follows:

$$Min\ OB_3 = \sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T} R_{si} X_{sit} \qquad (23)$$

**The model constraints**

The following constraints are embedded in the model to consider the different limitations.

**Quantity discount constraints**

Based on this constraint, an order with all unit discount cannot be planned if a supplier doesn't offer all unit discount. Furthermore, this constraint says that only one range of discount can be chosen.

$$\forall s,i,t \qquad (24)$$

There are two constraints that guarantee order quantity in all unit discount must be within the supplier's range.

$$\sum_{t=1}^{T} X_{sit} \leq Ub_{sik_s t} + M(1 - VAP_{sik_s t} \times Ad_{si}) \qquad \forall s, i, k_s, t \qquad (25)$$

$$\sum_{t=1}^{T} X_{sit} > Lb_{sik_s t} - M(1 - VAP_{sik_s t} \times Ad_{si}) \qquad \forall s, i, k_s, t \qquad (26)$$

Same as constraints (24-26), we have following constraints for incremental discount:

$$\sum_{k_s=1}^{K_S} VIP_{sik_s t} = Id_{si} \qquad \forall s, i, t \qquad (27)$$

$$\sum_{t=1}^{T} X_{sit} \leq Ub_{sik_s t} + M(1 - VIP_{sik_s t} \times Id_{si}) \qquad \forall s, i, k_s, t \qquad (28)$$

$$\sum_{t=1}^{T} X_{sit} > Lb_{sik_s t} - M(1 - VIP_{sik_s t} \times Id_{si}) \qquad \forall s, i, k_s, t \qquad (29)$$

**Demand constraints**

The demand constraint necessitates that demand from different markets for each product in each period must be equal to satisfied demand and lack of product.

$$d_{pmt} = T_{pmt} + B_{pmt} \qquad \forall m, p, t \qquad (30)$$

**Fixed ordering cost constraint**

This constraint specifies that order does not happen unless a fixed cost is applied.

$$\sum_{i=1}^{I} X_{sit} \leq M \times VFC_{st} \qquad \forall s, t \qquad (31)$$

**Capacity constraints**

The following constraint guarantee that the total production cannot exceed the maximum time in each period and the purchased items should not be greater than the maximum capacity of suppliers, respectively.

$$\sum_{p=1}^{P} time_p \times Y_{pt} \leq capacity_t \qquad \forall t \qquad (32)$$

$$X_{sit} \leq support_{si} \qquad \forall s, i, t \qquad (33)$$

**Inventory constraints**

To make a balance between the productions, holding inventory from previous periods, the quantity of purchased items and sent items, the following constraints are given:

$$Y_{pt} + XP_{p(t-1)} = \sum_{m=1}^{M} T_{pmt} + XP_{pt} \qquad \forall p, t \qquad (34)$$

$$\sum_{s=1}^{S} X_{sit} + II_{it-1} = \sum_{i=1}^{I} \sum_{p=1}^{P} \lambda_{ip} Y_{pt} + II_{it} \qquad \forall i, t \qquad (35)$$

**Maximum risk constraint**

This constraint says that risk imposed to the system for each item should be less than the maximum risk which presented by experts during all periods.

$$\sum_{s=1}^{S} R_{si} X_{sit} \leq RMAX_i \qquad \forall i, t \qquad (36)$$

**Variable Domain**

$$Y_{pt}, Xsit, Tpmt, IIit, XPpt, Bpmt \geq 0, \text{and integer}$$
$$VFC_{st}, VAP_{sik_s t}, VIP_{sik_s t} \in \{0,1\} \quad (37)$$

### 3.5. Mathematical solution approach

The proposed multi-objective linear model is converted to a single objective utilizing the fuzzy goal programming (FGP). Yaghoobi and Tamiz, (2007) categorized the major models in goal programming (GP) as a weighted goal programming (WGP), Lexicographic GP (LGP) and MINMAX GP (MGP). Furthermore, they developed a new method for solving FGP based on MGP. The general form of Yaghoobi and Tamiz, (2007) models is as follows:

$$\text{Max} = \lambda$$

$$f_i - p_i \leq b_i \qquad i = 1,...i_0 \quad (38)$$

$$f_i + n_i \leq b_i \qquad i = i_0 + 1,..., j_0 \quad (39)$$

$$f_i + n_i - p_i = b_i \qquad i = j_0 + 1,..., k \quad (40)$$

$$\lambda + \frac{1}{\Delta_i^U} p_i \leq 1 \qquad i = 1,...i_0 \quad (41)$$

$$\lambda + \frac{1}{\Delta_i^L} n_i \leq 1 \qquad i = i_0 + 1,..., j_0 \quad (42)$$

$$\lambda + \frac{1}{\Delta_i^L} n_i + \frac{1}{\Delta_i^U} p_i \leq 1 \qquad i = j_0 + 1,..., k \quad (43)$$

$$\lambda, n_i, p_i \geq 0 \qquad i = 1,..., k \quad (44)$$

Here, $\lambda$ , $p_i$ and $n_i$ are auxiliary variables, and $b_i$ is the amount of aspiration level. Moreover, $\Delta_i^U$ and $\Delta_i^L$ are the maximum possible deviation in minimization objective and minimum possible deviation in maximization objective, respectively. Constraints (38), (41) are related to minimization objectives and constraints (39), (42) are set for maximization objectives as well. Furthermore, constraints (40), (43) are meaningful in a situation that objective value must be equal to aspiration value.

