ISSN: 0975-766X
CODEN: IJPTFI
Available Online through
www.ijptonline.com
Research Article

A MULTI-OBJECTIVE MODEL FOR SUPPLIER EVALUATION AND SELECTION AND MULTI-PRODUCT ORDER ALLOCATION IN DRUG SUPPLY CHAIN

Ali Nazeri*, Mehdi Nosratpour
Department of Industrial engineering, Islamic Azad University, Damavand Branch, Damavand, Iran.
Email: nazeri@damavandiau.ac.ir

Received on 12-05-2016 *Accepted on 05-06-2016*

Abstract

One of the most important challenges of supply chain management is to select suppliers and allocate orders to them. Due to the vital importance of drugs to the society, one of the industries in which supply chain management is highly important is the pharmaceutical industry. Hence, a model was proposed in this paper, which aims to select the most appropriate suppliers and allocate the optimal number of orders to them by considering suitable indices in the supplier selection problem of the pharmaceutical industry. To this end, a mathematical programming model consisting of four objective functions and several constraints was designed and solved using the epsilon-constraint method. Results reflected the efficiency of the model for the drug supply chain.

Keywords: drug supply chain; supplier evaluation and selection; order allocation; multi-objective mathematical programming; Analytical Hierarchy Process

1. Introduction

Drug supply chain includes a set of activities targeted at the flow of drugs from raw materials to the end customer. This chain also includes the information and financial flows associated with these activities. Accordingly, it is possible to consider the drug supply chain a collection of members and components working as a system to actualize the chain goals. Among the important components of this system are the suppliers. In competitive environments, selection of suppliers is among the highly fundamental issues of companies. In such environments, the final price of the product is mainly influenced by the price of raw materials, and thus selection of appropriate suppliers reduces the purchase costs considerably (Kannan et al., 2013). In fact, successful supply chain management calls for an effective and efficient resourcing strategy to eliminate unreliability of supply and demand. Sourcing decisions are more vital than ever, because with an increase in purchase costs as compared to total costs, the purchase function and decisions become significantly important to any firm. On average, a production company spends 60% of its total transactions on the purchase of materials, commodities or services provided by foreign suppliers (De Boer et al., 2001). Hence, adoption of a suitable purchase strategy considerably influences the decrease in costs and the growth of profit.

Since the quality of the end product severely depends on the raw materials and efficiency of the supplier, appropriate performance of suppliers guarantees the drug supply chain sustainability (Nasiri& Pour Muhammadzia, 2015).

In general, suppliers are selected in two ways. In the first state, which is known as the “single-source” selection method, a single supplier can meet all of the needs of the buyer, and the buyer should only select the best supplier in the decision-making process.

In the second state, which is more generic and is known as the “multiple-source” selection method, a single supplier cannot meet all of the demands of the buyer and decisions must be made on the selection of several suppliers. Hence, to create a stable competitive atmosphere, companies should select the best suppliers and decide on the number of orders they are going to allocate to each supplier (Eliank&Armanri, 2009). Accordingly, employment of several suppliers guarantees timely deliveries and flexibility of order placement due to the diversity it brings to the company’s orders (Kannan et al., 2013).

In the present paper, an integrated model consisting of the Analytical Hierarchy Process (AHP) and multi-objective mathematical programing was proposed for prioritization of potential suppliers and allocation of orders to those suppliers. The proposed model is composed of a qualitative and a quantitative section. The qualitative section is dedicated to an AHP-based qualitative assessment of suppliers, while the quantitative part determines the optimal number of orders for each supplier based on factors defined as the objective functions.

In the present model, purchase costs, defective items, lead time, and ordering priority are considered the main factors involved in order allocation. The positive quality of this model is that it incorporates qualitative and quantitative factors simultaneously into a single mathematical model. In the second and third sections, the model structure and the given solution are explained, respectively. The fourth section of the paper presents numerical results, and finally this paper ends with conclusions and future work recommendations in section five.

