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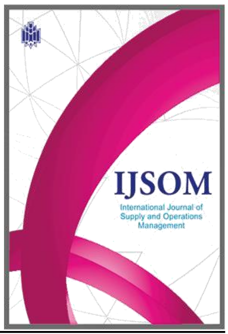

Supplier and Carrier Selection and Order Allocation by Considering Disruptions with AHP and Multi-objective Mathematical Programming

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Abstract

In this study, supplier and carrier selection and order allocation are considered to go for joint decision-making. To this end, some criteria including cost, quality, delivery, resilience, social responsibility and supplier profile are determined to select the weight of each supplier by AHP. Then, multi objective mathematical model is developed to select the appropriate supplier and carrier and allocate orders of multi product with different discount levels in each period by suitable carriers to each supplier. The objective functions in this study are minimizing cost, delivery and the number of defective items, and maximizing the efficiency of suppliers. Moreover, some constraints such as inventory capacity, shortage capacity, number of vehicle and breakdowns of them etc. are applied in this model. Finally, this model is solved by augmented ε-constraint method for determining pareto-optimal solution.

Keywords: Supplier and carrier selection; Order allocation; Resilience; Social responsibility; Price discount; Breakdown.

1. Introduction

In today's increasingly competitive markets, customer satisfaction is a vital corporate objective. Key elements to increasing customer satisfaction include the consistent production of high-quality products and provision of high quality customer service. It is recognized that the proper management of the supply chain cannot only diminish risks and uncertainty, but it can also optimize the inventory level and process cycle time. Thus, enterprises should try to satisfy customers and make a good profit (Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., 2003). In order for the supply chain management to be performed successfully, the purchasing function must be properly considered. If so, the significance of the purchasing function increases as the purchasing and outsourcing costs that are considered as a greater portion of the total costs of the manufacturing process get improved. Today's highly competitive environment is compelling manufacturing organizations to establish a long-term effective collaboration with efficient organizations. Supplier selection is one of the most important activities of acquisition as its results have a great impact on the quality of goods, performance of organizations and supply chains (Chen, C.T., Lin, C.T., Huang, S.F., 2006, Thrulogachantar, P., Zailani, S., 2011) . Through supplier selection, it is also possible to anticipate the evaluation of suppliers' potential to establish a collaborative relationship (Ha, B., Park, Y., Cho, S., 2011). Hence, suppliers' performance has a key role in cost, quality, delivery and service towards achieving the objectives of a supply chain. The overall objective of the supplier selection process is to reduce purchase risk, maximize overall value to the purchaser, and build the closeness and long-term relationships between buyers and suppliers (Chen, C.T., Lin, C.T., Huang, S.F., 2006).

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Resilience engineering (RE) is one of the proactive attitudes. From the perspective of organizational and safety management system, resilience is applied for unforeseen changes and even for catastrophic accidents to adapt and survive (Hollnagel, E., 2006). Resilience is also defined as a system property on how the system can still function to the desired level and endure disruptions when it suffers partial damage (Zhang, W.J., Lin, Y., 2010).

One of the issues worthy of studying is the consideration of purchasing cost, ordering cost and transportation cost in determining the quantity of purchase from different suppliers in such a way that inventories and shortage are considered for each product. Therefore, some objective functions increase and some others decrease as the number of orders placed by suppliers experience an increase. Hence, multi objective mathematical model is considered. In this study, other criteria such as social and resilience criteria are considered for supplier selection problem in addition to traditional criteria. In this regard, AHP is used for weighing and ranking suppliers. Moreover, different objectives such as minimizing total costs containing purchasing cost, ordering cost, transportation cost, inventory holding cost, and shortage cost are taken into consideration for each product in each period. To this end, some other points such as the kind of transportation vehicles in break level of each supplier's discount, minimization of the delay in late delivery of products, minimization of the rejected products, and maximization of the supplier's efficiency are regarded. The model is solved by augmented ε-constraint method in order to determine pareto-optimal solution.

2. Literature Review

Supplier selection and methodologies ranging from conceptual to empirical and modeling streams are among common topics of research in purchasing. Different criteria have complicated the supplier selection decisions; hence, multi-criteria are considered in decision-making process to facilitate this complexity. One of the earliest works on supplier selection is presented by Dickson. He introduced 23 supplier attributes that managers consider when selecting a supplier (Dickson, G., 1966). Several studies emphasized the relative importance of various supplier criteria such as price, quality, on-time delivery, and performance (Kannan, V.R., Tan, K.C., 2002, Wilson, E.J., 1994). By supplier selection, a company aims to have access to the suppliers that ensure a certain quality standard in terms of the characteristics of the purchased products or services (Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., 2006).