## 4. Results and case study

In this section, the effectiveness of the proposed method is shown by implementing a real-world case study for one of the electronic companies in Iran. The company produces a different kind of home appliances e.g. heater, cooler and washing machines. Moreover, one of the important product of this company is evaporative cooler that is planned in this case.

The traditional supplier selection process in the company was imprecise. Although the main criterion is price, they don't handle quantity discounts. However, new approaches help the company to select sustainable suppliers in addition to improving the above drawbacks. For saving business privacy, the name of the company and suppliers are conserved. The company produces four different evaporative cooler in the different sizes namely, P2500, P4500, P7000 and P6000eco which P7000 is the most powerfull and P2500 is the weakest but there is an issue that makes supplier selection problem more complicated in this case and it is P6000eco with sustainable capability. Each evaporative cooler is composed of three main items: Electric motor, Water-pump and Halm which Water-pump and Halm are the same in all product and the electric motor are different and change according to the model of the evaporative cooler.

The motor 0.125 is used in P2500, 0.33 is for P4500, 0.75 is used in P7000 and 0.5 is for P6000eco.

*a*) **P6000 eco evaporative cooler** *b*) **P2500 cooler**

**Figure 6. Two different products of the company**

According to performed meeting with decision-makers and experts in the company, important criteria are determined in the supplier evaluation process. These criteria and their definition are explained in Table 3. In addition, some criteria used as risk criteria for applying FMEA and some of them are used as criteria for implementation of fuzzy MOORA.

To simplify the case study instead of using specialized names for items we used Item1-6. Moreover, supplier1-8 are identified. It should be noted that the currency and prices are in TOMAN (the common currency in Iran).

**Table 3. Suggested sustainability criteria for the current case**

| Sustainable dimensions | Criteria | Definition | Reference |
|---|---|---|---|
| Economic | Cost | Measure performance of cost paid by suppliers | Valipour Parkouhi and Safaei Ghadikolaei, 2017 |
| | Quality | This criterion shows supplier ability to control service and product quality | Wen and Chi, 2010 |
| | Delivery | Shows the compliance of supplier from pre-designed to production plan | Ahi and Searcy, 2015 |
| Environmental | Environmental management system (EMS) | The supplier's policies such as ISO 14000 certification. | Govindan et al., 2013 |
| | Green supply chain | Bringing environment protection principle into the whole supply chain of suppliers. | Büyüközkan and Çifçi, 2011 |
| | Supplier's of supplier | Shows how much times supplier try to purchase items from suppliers. | Chiou et al., 2011 |
| Social | Worker safety and labor health | Determine, assess and control Harmful factor in the workplace | Azadnia et al., 2015 |
| | The interests and rights of employee | The real implementation of worker's interests and rights. | Kuo et al., 2010 |
| | Worker safety | Criteria for evaluating injuries happen on workers | Türkay et al., 2016 |
| | Worker dismissal | Shows number of fired worker | Expert opinion for case study |

Historical data for the potential market has been used to determine demand in the planning horizon. The evaporative cooler has four major local markets in Iran: Central district (Qom and Tehran Provinces), Western district (Hamedan and Kurdistan Provinces), Eastern district (Khorasan and Semnan Provinces) and Southern district (Kerman and Shiraz Provinces). Moreover, for this product seasonal demand is identified, i.e. in the spring and summer. Therefore, planning horizon broken into 4 periods, namely: spring, summer, fall, winter. The products demand in each period is shown in Table 4 for all markets.

**Table 4. Demand of different markets in each period**

| | | Period | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter |
| Product | Market | | | | |
| P2500 | Center | 340 | 350 | 290 | 285 |
| | West | 333 | 341 | 289 | 280 |
| | East | 300 | 310 | 270 | 270 |
| | South | 315 | 317 | 292 | 290 |
| P4500 | Center | 450 | 467 | 430 | 425 |
| | West | 440 | 452 | 438 | 436 |
| | East | 425 | 432 | 421 | 415 |
| | South | 434 | 441 | 430 | 400 |
| P7000 | Center | 290 | 297 | 280 | 278 |
| | West | 300 | 312 | 286 | 280 |
| | East | 290 | 295 | 289 | 285 |
| | South | 294 | 300 | 290 | 286 |
| P6000 eco | Center | 500 | 517 | 486 | 480 |
| | West | 490 | 498 | 481 | 480 |
| | East | 470 | 480 | 465 | 461 |
| | South | 486 | 490 | 480 | 471 |

The selling price may vary according to demand in each period. The selling price of different products in each period is shown in Table 5.

