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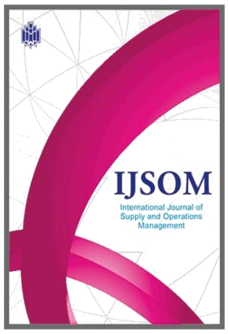

Developing an Optimal Policy for Green Supplier Selection and Order Allocation Using Dynamic Programming

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Abstract
Supplier selection is one of the critical issues in the supply chain. Green supplier selection is performed based on the assessment of quantitative and qualitative criteria in two fields including economic and environmental attributes. In this study, a two-level supply chain model has been proposed for green supplier selection and order allocation in a multi-period and single-product environment. In the first phase, the analytic hierarchical process (AHP) method is used to rank the suppliers and in the second phase, a model is designed based on constraints such as demand, capacity, and allowed level of inventory and shortage to maximize the total value of purchase (TVP) and total profit of purchase (TPP). Demand is assumed to be stochastic in different periods. Thus random demand leads to create various scenarios in the planning horizon. A new integrated approach is presented based on stochastic programming and dynamic programming to solve the problem. The incorporation of stochastic demand condition and application of dynamic programming is a novel idea. Finally, a numerical example is provided to investigate the procedure in details.

Keywords: Green Supplier Selection; Order Allocation; Dynamic Programming; Stochastic Programming.

1. Introduction

Organizations need to monitor internal factors; however, the need to manage and monitor resources and related elements outside the organization is significant because they need to achieve a competitive advantage to gain a larger share of the market. Accordingly, activities such as supply and demand planning, preparation, manufacturing and product planning, preventive maintenance, inventory control, distribution, delivery, and customer service were previously managed at the corporate level, but now they have been transferred to the supply chain management. Generally, the supply chain is composed of two or more organizations that are officially separated, but they are related to each other by the flow of materials, information, and financial flows. The process of integrating supply chain activities and also information sharing through improving the coordination activities in the supply chain, production, and supply of products leads to achieving continuous and reliable competitive advantage (Vahidi et al., 2017).

The vital part of the organizations' costs is the cost of raw material. Up to 70% of the expenses of companies is related to the cost of raw material. On the other hand, the quality of raw material is a crucial factor in the selection of suitable suppliers. Also, it is essential that the process of selecting suitable suppliers and allocating orders to suppliers be appropriately designed. Until 1980, the selection of suppliers was based on cost factors, but recently, the factors such as product quality, the shortest delivery time to the manufacturer, etc. were also considered. Thus, the methods of selecting suppliers have been designed based on the quantitative and qualitative factors. Hence, the selection of suppliers should be accomplished by conducting extensive comparison studies between suppliers using a set of factors. The order allocation process is undertaken to determine the order allocated to each supplier. Thus, different mathematical programming models are presented for this purpose. (Mafakheri et al., 2011)

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This research focuses on a multi-criteria decision-making methodology for the problem of selecting green suppliers and allocating orders when there are multiple suppliers, one product, and multiple periods. In the first phase, at first, criteria and sub-criteria are chosen to evaluate and select the suppliers in the green supply chain based on the literature review in this field. Then, using the AHP method, weights of criteria and sub-criteria are determined, and finally the suppliers are ranked. In the second phase, a model is designed, based on constraints such as demand, capacity, inventory level, and allowed shortage to maximize the value of the suppliers and the profit. Also, demand is assumed to be stochastic in each period, and this generates a set of scenarios during the time horizon. Finally, a solution algorithm with a new integrated approach is presented based on stochastic programming and dynamic programming, which is one of the best possible solution techniques for multi-objective problems based on uncertainty conditions. Dynamic programming is utilized when the sub-problems are dependent. In this category of problems, traditional approaches, where sub-problems are run repeatedly, are not efficient. In the dynamic programming approach, the sub-problems are solved once, and their solutions are stored in a table to be used for further analysis. Following this algorithm reduces the computational burden.

The remainder of the paper is organized as follows. In Section 2, the relevant literature review is presented. In Section 3, the method of AHP for ranking the suppliers is developed, and the two-objective mathematical programming model for selecting the suppliers and allocating the orders has been formulated using dynamic programming and stochastic programming in Section 4. A numerical example is solved for illustrating the application of the proposed methodology, and its performance is evaluated in section 5. A summary of the results and suggestions for future studies are presented in section 6.