Due to the increasing importance of supply chain management, recent approaches have been aimed at developing the models that can simultaneously look at procurement supplier, carrier selection, and order allocation problem. Basnet and Leung (Basnet, C., Leung, J.M.Y., 2005) proposed a mathematical model for integrated procurement lot-sizing with supplier selection problem. Later, Rezaei and Davoodi (Rezaei, J., Davoodi, M., 2008) presented a mixed integer programming model for multiple suppliers and multiple products over a finite planning horizon. They extended the work of Basnet and Leung (Basnet, C., Leung, J.M.Y., 2005) to study the effect of suppliers' capacity and quality on performance. Furthermore, in recent years, Razmi and Rafiei (Razmi, J., Rafiei, H., 2010) modeled supplier selection and order allocation by strategic items where the substitute of suppliers imposed the product a remarkable cost. Mafakheri et al. (Mafakheri, F., Breton, M., Ghoniem, A., 2011) considered multiple criteria in economical and environmental fields for supplier selection and order allocation. Lee et al. (Lee, A.H.I., Kang, H.Y., Lai, C.M., Hong, W.Y., 2013) proposed mixed integer programming (MIP) model to solve the lot-sizing problem for supplier selection and quantity discount. Few studies have proposed multi-period and multi-objective lot-sizing models (Ustun, O., Demirtas, E.A., 2008a, Rezaei, J., Davoodi, M., 2011).

Few studies have considered the combined problem related to the inbound transportation and procurement lot-sizing so as to optimize the total logistic cost over the planning horizon. Liao and Rittscher (Liao, Z., Rittscher, J., 2007) studied the integration of supplier selection, procurement lot-sizing, and carrier selection decisions. They considered dynamic demand situation and proposed a multi objective programming model for supplier selection, procurement lot-sizing and carrier selection decisions in each replenishment cycle. That study was aimed at minimizing the total logistic cost, the total quality rejected items, and the late deliveries. Mansini et al. (Mansini, R., Tocchella, B., Savelsbergh, M., 2012) presented an integer programming model to study a procurement setting in which suppliers offer total quantity discounts, and transportation costs are based on truckload shipping rates. The model is used to select a set of suppliers so as to satisfy product demand with minimal total cost.

Recently, Choudhary and Shankar (Choudhary, D., Shankar, R., 2011) studied a multi-period purchasing problem in which a buyer procures a single product from a single supplier considering economies of scale in purchasing and transaction costs along with supply chain disruptions. They proposed an integer programming model to establish tradeoffs among cost objectives and determine appropriate lot-size and its timing to minimize total cost over the decision horizon. Their study showed that lot-sizing decisions are influenced by the buyer's relative importance of purchasing, transaction, and inventory holding cost. Furthermore, supply chain disruptions can substantially influence the structure of solutions, and affect the buyer's total cost objective.

This study, for the first time, considers the supplier and carrier selection and order allocation for multi products with different carriers as well as discount level in each period. Therefore, AHP is used for weighting each supplier and, then, augmented ε-constraint method is applied to determine pareto optimal solution in multi objective model.

3. Methodology

3. 1. Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) was introduced as a multi-criteria decision-making approach by Saaty and has attracted the interest of many researchers mainly due to its appropriate mathematical properties and the fact that the required input data are rather easy to obtain.

AHP is a powerful decision-making tool that includes a technique for measuring the consistency of the already-made decisions. Moreover, decision-makers (DMs) have the alternative to make a more comprehensive conceptual comparison of different decision components using AHP. It has been seen in many applications of AHP that the consideration of different reciprocally exclusive multivariate criteria guarantees a higher standard of the solution by AHP and enhances consistency throughout the decision-making process. It is based on three principles, namely construction of a hierarchy, priority setting, and logical consistency.

3. 2. Augmented ε-constraint method

The ε-constraint method, which is proposed by Haimes et al. (Haimes, Y.Y., Wismer, D.A., Lasdon, D.S., 1971), is applied for multi objective problems. One of the objective functions is selected as the main objective function to be optimized, and all the other objective functions are converted into constraints by considering an upper bound for each of them. The four stages for augmented ε-constraint method are described below:

Step 1: one of the objective functions is set as the main objective function to be optimized and the other ones are converted to constraints. The appropriate interval for ε_k is determined by means of the payoff table. The payoff table is constructed by solving p (the number of objective functions) in different models. In each model, one objective function is selected to be optimized and the other objective functions are omitted. The ideal value and the nadir value for each objective function are obtained by solving these (p) models separately.

Step 2: Determine grid points (ε_k)
When the nadir and ideal values of the objective functions, which are converted into constraints, are obtained, the interval for ε_k (*k=2,…, p*) is created.
$\varepsilon_k \in$ [nadir value for objective function k; ideal value for objective function k]
The above-mentioned interval can be divided into some equal parts (e.g., q_k equal parts); therefore, these divided parts create $q_k + 1$ points on the interval. The values of ε_k are obtained by applying this method.

Step 3: The augmented ε-constraint model is solved for each vector of ε which has already been obtained in a previous step.