**Table 5. Selling price of different products in each period (Tomans)**

| Product | Period | | | |
|---|---|---|---|---|
| | Spring | Summer | Fall | winter |
| P2500 | 295000 | 315000 | 280000 | 275000 |
| P4500 | 655000 | 668000 | 650000 | 648000 |
| P7000 | 800000 | 810000 | 798000 | 799000 |
| P6000 eco | 1060000 | 1100000 | 1040000 | 1037000 |

In addition to purchasing raw material, other operation costs such as operator wages, and electricity cost is shown in Table 6.

**Table 6. Operation cost of manufacturing for different products in each period**

| Product | Period | | | |
|---|---|---|---|---|
| | Spring | Summer | Fall | Winter |
| P2500 | 118000 | 126000 | 112000 | 110000 |
| P4500 | 262000 | 267200 | 260000 | 259200 |
| P7000 | 320000 | 324000 | 319200 | 319600 |
| P6000 eco | 424000 | 440000 | 416000 | 414800 |

Table 7 is shown the lost sale cost for products in each market. Moreover, transportation cost for each item and product is represented in Tables 8 and 9.

**Table 7. Lost sale cost of products in each market**

| Product | Market | | | |
|---|---|---|---|---|
| | Center | West | East | South |
| P2500 | 59000 | 63000 | 56000 | 55000 |
| P4500 | 131000 | 133600 | 130000 | 129600 |
| P7000 | 160000 | 162000 | 159600 | 159800 |
| P6000 eco | 212000 | 220000 | 208000 | 207400 |

**Table 8. Transportation cost of each item from potential suppliers to the manufacturing plant**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | 4000 | 4250 | 4700 | 4500 | 1000 | 100 |
| Supplier2 | - | - | - | - | 500 | - |
| Supplier3 | - | - | - | - | 650 | - |
| Supplier4 | - | - | - | - | 900 | - |
| Supplier5 | - | - | 2500 | 2200 | - | - |
| Supplier6 | - | - | - | 3000 | - | - |
| Supplier7 | - | 4400 | 4800 | 4650 | - | - |
| Supplier8 | - | - | - | - | - | 190 |

**Table 9. Transportation cost of each product from manufacturing plant to each market**

| Product | Market | | | |
|---|---|---|---|---|
| | Center | West | East | South |
| P2500 | 10000 | 15000 | 20000 | 25000 |
| P4500 | 7000 | 40000 | 45000 | 50000 |
| P7000 | 12000 | 42000 | 47000 | 52000 |
| P6000 eco | 11000 | 36000 | 41000 | 46000 |

The proposed model considers multi-item and multi-product. Hence, a unit to change the number of product to required items and related coefficients are given in Table 10.

**Table 10. The number of required items in each product**

| Item | Product | | | |
|---|---|---|---|---|
| | P2500 | P4500 | P7000 | P6000 eco |
| Item1 | 1 | - | - | - |
| Item2 | - | 1 | - | - |
| Item3 | - | - | 1 | - |
| Item4 | - | - | - | 1 |
| Item5 | 1 | 1 | 1 | 1 |
| Item6 | 3 | 3 | 3 | 3 |

The fixed ordering cost for each supplier is equal to 1,000,000 TOMAN. Moreover, holding cost for item and product are given in Table 11. Table 13 represented type of discount offered by suppliers.

**Table 11. Holding cost of products and items**

| | Product | | | | Item | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P2500 | P4500 | P7000 | P6000 | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Holding cost | 30000 | 30000 | 30000 | 30000 | 6500 | 8000 | 12000 | 10000 | 2000 | 200 |

**Table 12. Maximum capacity of suppliers to provide items**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | 1200 | 2000 | 2000 | 1500 | 4500 | - |
| Supplier2 | - | - | - | - | 3000 | - |
| Supplier3 | - | - | - | - | 3500 | - |
| Supplier4 | - | - | - | - | 15000 | - |
| Supplier5 | - | - | 900 | 1000 | - | - |
| Supplier6 | - | - | - | 1600 | - | - |
| Supplier7 | - | 900 | 1600 | 1500 | - | - |
| Supplier8 | - | - | - | - | - | Inf. |

**Table 13. Type of discount that offers by different suppliers for each item**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | ND* | ID | AD* | ID* | ID | - |
| Supplier2 | - | - | - | - | AD | - |
| Supplier3 | - | - | - | - | AD | - |
| Supplier4 | - | - | - | - | ND | - |
| Supplier5 | - | - | ID | ND | - | - |
| Supplier6 | - | - | - | ID | - | - |
| Supplier7 | - | ID | AD | AD | - | - |
| Supplier8 | - | - | - | - | - | ND |

ND= associate supplier does not offer discount. AD= associate supplier offers all-unit discount. ID= associate supplier offers incremental discount.