2. Literature Review

Extensive studies were conducted on the methods of selecting the suppliers. Some of the essential researches are Weber et al. (1991), De Boer et al. (2001), Ho et al. (2010), and Chai et al. (2013). The literature shows that different criteria are proposed for selecting the suppliers. Degraeve and Roodhoft (1999) focused on the methods of supplier selection based on cost criteria. The researcher has discussed that considering only the cost criterion for evaluating the suppliers does not have an excellent performance, and several other factors should be taken into account. Dickson (1966) presented a list with 23 criteria to evaluate the suppliers for selecting the best one. In another study, Weber et al. (1991) investigated different methods of supplier selection, and concluded that three crucial criteria for assessing suppliers are quality, cost, and on-time delivery to the manufacturer. Other relevant critrria that are effective in the selection of suppliers are environmental factors, capacity and production facilities, geographical location, and so on.

In the literature, two approaches to supplier selection are available. In the first type, a supplier is fully able to meet the demands of the company, and the only decision for the company is to select one supplier. In the second approach, the problem of selecting from among several suppliers is under study, so that an individual supplier could not meet the total demand of company; thus, the demand of company should be divided between the suppliers. In this approach to supplier selection, there are two types of decisions. The first type is to determine which what suppliers should be selected, and the second type of decisions is to determine the order size from each supplier (Özgen et al. 2007, Kilic et al. 2013).

Different methods are applied to select the best suppliers so far. In general, they can be categorized into two approaches (1) individual approach (2) integrated approach Individual strategies for selecting the suppliers can be categorized as Multiple criteria decision making (MCDM), Mathematical Programming (MP), Artificial Intelligence (AI), while the integrated approach includes AHP, Analytic network process (ANP), data envelopment analysis (DEA), etc.

Razmi and Rafiei (2010) proposed a method for allocating orders in two stages so that the suppliers are ranked according to their quality characteristics using the ANP method in the first stage. Mixed-integer nonlinear linear programming (MINLP) method was employed for allocating the order quantities during the planning period in the second stage. Alidaee and Kochenberger (2005) developed a dynamic programming method for the single-sink, fixed charge transportation (SSFCT) problem. This method can be used for determining the optimal order quantity from a set of potential suppliers so that aggregate demand will be satisfied and the total cost will be minimized. Li et al. (2009) considered a problem of selecting suppliers based on price and demand. Mafakheri et al. (2011) analyzed the problem of selecting the suppliers and allocating the orders using the dynamic programming method. Ware et al. (2014) studied the dynamic supplier selection problem (DSSP) such that the parameters of the supply chain changed from period to period, and optimal order quantities for the selected suppliers were determined using the MINLP model. Moghaddam (2015) used the Monte Carlo simulation method with fuzzy goal programming (GP) to solve the problem of selecting suppliers. Pazhani et al. (2016) proposed an MINLP model to determine the optimal allocation of orders among the suppliers at different levels in the supply chain. Amorim et al. (2016) presented a mixed-integer programming (MIP) model for selecting the supplier in the food industry under stochastic conditions. Ghadimi et al. (2017) have used environmental and social criteria to evaluate the supplier and have used the Multi-Agent Systems (MAS) method to supplier evaluation and order allocation. Hamadan et al. (2017) have examined the green supplier selection and order allocation in situations, where the availability of suppliers differs from one period to another and uses fuzzy TOPSIS and AHP to evaluate suppliers.