2. Proposed Model Framework

The structure of the proposed model consists of a qualitative and a quantitative part. In the qualitative section, criteria for evaluation of suppliers in the pharmaceutical industry are determined. In the quantitative section, orders are allocated to the suppliers selected in the qualitative part.

2.1. Model's Qualitative Section

In this section, the suppliers' evaluation criteria are determined and the suppliers are assessed using AHP. The weights obtained from AHP, which are shown by W_{ij}, are used as the input to the assumed model. The AHP method is a multi-criteria decision-making method used for ranking and comparing different options and selecting the best option. This method is also used for determining the weights of criteria.

The different steps of the AHP method are as follows (Saati, 1980).

1- Formation of pair-wise comparison matrices for different levels using the table of preferences;

Table 1: Pair-wise comparison preferences.

Numerical value	Preferences
9	Completely preferred, completely more important, or completely more favorable
7	Very strong preference, importance or favorability
5	Strong preference, importance or favorability
3	Slightly preferred, more important or more favorable
1	Equal preference, importance or favorability
2, 4, 6, 8	Preferences between the above levels

2- Normalization (formation of a scale-free matrix)

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

3- Compatibility Test

CI= $(\lambda max - n)/n - 1$

CR=$^{CI}/_{RI}$

Table 2: Values of RI in relation to the number of elements.

N	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

4- Relative weight calculation

$$w_j = \frac{\sum_{j=1}^{n} r_{ij}}{n}$$

5- Final weight calculation

2.1.1. Determining Criteria for Supplier Selection

The criteria were determined based on the criteria used by Enyinda and Janel (2010) for the pharmaceutical industry. These criteria are presented in the following table.

Table 3: Criteria for supplier selection based on the research by Enyinda and Janel (2010).

Criterion
Quality (C_1)
Costs (C_2)
Regulatory Compliance (C_3)
Services (C_4)
Risk Management (C_5)
Suppliers' profile (C_6)

2.1.1.1. Defining the Research Criteria

- **Quality:**The quality of raw materials and the primarily required parts is essential. Since the pharmaceutical industry is a vital industry, FDA (U S Food and Drug Administration) has required all of the production companies to purchase the raw materials from supplier companies with credible qualitative certificates.
- **Costs:** This criterion is always considered an important factor for all industries in the literature of suppliers' evaluation and selection.
- **Regulatory Compliance:** The pharmaceutical industry has always been pressured by FDA to follow the rules and regulations governing the quality of drugs. Hence,pharmaceutical companies are interested in selection of suppliers whose products comply with the FDA standards.
- **Services:** Provision of proper services by suppliers is a constant necessity. The pharmaceutical industry's suppliers are expected to guarantee the supply of high-quality products and also to provide after sales services. These services include proper delivery time, added value services, and ease of communication.
- **Risk Management:** Suppliers should be capable of managing and reducing the supply risks. The suppliers' ability to manage risk has a significant effect on the reduction in costs, improvement of quality, operational efficiency, stability, and enhancement of the process and visibility of the supply chain.

- **Suppliers Profile:** This criterion includes fame, flexibility, production capacity, financial health, and production facilities of suppliers.

2.1.2. Creation of Pair-Wise Comparison Matrices

The data used in this section belongs to a pharmaceutical Iranian company and was extracted from Mr. Omid Khorasan's M.S. thesis (2010). First, the weights of research criteria were calculated using the pair-wise comparison matrix.

Table 4: The criteria pair-wise comparison matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	1	1	2	1	**3**
C_2	1	1	2	1	1	**1**
C_3	1	1/2	1	5	1	**5**
C_4	1/2	1	1/5	1	3	**2**
C_5	1/3	1	1	1/3	1	**5**
C_6	1/3	1	1/5	1/2	1/5	**1**

After normalizing the above matrix using the column method, the weight of each criterion was obtained using the geometric mean method.

Table 5: obtained weight.