Manufacturing time for products is 30, 34, 40 and 43 minutes for P2500, P4500, P7000 and P6000 eco, respectively. Furthermore, maximum time capacity in each period is 467,000 minutes. As mentioned, three types of purchasing cost are considered: constant cost without any discount which is shown in Table 14 and offered discounts which are shown in Table 15.

**Table 14. Buying price of items when no discount is offered**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | 65,000 | - | - | - | - | - |
| Supplier2 | - | - | - | - | - | - |
| Supplier3 | - | - | - | - | - | - |
| Supplier4 | - | - | - | - | 24,000 | - |
| Supplier5 | - | - | - | 162,500 | - | - |
| Supplier6 | - | - | - | - | - | - |
| Supplier7 | - | - | - | - | - | - |
| Supplier8 | - | - | - | - | - | 1,350 |

In this section, necessary data for implementation of the proposed method is provided. In the next step, fuzzy MOORA method and FMEA technique are applied to obtain the total discount risk of suppliers. Then, output data are utilized in the mathematical model that is proposed in Section 3.4.

**Table 15. Buying price of items when supplier offer all unit or incremental discounts**

| Supplier | Item | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Item2 | | Item3 | | Item4 | | Item5 | |
| | Quantity range | price | Quantity range | Price | Quantity range | price | Quantity range | price |
| Supplier1 | [0-500) | 145000 | [0-1000) | 160000 | [0-700) | 155000 | [0-2000) | 20000 |
| | [500-600) | 140000 | [1000-2000) | 150000 | [700-1400) | 150000 | [2000-4000) | 18000 |
| | [600-900) | 130000 | [2000-4000) | 145000 | [1400-1800) | 147000 | [4000-4800) | 17500 |
| Supplier2 | | | | | | | [0-1500) | 15000 |
| | | | | | | | [1500-2800) | 14000 |
| | | | | | | | [2800-3200) | 13500 |
| Supplier3 | | | | | | | [0-2200) | 26000 |
| | | | | | | | [2200-3000) | 25000 |
| | | | | | | | [3000-3800) | 20000 |
| Supplier5 | | | [0-300) | 167000 | | | | |
| | | | [300-600) | 160000 | | | | |
| | | | [600-900) | 155000 | | | | |
| Supplier6 | | | | | [0-500) | 144000 | | |
| | | | | | [500-1200) | 139000 | | |
| | | | | | [1200-1700) | 134000 | | |
| Supplier7 | [0-300) | 120000 | [0-500) | 185000 | [0-400) | 140000 | | |
| | [300-600) | 118000 | [500-1000) | 180000 | [400-800) | 138000 | | |
| | [600-700) | 112000 | [1000-1300) | 174000 | [800-1200) | 137000 | | |

Notice: in this case, the supplier offers the same price for incremental and all-unit but calculate total cost based on different discount formula explained before.

## 4.1. Application of fuzzy MOORA

Different criteria are suggested in Table 3 for fuzzy MOORA. Here, 7 criteria out 10 criteria are selected for fuzzy MOORA according to expert’s judgment. The selected criteria are cost, quality, delivery, environmental management system, green supply chain, worker safety and labor health, the interests and rights of the employee. Then, expert's opinions for each supplier and item is collected. For this purpose, Table 16 is used to transform the expert's opinions into triangular fuzzy numbers. The final result of fuzzy MOORA for each supplier and item is prepared in Table 17.

**Table 16. Linguistic terms for alternatives ratings for triangular fuzzy (Awasthi et al., 2010)**

| Linguistic term | Membership function |
|---|---|
| Very poor (VP) | (1,1,3) |
| Poor (P) | (1,3,5) |
| Fair (F) | (3,5,7) |
| Good (G) | (5,7,9) |
| Very good (VG) | (7,9,9) |