Vahidi et al. (2017) introduced the issue of sustainable supplier selection and used a two-step stochastic programming and hybrid SWOT-QFD method for selecting the supplier and order allocation. Cheraghalipour et al. (2018) examined the issue of sustainable supplier selection and order allocation considering quantity discounts under disruption risks, using the Best Worst Method to find supplier weights and Revised Multi Choice Goal Programming for solving the model. Goren (2018) presented A Decision Framework for Sustainable Supplier Selection and Order Allocation with Lost Sales, and Decision Making Trial and Evaluation Laboratory (DEMATEL) approach is used to calculate the weights of sustainable criteria and Taguchi Loss Functions for ranking. Park et al. (2018) have used two phases for Sustainable Supplier Selection and Order Allocation, which in the first phase identifies sustainable supplier regions through multi-attribute utility theory and in the second phase, a multi-objective integer linear programming model for Order Allocation. Lo et al. (2018) used a new model to integrate the two best-worst method and TOPSIS methods for supplier selection and used a fuzzy approach to solve the Order Allocation model. Jahantigh et al. (2018) have done research to assist managers and prioritize the objectives and introduced an integrated method combining focus-group interviews as a quantitative method and grey system theory as a quantitative method. Lo et al. (2018) proposed a novel model that integrates the best–worst method (BWM), modified fuzzy technique for order preference by similarity to ideal solution (TOPSIS), and fuzzy multi-objective linear programming (FMOLP) to solve problems in green supplier selection and order allocation. Hosseini et al. (2019) presented a model that could be utilized as a decision support tool to assist manufacturers in the performance assessment of supplier alternatives when cost and resilience are considered simultaneously. Mohammed et al. (2019) presented a hybrid Multi-Criteria Decision-Making (MCDM)-Fuzzy Multi-Objective Optimization (FMOO) approach for a sustainable supplier selection and order allocation problem by considering economic, environmental, and social criteria.

According to the summary of the relevant researches, we can find that most investigations have not considered environmental criteria. Also, some of these studies have not addressed order allocation simultaneously. Stochastic demand is one of the most critical issues in the real world that has been less considered in previous research. And finally, the incorporation of stochastic demand condition and application of dynamic programming is a novel idea.

The main innovations of the current paper are as follow:

- This research has formulated a new bi-objective mathematical model for the green supplier selection and order allocation problem when there are multiple suppliers, one product, and numerous periods. The first objective as a traditional goal seeks to maximize the total value of the purchase and the second objective as a novel weighted sum-based goal attempt to maximize the total score of all suppliers with respect to three green aspects. Also, Demand quantity during the period is assumed to be stochastic.

- A novel integrated solution approach, based on stochastic programming and dynamic programming is provided for the green supplier selection and order allocation problem under conditions of uncertainty.

- A Numerical example study is presented to show the usage of the provided methods.

3. Green Supplier Selection and Order Allocation

3.1. Problem description

Consider a manufacturer that all of his demand is supplied from n potential suppliers during the time horizon with T periods. Potential suppliers are evaluated based on four criteria, including price, quality, on-time delivery, and environmental considerations using the AHP method (Figure 1). The importance weight of each supplier is obtained using the AHP method. Then, these weights are used to define a function named total value of the purchase in the second stage of the solution algorithm. When the manufacturer is ranked, then we can determine the optimal order quantity from different suppliers with maximizing the total value of the purchase (TVP) and total profit purchase (TPP).

3.2. Order allocation model

To maximize the weighted sum of selected supplier for order allocation, a function named total value of the purchase (TVP) was defined based on the importance weight of suppliers. That is obtained using the AHP method in the first stage of the solution algorithm. The optimal order allocation should be determined such that this function will be maximized. On the other hand, the allocation with the most profit is preferred. As a result, a two-objective optimization model will be formulated.