Max $f_j(x) + \zeta \sum_{k\neq j} s_k$
s.t.
$x \in X$
$f_k(x) - s_k = \varepsilon_k \qquad k \neq j$
$s_k \in R^+$
Where ζ is a scalar between 0.001 and 0.000001.

4. Proposed model

The objective of this study is to propose a multi-criteria decision-making approach based on supplier and carrier selection and order allocation. In sustainable supplier selection processes, the company's ultimate aim is to have accessibility to suppliers that ensure a certain quality standard in terms of the characteristics of the purchased products or provided services while economic, social and environmental factors are being considered. The satisfaction of these objectives largely depends on the relationships between purchased product features and supplier assessment criteria. Thus, some criteria such as cost, quality, delivery, supplier profile, resilience, and social responsibility are considered for suppliers. Each of these criteria includes some sub-criteria, such as cost of product, cost of logistics, discount rate, warranties and claim policies, quality assurance, rejection rate of the product, efficacy of correlation action, capability of on time delivery, speed of delivery, financial position, geographical location, reputation, flexibility, self-organization, top management commitment, reporting culture, right of employee, government regulations, and work safety and labor health. Each supplier's characteristic succeeds in meeting the requirements established for the product purchased outside the company. After this step, it is time to draw up a supplier ranking list by MCDM methods. In this study, AHP is applied for calculating the weight of each supplier. Then, the supplier with the lowest rank is deleted from the list of suppliers.

Hence, the weights calculated in AHP method are used in multi objective mathematical model for order allocation of suppliers and selection of the suitable carrier for products where discount rate and rejection rate are assumed.
In this study, multi product multi period supplier selection and order allocation of the multi objective model are presented where some limitations are proposed for buyer and supplier, and transportation vehicle are considered as a problem. The mathematical model and assumptions are presented in the next section.

4. 1. Model assumptions

The proposed model is constrained by the following assumptions:

- Demand of each product is deterministic for each period over planning horizon.
- Shortages are allowed and completely backlogged.
- Production capacity of each product provided by suppliers is finite.
- Buyer's storage capacity for each product in each period is finite.
- Ordering cost is applied for each period in which an order is placed to the supplier.
- Transportation vehicles carrying products have a limited capacity.
- Inventory holding cost is considered when products are carried across a period in the planning horizon.
- Late deliveries from all the suppliers are assumed to be received in the following period.
- Suppliers bear transportation cost of late deliveries.
- Imperfection of each product is disposed in the same period at scrap value and is excluded from the inventory that is carried across a period in the planning horizon.
- Late deliveries to suppliers are assumed to be of perfect quality.

5. Mathematical model

Indices:

i: Index of parts, $i=1,\dots,I$.
j: Index of supplier, $j=1,\dots,J$.
k: Index of transportation carrier, $k=1,\dots,K$.
t: Set of discrete time periods, $t=1,\dots,T$.
m: Set of all-unite price break levels, $m=1,\dots,M$.

Parameters:

d_{it}: Buyer's demand of the product i in period t.
p_{ijmt}: Cost of procuring one unit of product i from supplier j at price break level m in period t.
b_{ijmt}: Quantity at which all-unit price break m occur at part i from supplier j in period t.
o_{jt}: Cost of ordering in period t at supplier j.
t_{jtk}: Buyer's transportation cost from supplier j in period t from carrier k.
q_{ijmt}: Percentage of rejected product i delivered by supplier j at price break level m in period t.
l_{ijmt}: Percentage of product i delivered late by supplier j at price break level m in period t.
c_{ij}: Capacity of product i from supplier j.
R_k: Full truck loads carrying capacity of carrier k.
v_{tk}: Total number of carrier k available in period t.
h_{it}: Buyer's unit inventory holding cost of the product i in period t.
w_t: Buyer's storage capacity in period t.
θ_{it}: Buyer's service level requirement of product i in period t so ($1-\theta_{it}$) is the proportion of end user demand of product i that are not met by buyer in period t.
I_{it}^{+}: Intermediate variable indicates inventory of the product i carried from period t to period $t+1$.
I_{it}^{-}: Intermediate variable indicates storage of the product i backlogged over from period t to period $t+1$.
g_{it}: Maximum acceptable late deliveries of product i in period t.
ss_{it}: Space of product i in period t.

BR_k: Maximum amount of breakdown for carrier *k*.
pp_k: Probability of breakdowns for carrier *k*.
ss_{it}: Shortage cost of product *i* in period *t*.
WS_j: Weight of supplier *j*.