**Table 17. Rank of suppliers for each item that obtained from the fuzzy MOORA method**

| Items | suppliers | $y_i^l$ | $y_i^m$ | $y_i^u$ | Score | Rank |
|---|---|---|---|---|---|---|
| Item 1 | s1 | 0.1383 | 0.1867 | 0.2783 | 0.2011 | 1 |
| Item 2 | s1 | 0.1128 | 0.1900 | 0.2672 | 0.1900 | 1 |
| | s7 | 0.0752 | 0.1380 | 0.2030 | 0.1387 | 2 |
| Item 3 | s1 | 0.1083 | 0.1761 | 0.2689 | 0.1844 | 2 |
| | s5 | 0.1197 | 0.1896 | 0.2668 | 0.1920 | 1 |
| | s7 | 0.0866 | 0.1638 | 0.2410 | 0.1638 | 3 |
| Item 4 | s1 | 0.1368 | 0.2140 | 0.2912 | 0.2140 | 1 |
| | s5 | 0.1132 | 0.1798 | 0.2570 | 0.1834 | 2 |
| | s6 | 0.0818 | 0.1363 | 0.1990 | 0.1390 | 4 |
| | s7 | 0.0850 | 0.1330 | 0.2102 | 0.1428 | 3 |
| Item 5 | s1 | 0.1494 | 0.2266 | 0.3038 | 0.2266 | 2 |
| | s2 | 0.0496 | 0.1042 | 0.1814 | 0.1117 | 4 |
| | s3 | 0.1885 | 0.2657 | 0.3250 | 0.2597 | 1 |
| | s4 | 0.0709 | 0.1481 | 0.2253 | 0.1481 | 3 |
| Item 6 | s8 | 0.1217 | 0.1845 | 0.2495 | 0.1852 | 1 |

## 4.2. Application of FMEA

According to expert opinion, related risk criteria for the current case study are cost, quality, delivery, supplier's of supplier, worker safety and worker dismissal. The planner needs to prepare a scheme for each criterion to evaluate the total risk. The final results of FMEA for each item is shown in Table 18.

**Table 18. Risk of suppliers for each item that obtain by the FMEA technique**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | 0.25 | 0.27 | 0.17 | 0.19 | 0.17 | - |
| Supplier2 | - | - | - | - | 0.33 | - |
| Supplier3 | - | - | - | - | 0.11 | - |
| Supplier4 | - | - | - | - | 0.15 | - |
| Supplier5 | - | - | 0.272 | 0.273 | - | - |
| Supplier6 | - | - | - | 0.24 | - | - |
| Supplier7 | - | 0.29 | 0.32 | 0.31 | - | - |
| Supplier8 | - | - | - | - | - | 0.12 |

It is clear that results of fuzzy MOORA are not the same as FMEA results.

The fuzzy MOORA result is a positive score which means higher the better, however FMEA results are generally negative and lower is better. To handle this issue and integrate the results of fuzzy MOORA and FMEA, the FMEA results are assumed as a fixed parameter it will be multiplied in (1-fuzzy MOORA). The results of this procedure are presented in Table 19. This values is called discount risk and will be used in the third objective function as $Rs_i$ parameter.

**Table 19. Discount risk of supplier for each item (integration result of fuzzy MOORA and FMEA)**

| Supplier | Item | | | | | |
|---|---|---|---|---|---|---|
| | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Supplier1 | 0.20 | 0.223 | 0.14 | 0.15 | 0.13 | - |
| Supplier2 | - | - | - | - | 0.29 | - |
| Supplier3 | - | - | - | - | 0.08 | - |
| Supplier4 | - | - | - | - | 0.13 | - |
| Supplier5 | - | - | 0.220 | 0.222 | - | - |
| Supplier6 | - | - | - | 0.21 | - | - |
| Supplier7 | - | 0.25 | 0.260 | 0.266 | - | - |
| Supplier8 | - | - | - | - | - | 0.099 |

To solve the multi-objective model by Yaghoobi and Tamiz (2007) approach, the aspiration level and maximum available deviation for each objective function should be determined. Here, each objective is solved separately and
the objective values are considered as aspiration level.. Thus, aspiration level for the first objective is 8,378,624,000 and for the second objective is 5. For the third objective, if we solve it separately, the objective value and all decision variables will be equal to zeroes because this objective tries to minimize the total discount risk. However, risk value is zero if there is no production. It seems that determining the aspiration level with this technique is not logical for the third objective. The amount of production in the first objective is assumed to be fixed parameters in the third objective to avoid this problem.

Thus, this situation finds the best supplier that minimizes the total risks. Therefore, objective value or aspiration level for the third objective is 12344. Determining maximum deviation is exactly depends on senior managers. They tolerate to lose 10% of the total benefit in exchange for selecting sustainable suppliers. So, $\Delta_i^L$ is equal to 837,862,400 for the first objective. Moreover, for other objectives $\Delta_i^U$ are 1 and 1,234.

### 4.3. Results

The amount of ordering ($X_{sit}$) is given in Table 20. The production plan in each period is shown in Table 21.