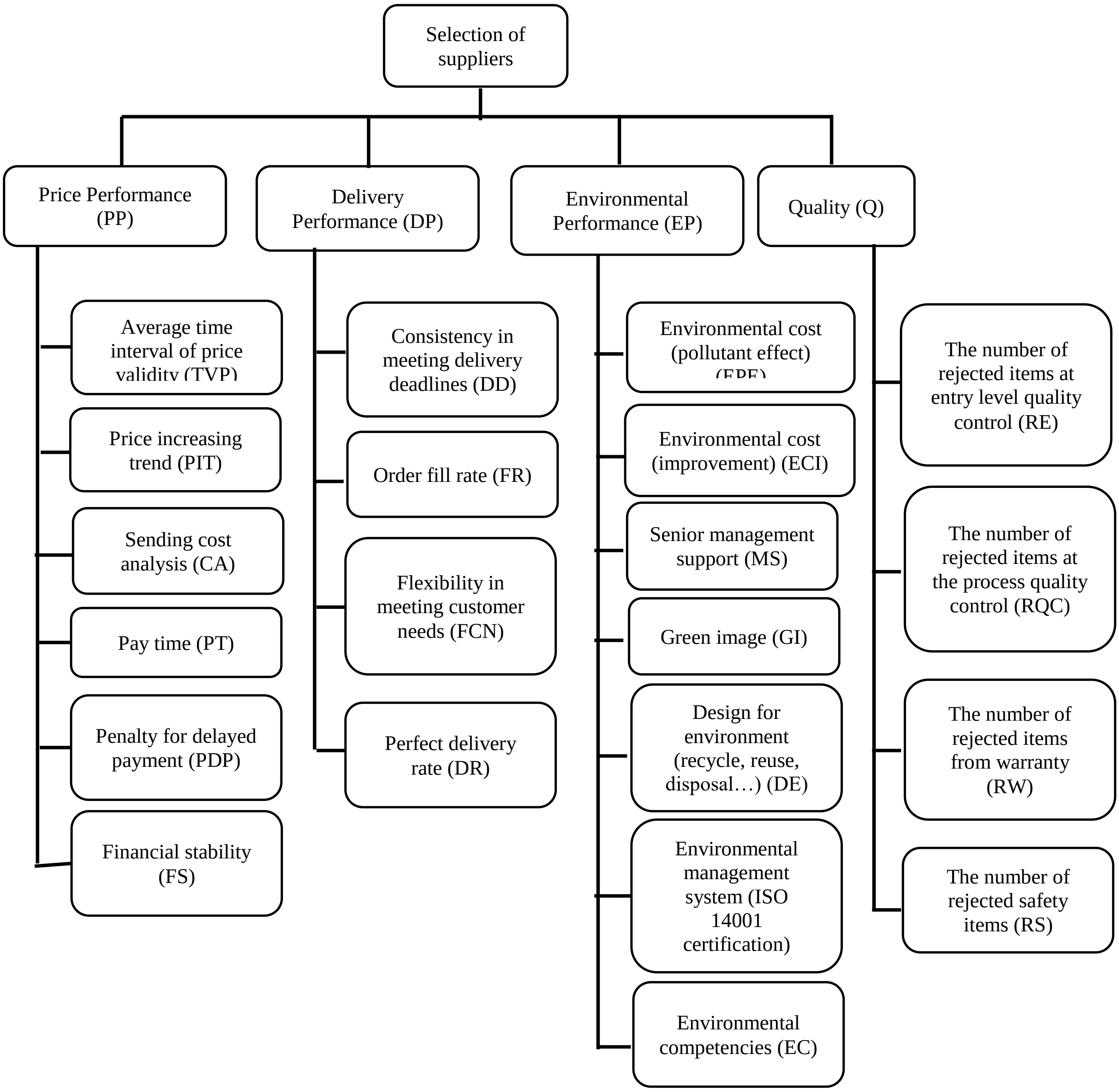

Figure 1. AHP process for supplier ranking (Kokangul and Susuz, 2009; Humphreys et al., 2003; Mafakheri et al., 2011).

Subscripts:

- t The period index (t= 1, 2, ... , T)
- i The supplier index (i= 1, 2, ... , n)
- s Set of disruption scenarios (s= 1, 2, ... , S)

Parameters:

- x Available inventory
- X Maximum allowed inventory level
- Y Maximum allowed shortage level
- b_i Capacity of supplier i
- w_i Importance weight of supplier i
- D_t^s Demand in period t under scenario s
- h_t Holding cost per each item in period t
- A_t Shortage cost per each item in period t
- R_t Gained Revenue per each item in period t

p_{it} Buying cost from the supplier *i* per each item in period *t*

Decision variables:

x_t^s Inventory level at the end of period *t* under scenario *s*

y_t^s Shortage level at the end of period *t* under scenario *s*

q_{it}^s Order quantity from the supplier *i* in period *t* under scenario *s*

$$k \quad \begin{cases} 1 & \text{if there is inventory} \\ 0 & \text{if there is shortage} \end{cases}$$

Objective and constraints:

For managing different scenarios of demand in the supply chain, a scenario based supply chain model is formulated as follows.

$$max\,TVP = \sum_{s=1}^{S} \frac{1}{S} \sum_{t=1}^{T} \sum_{i=1}^{n} w_i q_{it}^s \tag{1}$$

$$max\,TPP = \sum_{s=1}^{S} \frac{1}{S} (\sum_{t=1}^{T} R_t\, min(x_{t-1}^s + \sum_{i=1}^{n} q_{it}^s\,, D_t^s) - \sum_{t=1}^{T} h_t\, x_t^s - \sum_{t=1}^{T} A_t\, y_t^s - \sum_{t=1}^{T} \sum_{i=1}^{n} p_{it} q_{it}^s) \tag{2}$$

s.t.