Decision variables:
x_{ijmtk}: Quantity of product *i* that buyer procures from supplier *j* at price level *m* in period *t* and transports it using carrier *j*.
y_{ijmtk}: Binary variable used in separating price levels *m* for product *i* in a transaction between buyer and supplier *j* in period *t* using carrier *k*.
u_{ijmtk}: Binary variable indicating whether carrier *k* is selected or not for transporting procured lot-size from supplier *j* for product *i* at price level *m* in period *t*.
z_{jt}: Binary variable indicating whether supplier *j* is chosen or not in period *t*.

$$Minimize\ Z_1 = \sum_i \sum_j \sum_m \sum_t \sum_k p_{ijmt}\ x_{ijmtk} + \sum_j \sum_t o_{jt}\, z_{jt} + \sum_i \sum_j \sum_m \sum_t \sum_k t_{jtk}\, u_{ijmtk} + \sum_i \sum_t h_{it}\, I_{it}^{+} + \sum_i \sum_t s_{it}\, I_{it}^{-}$$

$$Minimize\ Z_2 = \sum_i \sum_j \sum_m \sum_t \sum_k l_{ijmt}\ x_{ijmtk}$$

$$Minimize\ Z_3 = \sum_i \sum_j \sum_m \sum_t \sum_k q_{ijmt}\ x_{ijmtk}$$

$$Maximize\ Z_4 = \sum_i \sum_j \sum_m \sum_t \sum_k WS_j\ x_{ijmtk}$$

$$I_{it}^{+} - I_{it}^{-} = I_{i(t-1)}^{+} + \sum_j \sum_m \sum_k x_{ijmtk} + \sum_j \sum_m \sum_k l_{ijmo}\, x_{ijmtk} - \sum_j \sum_m \sum_k l_{ijmt}\, x_{ijmtk} - \sum_j \sum_m \sum_k q_{ijmt}\, x_{ijmtk} - d_{it} - I_{i(t-1)}^{-} \qquad \forall t, o = t-1 \qquad (1)$$

$$\sum_m \sum_k x_{ijmtk} \le d_{it}\, z_{jt} \qquad \forall i, \forall j, \forall t \qquad (2)$$

$$b_{ij(m-1)t}\, y_{ijmtk} \le x_{ijmtk} \le b_{ijmt}\, y_{ijmtk} \qquad \forall i, \forall j, \forall t, \forall m, \forall k \qquad (3)$$

$$\sum_m \sum_k y_{ijmtk} = z_{jt} \qquad \forall i, \forall j, \forall t \qquad (4)$$

$$\sum_i \sum_j \sum_m x_{ijmtk}\, s_{it} \le v_{tk}\, R_k\ u_{ijmtk} \qquad \forall t, \forall k \qquad (5)$$

$$\sum_i \sum_m \sum_k u_{ijmtk} \le z_{jt} \qquad \forall j, \forall t \qquad (6)$$

$$\sum_i \sum_j \sum_m u_{ijmtk} = v_{tk} \qquad \forall t, \forall k \qquad (7)$$

$$\sum_i I_{it}^{+} \le w_t \qquad \forall t \qquad (8)$$

$$\sum_i I_{it}^{-} \le (1-\theta_t) d_{it} \qquad \forall t \qquad (9)$$

$$\sum_j \sum_m \sum_k l_{ijmt}\ x_{ijmtk} \le g_{it}\, d_{it} \qquad \forall i, \forall t \qquad (10)$$

$$\sum_i \sum_j \sum_m \sum_t u_{ijmtk}\, pp_k \le BR_k \qquad \forall k \qquad (11)$$

$$\sum_m \sum_k x_{ijmtk} \le c_{ij} \qquad \forall i, \forall j, \forall t \qquad (12)$$

$$\sum_j \sum_m \sum_k x_{ijmtk} \le d_{it} \qquad \forall i, \forall t \qquad (13)$$

$$I_{it}^{+}, I_{it}^{-} \ge 0 \qquad \forall i, \forall t \qquad (14)$$

$$x_{ijmtk} \ge 0 \quad \&\quad integer \qquad \forall i, \forall j, \forall m, \forall t, \forall k \qquad (15)$$

$$y_{ijmtk} \in \{0,1\} \qquad \forall i, \forall j, \forall m, \forall t, \forall k \qquad (16)$$

$$u_{ijmtk} \in \{0,1\} \qquad \forall i, \forall j, \forall m, \forall t, \forall k \qquad (17)$$

$$z_{jt} \in \{0,1\} \qquad \forall j, \forall t \qquad (18)$$

The first objective function minimizes the total cost, including purchasing cost, ordering cost, transportation cost, inventory holding cost, and shortage cost of inventory for each product in each period by considering the kind of transportation vehicles in break level of discount of each supplier. The second objective function minimizes the late delivery of product with each supplier in break level in each period. The third objective function minimizes the rejected products and the fourth objective function maximizes the efficiency of the supplier by considering the weights of qualitative attributes that are calculated from AHP method.

Constraint (1) states the balance of inventory in each period by investigating the effects of inventory and shortage on prior period, late delivery, and defective products. Constraint (2) shows that the number of each product procured from each supplier at price break level using transportation vehicle are lower than or equal to the added demand of each product in each interval period. Constraint (3) considers the quantity discount of each product from each supplier in each period.