WC_1	WC_2	WC_3	WC_4	WC_5	WC_6
0.21	0.18	0.27	0.13	0.14	**0.07**

The CR index is 0.4, which reflects the compliance of the pair-wise comparison matrix.

In the following, a pair-wise comparison is made between the options based on the 6 criteria.

Table 6: The pair-wise comparison matrix for comparing the options based on the quality criterion.

C_1	A_1	A_2	A_3	A_4	W_j
A_1	1	1/2	1/4	1/2	**0.110**
A_2	2	1	1/2	1/2	**0.187**
A_3	4	2	1	2	**0.439**
A_4	2	2	1/2	1	**0.265**

Table 7: The pair-wise comparison matrix for comparing the options based on the cost criterion.

C_2	A_1	A_2	A_3	A_4	W_j
A_1	1	2	1/3	1/3	**0.143**
A_2	1/2	1	1/3	1/3	**0.093**
A_3	3	3	1	2	**0.459**
A_4	3	3	1/2	1	**0.305**

Table 8: The pair-wise comparison matrix for comparing the options based on the regulatory compliance criterion.

C_3	A_1	A_2	A_3	A_4	W_j
A_1	1	3	1/3	1/3	**0.156**
A_2	1/3	1	1/5	1/3	**0.078**
A_3	1	5	1	2	**0.466**
A_4	3	3	1/2	1	**0.299**

Table 9: The pair-wise comparison matrix for comparing the options based on the services criterion.

C_4	A_1	A_2	A_3	A_4	W_j
A_1	1	2	1/3	1/4	**0.127**
A_2	1/2	1	1/7	1/7	**0.052**
A_3	3	7	1	1/2	**0.324**
A_4	4	7	2	1	**0.497**

Table 10: The pair-wise comparison matrix for comparing the options based on the risk management criterion.

C_5	A_1	A_2	A_3	A_4	W_j
A_1	1	2	1/5	1/3	**0.113**
A_2	1/2	1	1/7	1/5	**0.064**
A_3	5	7	1	1/2	**0.455**
A_4	3	5	2	1	**0.368**

Table 11: The pair-wise comparison matrix for comparing the options based on the suppliers' profile criterion.

C_6	A_1	A_2	A_3	A_4	W_j
A_1	1	2	½	1/4	**0.129**
A_2	½	1	¼	1/8	**0.047**
A_3	2	4	1	1/2	**0.283**
A_4	4	8	2	1	**0.540**

Table 12: Final suppliers' weights matrix.

	C_1= 0.21	C_2= 0.18	C_3= 0.27	C_4= 0.13	C_5= 0.14	C_6= 0.07	W_j
A1	0.12	0.14	0.15	0.12	0.11	0.13	0.131
A2	0.18	0.10	0.10	0.07	0.08	0.05	0.106
A3	0.44	0.46	0.46	0.32	0.45	0.30	0.425
A4	0.26	0.30	0.29	0.49	0.36	0.52	0.337

As shown, the suppliers were prioritized and their final weights, which are shown in column W_j, were used as the input of the multi-objective model.

2.2. Model's Quantitative Section

In this section, the multi-objective model for the problem of allocation of orders to suppliers is presented. The proposed model is a linear model. First, the research problem is stated. Then, the research parameters and variables are defined, and finally the objective functions and formulated constraints are presented.

2.2.1. Problem Statement and Proposed Model

It is assumed that a buyer buys *m* commodities from *n* suppliers in a cycle. The buyer's demand is also assumed to be invariant. A set of suppliers are previously determined based on some specific criteria (e.g. quality, services, delivery, maintenance, etc.) and the orders are multi-product orders. In addition, it is assumed that the capacity of each supplier is limited and the quantity of orders allocated to each supplier should be equal to/larger than the supplier's capacity. This situation complies more with actual business scenarios.

Reducing the lead time and the number of defective items is also another of problem goals. The present research aimed to determine the number of orders allocated to each supplier, to minimize the lead time, percentage of defective items, and prices, and to make maximum use of suppliers' capacities.