$$0 \le q_{it}^s \le b_i \qquad \forall i,t,s \tag{3}$$

$$0 \le x_t^s \le Xk \qquad \forall t,s \tag{4}$$

$$0 \le y_t^s \le Y(1-k\,) \qquad \forall t,s \tag{5}$$

$$x_{t-1}^s + \sum_{i=1}^{n} q_{it}^s = x_t^s + D_t^s - y_t^s \qquad \forall t,s \tag{6}$$

$$x_t^s \ge 0,\; y_t^s \ge 0, q_{it}^s \ge 0,\; k = 0,1 \tag{7}$$

In this model, equation (1) indicates the first objective function that is maximizing the total value of the purchase (TVP) and equation (2) demonstrates the second objective function that is maximizing total profit (TPP) which includes revenue from selling, holding cost, shortage cost, buying cost. Constraint (3) shows the maximum capacity of suppliers. Constraints (4) and (5) indicate the maximum allowed inventory level and the maximum allowed shortage level. Constraint (6) shows the changes in the inventory level based on the demand under each scenario. Constraint (7) denotes that the decision variables are non-negative. The objective of this model is to optimize both objective functions of TVP and TPP simultaneously.

4. Dynamic Programing Method

Since inventory holding cost, inventory shortage cost, purchasing prices, and demand are time-varying in the model under consideration, the profit objective function (and its related constraints ((3), (4), (5), (6) and (7)) could be clearly determined by a dynamic value function (with a recursive computation formula) as follows that this type of dynamic function is provided in (Mafakheri et al., 2011):

$$V_{1t}(x) = max \sum_{s=1}^{S} \tfrac{1}{S} (\sum_{t=1}^{T} R_t\, min(x_{t-1}^s + \sum_{i=1}^{n} q_{it}^s\,, D_t^s) - \sum_{t=1}^{T} h_t\, x_t^s - \sum_{t=1}^{T} A_t\, y_t^s - \sum_{t=1}^{T} \sum_{i=1}^{n} p_{it} q_{it}^s) + V_{1,t+1}(x + \sum_{i=1}^{n} q_{it}^s - D_t^s + y_t^s) \tag{8}$$

$$0 \le q_{it}^s \le b_i$$
$$0 \le x_t^s \le Xk$$
$$0 \le y_t^s \le X(1-k\,)$$

Where Stage is the decision dates in periods, *t*= 1, 2 ..., *T*. The state variable is the inventory level in periods of decision under scenario *s*, *x*= 1, 2... *X*. The decision variable is order quantity from the supplier *i* in period t under scenario *s*, $q_{it}^s = 0, \dots, b_i$. $V_{1t}(x)$ is the max total profit of purchase if the inventory level is *x*.

Since both the TVP and TPP objective functions need to be optimized simultaneously, so we apply a distance-to-ideal (Collette et al., 2004) to integrate the TVP and TPP function, using the optimal value of individual objectives and its related constraints ((3), (4), (5), (6), (7) and (8)) (Mafakheri et al., 2011).
Finally, we formulate a dynamic programming model as following:

$$V_{1t}(x) = min\left\{(TVP_{max}^{t}(x) - \sum_{s=1}^{S}\frac{1}{S}\sum_{t=1}^{T}\sum_{i=1}^{n} w_i q_{it}^{s}(x))/(TVP_{max} - TVP_{min}) + (TPP_{max}^{t}(x) - \sum_{s=1}^{S}\frac{1}{S}(\sum_{t=1}^{T} R_t\, min(x_{t-1}^{s} + \sum_{i=1}^{n} q_{it}^{s}, D_t^{s}) - \sum_{t=1}^{T} h_t\, x_t^{s} - \sum_{t=1}^{T} A_t\, y_t^{s} - \sum_{t=1}^{T}\sum_{i=1}^{n} p_{it} q_{it}^{s}(x))/(TPP_{max} - TPP_{min}) + V_{1,t+1}(x + \sum_{i=1}^{n} q_{it}^{s} - D_t^{s} + y_t^{s})\right\} \quad (9)$$

$$0 \le q_{it}^{s} \le b_i$$
$$0 \le x_t^{s} \le \mathrm{X}k$$
$$0 \le y_t^{s} \le \mathrm{X}(1-k)$$

In dynamic programming model, we tried to minimize the total normalized deviation of each objective function from their optimal values when the value of inventory level is (x). $TVP_{max}^{t}(x)$ is the maximum value of TVP function in period t when the inventory level is (x). $TPP_{max}^{t}(x)$ is the maximum value of TPP function in period t when the inventory level is (x). TVP_{max} is the maximum value of TVP function in all time periods. TVP_{min} is the minimum value of TVP function in all time periods. TPP_{max} is the maximum value of TPP function in all time periods. TPP_{min} is the minimum value of TPP function in all time periods.