Constraint (4) demonstrates the number of suppliers that can be selected for each period in planning horizon. Constraint (5) investigates the full capacity of vehicle that is calculated by accumulating the space of each product. Constraints (6) and (7) guarantee that if the suppliers are selected, the carriers are assigned to them and the total number of carriers are equal to the added suppliers.

Constraint (8) shows the storage capacity of inventory of products in each period. Moreover, constraint (9) guarantees that the shortage capacity is not met with suppliers. Constraint (10) shows the maximum late deliveries of each product by considering the demands of each product in each period; and constraint (11) controls the maximum number of breakdowns that occur to all vehicles.

Constraints (12) and (13) consider the capacity and demand of each product in each period. Constraint (14) demonstrates that the inventory and shortage of each product in each period are positive. Constraint (15) demonstrates that the number of the product units met in each period by each supplier at price break level is positive and integer. In the same way, constraints (16), (17) and (18) are considered as binary variables.

٦. Numerical Experiment

In this study, there are four suppliers out of which three ones are selected and one is deleted. The weights of suppliers are calculated by AHP method and the lowest weight is deleted from the pool of suppliers. Then, a multi-objective mathematical model was developed to calculate the number of orders placed by each supplier in each period with discount level and suitable transportation vehicles. Firstly, 6 criteria are considered, each of which contains some sub-criteria.

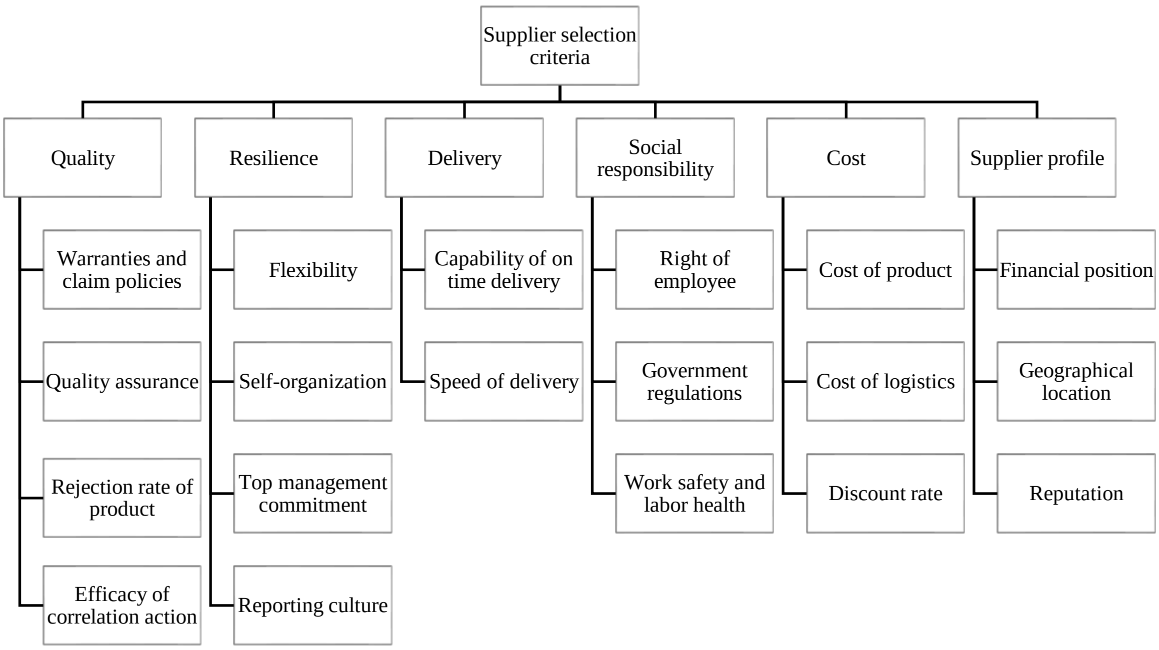

Figure 1. The AHP graph

Table 1. Comparison among sub-criteria with respect to factor resilience

	Self-organization	Top management commitment	Reporting culture
Flexibility	3	$\frac{1}{3}$	5
Self-organization		$\frac{1}{5}$	3
Top management commitment			7

Table 2. Comparison among suppliers with respect to factor flexibility

	Supplier 2	Supplier 3	Supplier 4
Supplier 1	$\frac{1}{5}$	$\frac{1}{3}$	3
Supplier 2		3	9
Supplier 3			5

Figure 1 shows the factors and their hierarchy. For instance, the comparison among alternatives is demonstrated with respect to criterion of resilience in Table 1. Similarly, the comparison of sub-criteria in terms of flexibility is shown in Table 2. Finally, AHP models for the test problems are run using Expert choice software in order to obtain weights and final scores of the alternatives. These results are shown in Figure 2.