**Table 20. Decision variable for buying items**

| | | Spring | Summer | Fall | Winter |
|---|---|---|---|---|---|
| Item 1 | Supplier 1 | 0 | 756 | 577 | 838 |
| Item 2 | Supplier 1 | 900 | 900 | 900 | 900 |
| | Supplier 7 | 700 | 700 | 700 | 700 |
| Item 3 | Supplier 1 | 1000 | 0 | 1000 | 0 |
| | Supplier 5 | 600 | 778 | 600 | 674 |
| Item 4 | Supplier1 | 1400 | 143 | 700 | 692 |
| | Supplier 6 | 1200 | 1200 | 1200 | 1200 |
| Item 5 | Supplier 1 | 4000 | 4000 | 4000 | 4000 |
| | Supplier 2 | 630 | 1500 | 2828 | 0 |
| Item 6 | Supplier 8 | 13890 | 16332 | 16290 | 16362 |

**Table 21. Decision variable for manufacturing product in each period**

| Product | Time period | | | |
|---|---|---|---|---|
| | Spring | Summer | Fall | Winter |
| P2500 | 0 | 756 | 577 | 838 |
| P4500 | 1217 | 1792 | 1715 | 1676 |
| P7000 | 1467 | 911 | 1226 | 1048 |
| P6000 eco | 1946 | 1985 | 1912 | 1892 |

Furthermore, inventory cost for final products and items is considered in the current model. Table 22 is the optimum quantity of products and items that would be held as inventory in each period. It is clear that holding items at the end of planning horizon cause to lose profit, so in the winter, all inventory of items are equal to zero.

**Table 22. Inventory level of different products and items in each period**

| | Product | | | | Item | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | P2500 | P4500 | P7000 | P6000 | Item1 | Item2 | Item3 | Item4 | Item5 | Item6 |
| Spring | 0 | 1217 | 1467 | 1946 | 0 | 383 | 133 | 654 | 0 | 0 |
| Summer | 756 | 1792 | 911 | 1985 | 0 | 191 | 0 | 12 | 56 | 0 |
| Fall | 577 | 1715 | 1226 | 1912 | 0 | 76 | 374 | 0 | 1454 | 0 |
| Winter | 838 | 1676 | 1048 | 1892 | 0 | 0 | 0 | 0 | 0 | 0 |

## 5. Discussion

Sustainable supplier selection and order allocation are critical problems in green supply chain management. As it can be observed in Tables 1 and 2, previous works on supplier selection problem only considered the specific dimension of this problem. For instance, Awasthi et al., (2018) and Banaeian et al., (2018) considered the sustainability of supplier without risk consideration or some researchers like Li and Zeng (2014) considered the risk of suppliers form the economic criteria without considering other aspects of sustainability. In the other related research Çebi and Otay (2016) and Meena and Sarmah (2016) considered all-unit and incremental discount in their model, however they neglected sustainability and risk issues. Therefore, the current study presented a comprehensive approach for supplier selection problem in which profits, sustainability, risk, all unit and incremental quantity discount, lost sale are embedded in a framework for the first time. This study completely covers the weaknesses that discovered in the previous studies. In this section, sensitivity analysis on risk, discount and lost sale are performed to validate the current study.

### 5.1. Risk analysis

In the study by Akkaya et al., (2015), suppliers are ranked according to fuzzy MOORA method. However, in this paper, FMEA technique is applied in addition to fuzzy MOORA. The influence of risk on the performance of suppliers is shown in Fig 7. For example, supplier #6 for item 4 have 4$^{th}$ rank in fuzzy MOORA, but after consideration of risk and multiplying in FMEA result it is changed to the second rank. However, in some cases, a supplier in both situation (with risk and without risk) has the same rank (i.e. supplier #7 and item 2). Therefore, Fig 7 prepares a useful comparison between ranking approach proposed by Akkaya 2015 and the current study. While Dweiri et al., (2017) and Rao et al., (2017) used different MCDM method for evaluating sustainable criteria of the supplier but the finding of this study show that using an MCDM method is not enough for supplier evaluation. It was proven that risk consideration is necessary because according to Fig 7 and most of the supplier's rank change significantly by investigating risk.  It should be noted that only one supplier can supply item 1, and for simplification is not shown in Fig 7.