2.2.2. Assumptions

A) Several commodities are purchased from each supplier.

B) Suppliers' commodity shortage is not acceptable.

C) The demand is final.

The following notations are used in the model formulation.

2.2.3. Parameters

i- Suppliers' index

j- Commodities index

n- Number of suppliers

m- Number of commodities

Dj- Demand volume

Xij- Size of the order allocated to the i-th supplier for the supply of the j-th commodity or product

Cij- Capacity of the i-th supplier to supply the j-th commodity or product

Wij- Total weight (priority degree) of the i-th supplier (obtained by AHP)

Pij- Unit price of the j-th commodity supplied by the i-th supplier

Qj- The highest allowable failure ratio (%)

qij- Average failure percentage of the j-th commodity provided by the i-th supplier

tij- Lead time percentage of the j-th commodity supplied by the i-th supplier

B – Maximum purchase budget

M – An adequately large number

2.2.4. Decision variables

X_{ij}- The volume of the order allocated to the i-th supplier for the j-th product

Yi – Boolean variable: If an order is allocated to thei-th supplier, Y is equal to 1; otherwise it is equal to zero.

2.2.5. Objective Functions

1- Objective: To allocate more orders to more appropriate suppliers

$$\text{MAX } Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} w_{ij} x_{ij}$$

2- Objective: To minimize the percentage of defective items

$$\text{MIN } Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} q_{ij} x_{ij}$$

3- Objective: To minimize the lead time percentage

MIN $Z_3 = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} x_{ij}$

4- Objective: To minimize purchase costs

MIN $Z_4 = \sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij} x_{ij}$

Constraints:

1- $\begin{cases} \sum_{j=1}^{n} x_{ij} \le MY_i \ \forall\ i \\ Y_i \le M \sum_{j=1}^{n} x_{ij} \forall\ i \end{cases}$

2- $\sum_{i=1}^{m} \sum_{i=1}^{n} p_i x_{ij} \le B$

3- $\sum_{i=1}^{m} x_{ij} = D_j \forall\ j$

4- $\sum_{i=1}^{m} q_{ij} x_{ij} \le Q_j D_j \ \forall\ j$

5- $x_{ij} \le c_{ij} \forall\ i, j$

3. Solving the Proposed Model Using the Epsilon Constraint Algorithm

Various solutions have been proposed for multi-objective programming problems. Two of these methods are the Modified Werner (MW), max-min, and epsilon methods. In this investigation, the epsilon-constraint method was used to solve the model and obtain Pareto solutions.

The steps of the epsilon-constraint method are as follows (Qodsipour, 2013):

1- One of the objective functions is selected as the main objective function.
2- The problem is solved with a different objective function in each run and the optimal values of each function are obtained.
3- The interval between two optimal values of secondary objective functions is set to a predetermined number and a table of epsilon values is obtained.
4- Each time, the problem is solved with the main objective function and a different epsilon value.
5- The resulting Pareto solutions are reported.

3.1. Parameter Adjustment and Sample Problem Specifications

Data on order allocation was not available, and thus to implement the model the parametric values were generated with a uniform distribution. Table (13) presents the ranges of these distribution functions.

Table (13): Probability distribution functions for generation of parameters.

Variable	
w_{ij}	U(3,10)
q_{ij}	U(0.02,.07)

p_{ij}	U(150,350)
t_{ij}	U(.1,.15)
D_j	U(50000,70000)
Q_j	U(.07,.09)
C_{ij}	U(40000,50000)

The sample problem was coded in Lingo with 10 suppliers and 3 products, and a total of 30 Pareto solutions were obtained. Afterwards, using TOPSIS, the resulting Pareto solutions were ranked.

The TOPSIS method steps are enumerated in the following (Chen et al., 2006).