Figure 2. The weights of each supplier by AHP

Then, supplier 4 is deleted from the list of supply products and the rest of them are incorporated together to allocate the quantity of the product model. In this study, multi-objective mixed integer mathematical model was investigated for order allocation of each product to each supplier in discount level by selecting proper transportation vehicles. The augmented ε-constraint method is applied to find the efficient solution in multi-objective problem. All the data used for solving this problem is shown in Table 3. In this model, suppliers are selected and the purchased quantities are determined while considering the limited capacity, the number of transportation vehicles and their breakdowns, and the storage capacity related to each supplier.

Table 3. Demand of products in each period

Types of products		Period (t)		
		1	2	3
	1	650	650	700
	2	520	500	500

The results of ε-constraint method are shown in Tables 4, 5 and 6. The payoff table is shown in Table 4. In this method, 11 grid points were generated by using the obtained interval for ε_k as presented in Table 5. Pareto solution and the quantities of each product purchased from each supplier, along with each period, the selected discount level, and selection of the suitable carrier are shown in Table 6.

Table 4. Payoff table

	F1	**F2**	**F3**	**F4**
F1	268276.607	331.484	297.864	1014.502
F2	292719.556	266.533	260.944	1039.454
F3	301360.712	270.213	254.047	1046.654
F4	336420.183	488.495	422.675	1237.659

Table 5. Grid point

	G0	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**
F2	488.495	466.299	444.103	421.907	399.71	377.514	355.318	333.122	310.926	288.73	266.533
F3	422.675	405.812	388.949	372.086	355.224	338.361	321.498	304.635	287.772	270.91	254.047
F4	1014.5	1036.818	1059.133	1081.449	1103.765	1126.08	1148.396	1170.712	1193.027	1215.343	1237.659

Table 6. Pareto solution and order allocated of each product to each supplier in discount level in each period by transportation vehicles

Pareto solution	Objectives	x_{ijmtk}
1	$f_1 = 268276.61$ $f_2 = 331.48$ $f_3 = 297.86$ $f_4 = 1014.5$	$x_{11112} = 150, x_{12212} = 273,$ $x_{12221} = 292, x_{12231} = 305,$ $x_{13212} = 400, x_{13222} = 400,$ $x_{13232} = 250, x_{21112} = 150,$ $x_{22212} = 350, x_{22222} = 200,$ $x_{22231} = 350, x_{23112} = 112,$ $x_{23222} = 362$
2	$f_1 = 273430.91$ $f_2 = 288.73$ $f_3 = 270.11$ $f_4 = 1018.08$	$x_{11212} = 300, x_{12211} = 350,$ $x_{12222} = 350, x_{12232} = 350,$ $x_{13111} = 135, x_{13221} = 340,$ $x_{13232} = 250, x_{21111} = 150,$ $x_{22211} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23112} = 112,$ $x_{23121} = 182$
3	$f_1 = 292719.56$ $f_2 = 266.53$ $f_3 = 260.94$ $f_4 = 1039.45$	$x_{11211} = 300, x_{11221} = 280,$ $x_{12211} = 350, x_{12222} = 350,$ $x_{12231} = 350, x_{13121} = 250,$ $x_{21211} = 300, x_{21222} = 300,$ $x_{22211} = 350, x_{22222} = 350,$ $x_{22231} = 350$
4	$f_1 = 272482.06$ $f_2 = 291.52$ $f_3 = 270.91$ $f_4 = 1023.2$	$x_{11131} = 75, x_{11211} = 202,$ $x_{12211} = 350, x_{12221} = 350,$ $x_{12231} = 350, x_{13111} = 238,$ $x_{13221} = 359, x_{21111} = 150,$ $x_{21131} = 150, x_{22211} = 350,$ $x_{22221} = 350, x_{22231} = 350,$ $x_{23111} = 112, x_{23121} = 182$
5	$f_1 = 301360.71$ $f_2 = 270.21$ $f_3 = 254.05$ $f_4 = 1046.65$	$x_{11211} = 300, x_{11222} = 300,$ $x_{12211} = 350, x_{12221} = 350,$ $x_{12231} = 350, x_{13121} = 230,$ $x_{21211} = 300, x_{21231} = 300,$ $x_{22211} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23121} = 24$
6	$f_1 = 269201.85$ $f_2 = 351.09$ $f_3 = 309.41$ $f_4 = 1036.82$	$x_{11211} = 300, x_{11221} = 300,$ $x_{12211} = 350, x_{12221} = 350,$ $x_{12231} = 350, x_{13121} = 230,$ $x_{21211} = 300, x_{21231} = 300,$ $x_{22211} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23121} = 24$
7	$f_1 = 270157.12$ $f_2 = 355.79$ $f_3 = 314.11$ $f_4 = 1059.13$	$x_{11211} = 300, x_{11221} = 300,$ $x_{12211} = 350, x_{12221} = 350,$ $x_{12231} = 350, x_{13121} = 230,$ $x_{21211} = 300, x_{21231} = 300,$ $x_{22211} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23121} = 24$
8	$f_1 = 271145.71$ $f_2 = 362.4$ $f_3 = 320.36$ $f_4 = 1081.45$	$x_{11131} = 144, x_{11211} = 260,$ $x_{12211} = 300, x_{12212} = 350,$ $x_{12221} = 350, x_{12231} = 350,$ $x_{13112} = 220, x_{21112} = 150,$ $x_{21121} = 150, x_{21131} = 150,$ $x_{22212} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23111} = 130$
9	$f_1 = 272175.66$ $f_2 = 371.39$ $f_3 = 328.53$ $f_4 = 1103.76$	$x_{11121} = 105, x_{11211} = 300,$ $x_{11231} = 212, x_{12211} = 350,$ $x_{12221} = 350, x_{12231} = 350,$ $x_{13111} = 105, x_{21112} = 150,$ $x_{13122} = 250, x_{21121} = 150,$ $x_{21131} = 150, x_{21212} = 259,$ $x_{22211} = 350, x_{22221} = 350,$ $x_{22231} = 350, x_{23121} = 24$