5. Numerical Example

In order to illustrate the application and usefulness of the proposed method, a numerical example has been solved. In this example, three suppliers are considered, and we must make decisions about the amount of purchase from each supplier to maximize the total value of purchase and total profit in the planning horizon. It should be noted that the implementation of the model with the help of GAMS software is accomplished.

First, the weight will be assigned to each supplier using the AHP method. Thus, pairwise comparison of main criteria is performed based on objectives to prioritize each criterion. The criteria are compared pairwise based on objectives as denoted in Table1. Data of the pairwise comparison matrix is denoted in Tables 2-5. Finally, we computed the importance weight of each supplier using the weighted mean method. The result is shown in Table 6. (Mafakheri et al., 2011)

Table 1. Evaluation of criteria with respect to goal

Criteria	PP	DP	EP	Q	Priority vector
PP	1	2	4	3	0.450
DP	1/2	1	3	1/2	0.191
EP	1/4	1/3	1	1/5	0.075
Q	1/3	2	5	1	0.284

Table 2. Evaluation of suppliers with respect to price performance.

Criteria/ suppliers	TVP (0.301)	PIT (0.273)	CA (0.163)	PT (0.075)	PDP (0.122)	FS (0.066)	PP
I	0.557	0.677	0.102	0.090	0.665	0.624	0.498
II	0.321	0.192	0.366	0.303	0.231	0.239	0.272
III	0.122	0.131	0.532	0.607	0.104	0.137	0.227

Table 3. Evaluation of suppliers with respect to delivery performance

Criteria/ suppliers	DD (0.444)	FR (0.325)	FCN (0.058)	DR (0.173)	DP
I	0.102	0.557	0.620	0.104	0.280
II	0.366	0.321	0.283	0.231	0.323
III	0.532	0.122	0.097	0.665	0.397

Table 4. Evaluation of suppliers with respect to environmental performance

Criteria/ suppliers	EPE (0.302)	ECI (0.205)	MS (0.103)	GI (0.120)	DE (0.121)	EMS (0.048)	EC (0.101)	EP
I	0.557	0.109	0.677	0.624	0.620	0.090	0.624	0.478
II	0.321	0.297	0.192	0.239	0.239	0.303	0.239	0.279
III	0.122	0.594	0.131	0.137	0.137	0.607	0.107	0.243

Table 5. Evaluation of suppliers with respect to quality

Criteria/ suppliers	RE (0.232)	RQC (0.190)	RW (0.063)	RS (0.515)	Quality
I	0.639	0.677	0.109	0.090	0.330
II	0.243	0.192	0.297	0.303	0.267
III	0.118	0.131	0.594	0.607	0.403

Table 6. AHP ranking of suppliers

Criteria/ suppliers	PP (0.450)	DP (0.191)	EP (0.075)	Q (0.284)	AHP ranking (weight)
I	0.498	0.280	0.478	0.330	0.407
II	0.275	0.323	0.279	0.267	0.283
III	0.227	0.397	0.243	0.403	0.310

The input data to of case study are given in Table 7 and 8. It is worth noting that demand in each period is selected from possible values of 3, 4, and 5 with equal probability, and therefore, 27 scenarios will be created in three periods. Holding cost for each unit in all periods is 1 ($h_t = 1$). Cost of one shortage is 12 for all periods($A_t = 12$). Revenue from each product in all periods is $30(R_t = 30)$. Maximum allowed inventory level is 2 ($X = 2$) and maximum allowed shortage level is $10(Y = 10)$.