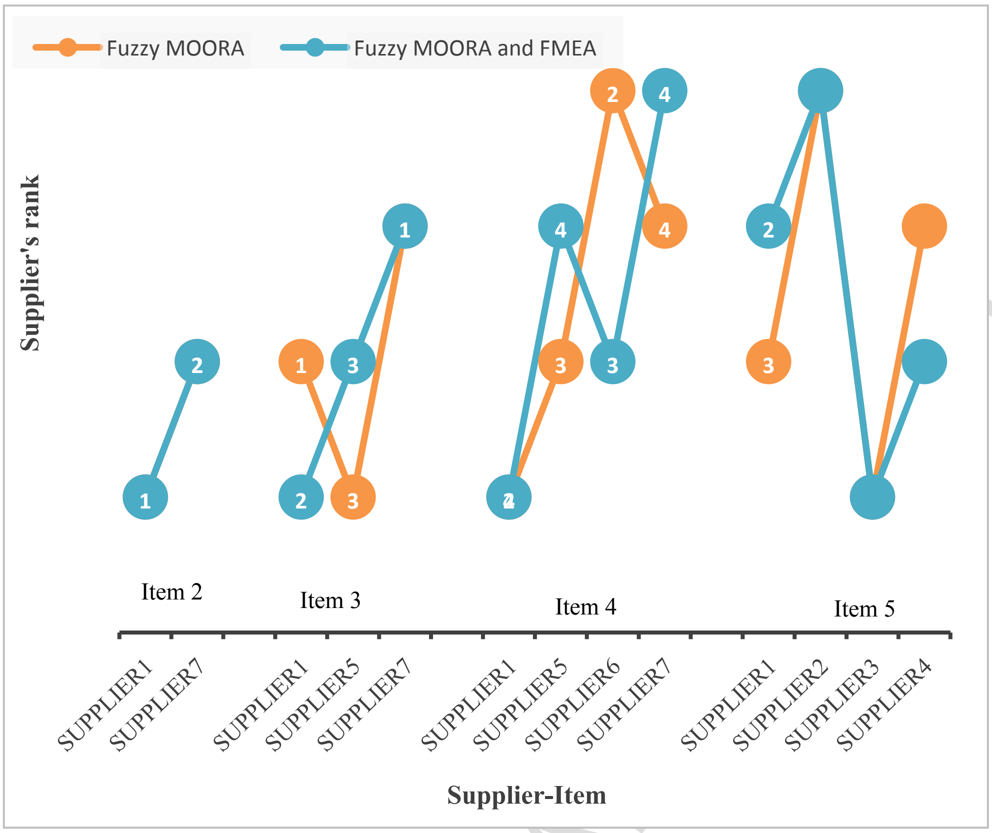


**Figure 7. Rank of suppliers for each item, before and after risk consideration**

### 5.2. Discount analysis

Vahidi et al., (2018) evaluated the suppliers according to sustainable criteria where they neglected quantity discounts. In the current study, the quantity discount is considered along with sustainable objectives. In this section, an analysis is preformed to calculate lost profit in the case that quantity discount is not considered. Hence, four scenarios are arranged. Firstly, it is assumed that supplier does not offer any discount. Secondly, it is assumed that supplier offers all unit discount. In the 3rd scenario, the supplier offers only incremental discount and finally incremental and all unit discounts are considered, simultaneously. The computation for the analysis is presented in Fig 8. As it shows, the amount of profit in different scenarios is significantly different and it is very sensitive to the incremental discount. Therefore, one of the important finding of the current work is proposing more profit along with reducing sustainability risks.