Table 6. Continued

Pareto solution	Objectives	x_{ijmtk}
10	$f_1 = 275730.43$ $f_2 = 397.29$ $f_3 = 344.37$ $f_4 = 1126.08$	$x_{11211} = 300$, $x_{11221} = 300$, $x_{11231} = 168$, $x_{12211} = 350$, $x_{12221} = 350$, $x_{12231} = 105$, $x_{13112} = 119$, $x_{21121} = 150$, $x_{21211} = 280$, $x_{21231} = 300$, $x_{22211} = 350$, $x_{22221} = 350$, $x_{22231} = 350$
11	$f_1 = 279683.47$ $f_2 = 419.71$ $f_3 = 369.35$ $f_4 = 1148.4$	$x_{11112} = 150$, $x_{11131} = 137$, $x_{12211} = 350$, $x_{12222} = 300$, $x_{12231} = 350$, $x_{13212} = 309$, $x_{13222} = 400$, $x_{13232} = 282$, $x_{21112} = 150$, $x_{21131} = 150$, $x_{22212} = 350$, $x_{22222} = 292$, $x_{22231} = 350$, $x_{23112} = 112$, $x_{23131} = 15$, $x_{23222} = 252$
12	$f_1 = 285837.11$ $f_2 = 474.9$ $f_3 = 396.05$ $f_4 = 1170.71$	$x_{11112} = 150$, $x_{11131} = 150$, $x_{11221} = 300$, $x_{12211} = 293$, $x_{12221} = 350$, $x_{12232} = 256$, $x_{13212} = 400$, $x_{13232} = 358$, $x_{21111} = 150$, $x_{21121} = 150$, $x_{21132} = 150$, $x_{22211} = 297$, $x_{22221} = 350$, $x_{22231} = 350$, $x_{23112} = 188$, $x_{23131} = 42$
13	$f_1 = 292993.78$ $f_2 = 479.6$ $f_3 = 400.74$ $f_4 = 1193.03$	$x_{11111} = 150$, $x_{11131} = 150$, $x_{11221} = 300$, $x_{12212} = 297$, $x_{12221} = 350$, $x_{12232} = 235$, $x_{13211} = 400$, $x_{13222} = 400$, $x_{13232} = 400$, $x_{21112} = 150$, $x_{21122} = 150$, $x_{21131} = 150$, $x_{22131} = 4$, $x_{22212} = 200$, $x_{23212} = 306$, $x_{23221} = 400$
14	$f_1 = 301400.77$ $f_2 = 462.1$ $f_3 = 406.37$ $f_4 = 1215.34$	$x_{11111} = 150$, $x_{11132} = 150$, $x_{11222} = 300$, $x_{12211} = 297$, $x_{12231} = 313$, $x_{13212} = 400$, $x_{13222} = 400$, $x_{13232} = 400$, $x_{21111} = 150$, $x_{21122} = 150$, $x_{21131} = 150$, $x_{22131} = 4$, $x_{22211} = 200$, $x_{23221} = 400$, $x_{23231} = 400$
15	$f_1 = 336420.18$ $f_2 = 488.5$ $f_3 = 422.67$ $f_4 = 1237.66$	$x_{11112} = 150$, $x_{11132} = 150$, $x_{11221} = 300$, $x_{12212} = 350$, $x_{12221} = 350$, $x_{12232} = 350$, $x_{13212} = 338$, $x_{13231} = 400$, $x_{21111} = 150$, $x_{21131} = 150$, $x_{21221} = 300$, $x_{22132} = 152$, $x_{22211} = 350$, $x_{22221} = 238$, $x_{23112} = 112$, $x_{23231} = 264$

7. Conclusion

In this study, supplier and carrier selection and order allocation were simultaneously taken into account. For this purpose, at first, some criteria and sub-criteria were selected based on expert opinion. Hence, AHP was applied to calculate the weights of each sub-criterion, criterion, and alternative. Then, a multi objective mixed integer programming model was developed for supplier and carrier selection and order allocation. Doing so, different objectives such as total cost minimization, the late delivery of products, and the rejected products, and maximizing the weights of qualitative attributes were considered and, then, calculated by AHP. Several constraints including inventory, demand, quantity of discount, the number of suppliers in each period, carrier capacity, carrier breakdown and the level of shortage were considered in this model. Pareto optimal solution and the quantity of each product allocated to each supplier in each period were calculated by augmented ε-constraint method.