Table 7. Demand information

scenario	Period 1 (t=1)	Period 2 (t=2)	Period 3 (t=3)
Scenario 1	3	3	3
Scenario 2	4	3	3
Scenario 3	5	3	3
Scenario 4	3	4	3
Scenario 5	4	4	3
Scenario 6	5	4	3
Scenario 7	3	5	3
Scenario 8	4	5	3
Scenario 9	5	5	3
Scenario 10	3	3	4
Scenario 11	4	3	4
Scenario 12	5	3	4
Scenario 13	3	4	4
Scenario 14	4	4	4
Scenario 15	5	4	4
Scenario 16	3	5	4
Scenario 17	4	5	4
Scenario 18	5	5	4
Scenario 19	3	3	5
Scenario 20	4	3	5
Scenario 21	5	3	5
Scenario 22	3	4	5
Scenario 23	4	4	5
Scenario 24	5	4	5
Scenario 25	3	5	5
Scenario 26	4	5	5
Scenario 27	5	5	5

Table 8. Price and capacity information

suppliers	Ordering price (per unit)			Capacity
	Period 1	Period 2	Period 3	
I	9	9	10	3
II	7	7	6	3
III	5	8	8	5

First, we solve the model order allocation to maximize the objective function of TPP by considering the equation (2) as the single objective function then the mathematical model is solved, and the optimal solution has been determined. This optimal solution is substituted in the TVP function defined in the equation (1) to determine the value of $\boldsymbol{TVP_{min}}$. The values of optimal order quantity and the value of TVP under different scenarios are shown in Table 9. Then, we solve the model with the goal of maximizing TVP function and the same the procedure is conducted for determining the value of $\boldsymbol{TPP_{min}}$. The results are shown in Table 10.

Table 9. Optimal order quantities with respect to maximizing TPP

Total TPP=TPP_{max}				286.556							
Total TVP=TVP_{min}				3.557							
Scenario1				Scenario2				Scenario3			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	1	3	q_{II}	0	1	3	q_{II}	0	1	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario4				Scenario5				Scenario6			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	2	3	q_{II}	0	3	3	q_{II}	0	2	3
q_{III}	5	0	0	q_{III}	5	0	0	q_{III}	5	0	2
Scenario7				Scenario8				Scenario9			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	3	3	q_{II}	0	3	3	q_{II}	0	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario10				Scenario11				Scenario12			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	2	3	q_{II}	0	2	3	q_{II}	0	2	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario13				Scenario14				Scenario15			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	3	3	q_{II}	0	3	3	q_{II}	0	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2

Table 9. Continued

Scenario16				Scenario17				Scenario18			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	1	3	3	q_{II}	1	3	3	q_{II}	1	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario19				Scenario20				Scenario21			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	0	3	3	q_{II}	0	3	3	q_{II}	0	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario22				Scenario23				Scenario24			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	1	3	3	q_{II}	1	3	3	q_{II}	1	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2
Scenario25				Scenario26				Scenario27			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	0	0	0	q_I	0	0	0	q_I	0	0	0
q_{II}	2	3	3	q_{II}	2	3	3	q_{II}	2	3	3
q_{III}	5	0	0	q_{III}	5	0	1	q_{III}	5	0	2

Table 10. Optimal order quantities with respect to maximizing TVP

Total TPP=TPP_{min}				-104.407							
Total TVP=TVP_{max}				4.593							
Scenario1				Scenario2				Scenario3			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	0	0	0	q_{III}	0	0	1	q_{III}	0	0	2
Scenario4				Scenario5				Scenario6			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	0	1	0	q_{III}	0	1	1	q_{III}	0	1	2
Scenario7				Scenario8				Scenario9			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	0	2	0	q_{III}	0	2	1	q_{III}	0	2	2

Table 10. Continued

Scenario10				Scenario11				Scenario12			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	1	0	0	q_{III}	1	0	1	q_{III}	3	0	0
Scenario13				Scenario14				Scenario15			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	1	1	0	q_{III}	1	1	1	q_{III}	1	1	2
Scenario16				Scenario17				Scenario18			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	3	0	0	q_{III}	3	0	1	q_{III}	3	0	2
Scenario19				Scenario20				Scenario21			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	0	0	q_{III}	2	0	1	q_{III}	4	0	0
Scenario22				Scenario23				Scenario24			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	1	0	q_{III}	2	1	1	q_{III}	2	1	2
Scenario25				Scenario26				Scenario27			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	3	q_I	3	3	3	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	2	0	q_{III}	2	2	1	q_{III}	2	2	2

Now, we substitute the values of TVP_{max} and TPP_{max} along with the values of TPP_{min} and TVP_{min} in the dynamic programming model formulated in the equation (8) that is designed to maximize both objective functions by determining optimal order quantities under different scenarios. The results are denoted in Table 11.