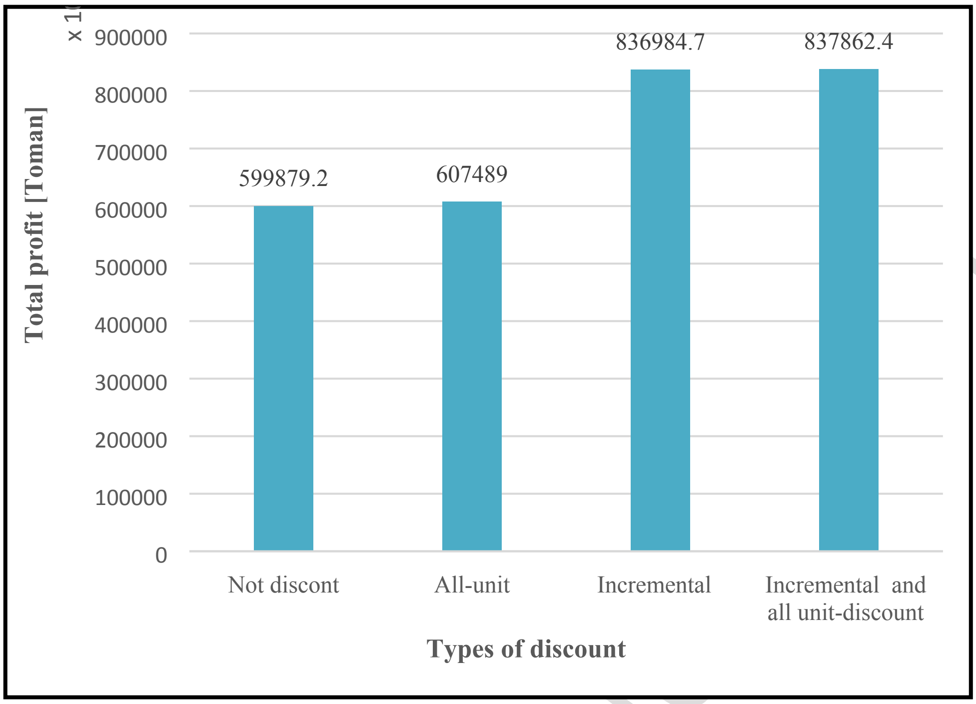


**Figure 8. Total profit in different types of pricing scenarios offered by suppliers**

### 5.3. Lost sale analysis

Lost sale is one of the most important issues in a supply chain. However, many researchers neglected lost sale despite its importance (Moghaddam 2015; PrasannaVenkatesan and Goh 2016). One of the important findings of this research is preparing a structure for managers to reduce or avoid lost sale. According to the case study analysis, there are three main limitations that are source of lost sale: 1) production capacity, 2) supplier's capacity, 3) maximum available discount risk. To identify the impacts of each limitation on the total lost sale, the first objective is solved separately for each source. The results are illustrated in Fig 9. It is clear that 23% of the lost sale is related to the supplier's capacity, 77% back to the production capacity and discount risk has no influence on lost sale. By recognizing the source of lost sale, the manager can choose appropriate policies. To handle the supplier's capacity, the company can find and order items from different sources. Furthermore, to deal with production capacity, the company can use over time or hire new workers.

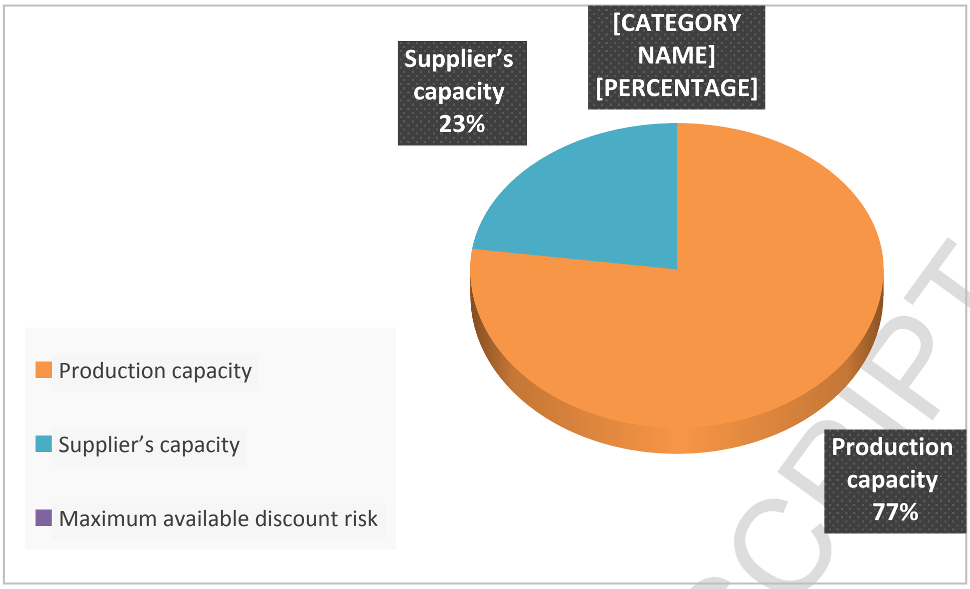


**Figure 9. Influence of each limitation on lost sale**

## 6. Conclusion

In this paper, a novel comprehensive approach is developed to solve the sustainable supplier selection and order allocation problem, simultaneously. Therefore, a multi-product, multi-item, multi-supplier and multi-period model with quantity discount consideration was designed.
Identification of economic, environmental and social criteria and their definition according to expert's opinion and literature was the first step to implement the proposed approach. Then, the fuzzy MOORA method is applied to obtain suppliers score and rank. However, to have a better and more accurate judgment about supplier's sustainability indices, it is necessary to consider suppliers risks within the fuzzy MOORA. Hence, FMEA technique has been used in this study to obtain risk values for each supplier. In the next step, the results of integrating the FMEA and fuzzy MOORA are imported as parameters for the third objective function. The efficiency and applicability of the proposed approach are illuminated with a case study of the evaporative cooler in a home appliance industry by considering four products, six items, eight suppliers and four periods in one-year planning horizon.
It is notable that most of many aspects of supplier selection problem is considered by applying the proposed approach, and overall assessment of supplier's sustainability is given by using Fuzzy MOORA. Furthermore, for the situation that supplier faces with some risks, the FMEA technique is applied. Moreover, to have more realistic approach all-unit and incremental quantity discount is considered in the mathematical model.
Other types of discount such as seasonal and geographical discounts could be analyzed as future work. In addition, the proposed mathematical model can be improved by considering uncertain parameters and developing a stochastic or robust model. To solve the larger scale problems a meta-heuristic algorithm can be useful.

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