References

Basnet, C., Leung, J.M.Y., (2005). Inventory lot-sizing with supplier selection, *Computer and Operations Research*, Vol. 32, pp. 1–14.

Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., (2006). A fuzzy-QFD approach to supplier selection, *Journal of Purchasing & Supply Management*, Vol. 12, pp. 14–27.

Chen, C.T., Lin, C.T., Huang, S.F., (2006). A fuzzy approach for supplier evaluation and selection in supply chain management, *International Journal of Production Economy*, Vol. 102, pp. 289–301.

Choudhary, D., Shankar, R., (2011). Modeling and analysis of single item multiperiod procurement lot-sizing problem considering rejections and late deliveries, *Computers & Industrial Engineering*, Vol. 61, pp. 1318–1326.

Demirtas, E.A., Ustun, O., (2009). Analytic network process and multi-period goal programming integration in purchasing decisions, *Computers & Industrial Engineering*, Vol. 56(2), pp. 677–690.

Dickson, G., (1966). An analysis of vendor selection systems and decisions, *Journal of Purchasing*, Vol. 2, pp. 28–41.

Ha, B., Park, Y., Cho, S., (2011). Suppliers' affective trust and trust in competency in buyer, *International Journal of Operation Production Management*, Vol. 31, pp. 56–77.

Haimes, Y.Y., Wismer, D.A., Lasdon, D.S., (1971). On bi-criterion formulation of the integrated systems identification and system optimization, IEEE Transaction System Manufacturing Cybern SMC, Vol. 1, pp. 296–297.

Hollnagel, E., (2006). Resilience: the challenge of the unstable. In: Hollnagel, E., Woods, D., Leveson, N. (Eds.), Resilience Engineering: Concepts and Precepts. Ashgate, London, pp. 8–17.

Kannan, V.R., Tan, K.C., (2002). Supplier selection and assessment: Their impact on business performance, *Journal of Supply Chain Management*, Vol. 38, pp. 11–21.

Lee, A.H.I., Kang, H.Y., Lai, C.M., Hong, W.Y., (2013). An integrated model for lot sizing with supplier selection and quantity discounts, *Applied Mathematical Modelling*, Vol. 37, pp. 4733–4746.

Liao, Z., Rittscher, J., (2007). Integration of supplier selection, procurement lot sizing and carrier selection under dynamic demand conditions, *International Journal of Production Economics*, Vol. 107, pp. 502–510.

Mafakheri, F., Breton, M., Ghoniem, A., (2011). Supplier selection-order allocation: a two stage multiple criteria dynamic programming approach, *International Journal of Production Economics*, Vol. 132, pp. 52-57.

Mansini, R., Tocchella, B., Savelsbergh, M., (2012). The supplier selection problem with quantity discounts and truck load shipping, *Omega*, Vol. 40, pp. 445–455.

Razmi, J., Rafiei, H., 2010. An integrated analytic network process with mixed integer non-linear programming to supplier selection and order allocation, *International Journal of Advance Manufacturing Technology*, Vol. 49, pp. 1195–1208.

Rezaei, J., Davoodi, M., (2008). A deterministic, multi-item inventory model with supplier selection and imperfect quality, *Applied Mathematical Modelling*, Vol. 32, pp. 2106–2116.

Rezaei, J., Davoodi, M., (2011). Multi objective models for lot-sizing with supplier selection, *International Journal of Production Economics*, Vol. 130(1), pp. 77–86.

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., (2003). Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, 2nd ed., McGraw-Hill, Boston, MA.

Thrulogachantar, P., Zailani, S., (2011). The influence of purchasing strategies on manufacturing performance, *Journal of Manufacture Technology Management*, Vol. 22, pp. 641–663.

Ustun, O., Demirtas, E.A., (2008a). An integrated multi-objective decision-making process for multi-period lot-sizing with supplier selection, *Omega*, Vol. 36, pp. 509–521.

Ustun, O., Demirtas, E.A., (2008b). Multi-period lot-sizing with supplier selection using achievement scalarizing functions, *Computers & Industrial Engineering*, Vol. 54(4), pp. 918–931.

Wilson, E.J., (1994). The relative importance of supplier selection criteria: A review and update, *International Journal of Purchasing and Materials Management*, Vol. 30, pp. 34–41.

Zhang, W.J., Lin, Y., (2010). On the principle of design of resilient systems—application to enterprise information systems, *Enterprise Information Systems*, Vol. 4, pp. 99–110.