Table 11. Optimal order quantities obtained in dynamic programming model

Total TPP				**Table 11.** Optimal order quantities obtained in dynamic programming model 259.6667							
Total TVP				4.463667							
Scenario1				Scenario2				Scenario3			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	1	3	q_I	3	1	3	q_I	3	1	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	0	0	q_{III}	2	0	1	q_{III}	2	0	2
Scenario4				Scenario5				Scenario6			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	1	0	q_{III}	2	1	0	q_{III}	2	1	0
Scenario7				Scenario8				Scenario9			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	2	2	0	q_{III}	2	2	0	q_{III}	2	2	0
Scenario10				Scenario11				Scenario12			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	1	3	q_I	3	1	3	q_I	3	1	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	3	0	0	q_{III}	3	0	1	q_{III}	3	0	2
Scenario13				Scenario14				Scenario15			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	1	0	q_{II}	0	1	0	q_{II}	0	1	0
q_{III}	3	0	0	q_{III}	3	0	0	q_{III}	3	0	0
Scenario16				Scenario17				Scenario18			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	2	0	q_{II}	0	2	0	q_{II}	0	2	0
q_{III}	3	0	0	q_{III}	3	0	0	q_{III}	3	0	0
Scenario19				Scenario20				Scenario21			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	1	3	q_I	3	1	3	q_I	3	1	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	4	0	0	q_{III}	4	0	1	q_{III}	4	0	2

Table 11. Continued

Scenario22				Scenario23				Scenario24			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	4	1	0	q_{III}	4	1	0	q_{III}	4	1	0
Scenario25				Scenario26				Scenario27			
Period	1	2	3	Period	1	2	3	Period	1	2	3
q_I	3	3	1	q_I	3	3	2	q_I	3	3	3
q_{II}	0	0	0	q_{II}	0	0	0	q_{II}	0	0	0
q_{III}	4	2	0	q_{III}	4	2	0	q_{III}	4	2	0

Based on the solutions of the dynamic programming model, it can be seen that the value of TVP function is reduced by 9% relative to its maximum value and value of TPP function is reduced by 3% concerning its maximum value. While if we only consider the maximization of the TVP function, then TPP value will decrease by 23% relative to its maximum value. Similarly, if we only consider the maximization of the TPP function, then TVP value will decrease by 136% to its peak value. Therefore, the method of minimizing the deviation of objective functions from their optimal value using Dynamic programming method will lead to better solutions.

The complexity of the proposed method in the first phase (ranking suppliers) depends on the number of suppliers and assessment criteria. With an increase in the number of suppliers, the complexity will increase. In the second phase, the size of solution space for searching the optimal policy in the dynamic programming method depends on the number of periods (T), maximum allowed inventory level (X), maximum allowed shortage level (Y), maximum amount of purchased products from suppliers (Q), the number of possible scenarios for demand D_t^s . With an increase in each of the mentioned parameters, we may have difficulty in finding the optimal policy in the dynamic programming method.

6. Conclusion

In this study, to make decisions about the amount of purchase from each supplier, first AHP method is used to rank suppliers according to the decision-making criteria. The importance weights of each supplier obtained in the AHP method are used to define the objective function that is to maximize the weighted sum of selected suppliers. On the other hand, most organizations are willing to increase their profits. Thus optimal order quantities will be obtained using a dynamic programming method to minimize the total normalized deviation of each objective function from their optimal value. In this model, demand in each period is random. Thus, different scenarios of demand may accrue in the planning horizon. Finally, a simple numerical example with two objective functions is presented to demonstrate the efficiency and effectiveness of the dynamic programming method. The proposed approach provides a decision framework for managers when there are multiple suppliers, one product, and numerous periods so that they can evaluate and select the suppliers. A managerial insight is that stochastic demand in each period leads to different scenarios, which influences the decision of the optimal order quantity in each period and plays a significant role in optimizing the total profit of the supply chain. There are several areas for future researchincluding the following:

- The problem can be ranked using a method that is considered uncertainty caused by personal judgment and incomplete information.
- The model can be extended to consider other stochastic parameters.
- The problem can be extended for the case of multi-products in which each product has different prices in different periods.
- Other multi-objective solution methods can be considered for the problem.

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