1- Formation of a normal matrix using the Euclidean norm method

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

2- Formation of a weighted normal matrix

3- Determining the positive and negative ideal solutions

$$A^+ = \left\{ V_1^+, V_2^+, \ldots, V_j^+, \ldots, V_n^+ \right\}$$

$$A^- = \left\{ V_1^-, V_2^-, \ldots, V_j^-, \ldots, V_n^- \right\}$$

4- Calculating the dissociation (distance) for each positive and negative solution

$$d_{i+} = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^+ \right)^2 \right\}^{0.5} ; i = 1,2,\ldots, m$$

$$d_{i-} = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^- \right)^2 \right\}^{0.5} ; i = 1,2,\ldots, m$$

5- Calculating relative closure based on the ideal solution for each option

$$cl_{i+} = \frac{d_{i-}}{\left(d_{i+} + d_{i-} \right)} \quad ; 0 \le cl_{i+} \ge 1 \quad i = 1,2,\ldots, m$$

The criteria considered for assessment of Pareto solutions included the first objective function, the second objective function, the third objective function, and the fourth objective function. The results were presented in two states: when all of the criteria are weightless, and when all of the criteria are weighted. The criteria weights were determined as follows after consulting the experts.

Table 14.

Criterion	Objective 1	Objective 2	Objective 3	Objective 4
Weight	0.35	0.15	0.30	0.20

In the weightless criteria case, Pareto solution no. 24 was selected as the best solution with utility coefficient of 0.603. This solution was followed by solutions no. 18 and 16 with respective utility coefficients of 0.60 and 0.583. As seen, the utility coefficients of solutions 24 and 18 are very close.

Pareto solution no. 24 is given in the following.

Table 15.

Supplier	First product	Second product	Third product
Supplier 1	0	0	49100
Supplier 2	0	31629	0
Supplier 3	0	4407	0
Supplier 4	6782	0	12225
Supplier 5	26890	31650	8004
Supplier 6	0	417	0
Supplier 7	0	0	1671
Supplier 8	0	1261	0
Supplier 9	2312	0	0
Supplier 10	31016	636	0

With weighted criteria, Pareto solution no. 4 was selected as the solution with a utility coefficient of 0.647. This was followed by solutions 25 and 26 with respective utility coefficient of 0.637 and 0.635.

Pareto solution no. 4 is given in the following.

Table 16.

Supplier	First product	Second product	Third product
Supplier 1	0	0	0
Supplier 2	0	0	0
Supplier 3	0	0	0
Supplier 4	0	0	36710
Supplier 5	38165	46440	34290

Supplier 6	28835	0	0
Supplier 7	0	0	0
Supplier 8	0	23560	0
Supplier 9	0	0	0
Supplier 10	0	0	0

4- Sensitivity Analysis

Sensitivity analysis of each model under certain conditions and comparison of performances of that model under other conditions is a reliable way of determining the model's efficiency and discovering the critical conditions under which the model is unreliable. This method is, in fact, a kind of calibration of the model under actual conditions (Maleknezhad& Kothari, 2008).

As seen in the previous section, as the objective function's weight changes the TOPSIS-selected Pareto solution varies. Hence, for the purpose of sensitivity analysis, each objective function is set to 0.4 and the coefficients of other objective functions are set to 0.2. Next, the number of selected suppliers in the selected Pareto solution is examined. The related weights in the four states are as follows.

Table 17.

Criterion	Objective 1	Objective 2	Objective 3	Objective 4
State 1	0.4	0.2	0.2	0.2
State 2	0.2	0.4	0.2	0.2
State 3	0.2	0.2	0.4	0.2
State 4	0.2	0.2	0.2	0.4

Table 18.

Criterion	Supplier	No.	Product 1	Product 2	Product 3
State 1	Selected quantity	17	2	3	2
	No.		5, 8	1, 7, 8	1, 5
State 2	Selected quantity	13	4	5	6
	No.		2, 3, 7, 10	1, 2, 7, 8, 10	1, 2, 3, 5, 6, 8

State 3	Selected quantity	14	2	2	2
	No.		5, 9	3, 8	1, 9
State 4	Selected quantity	3	2	2	2
	No.		3, 7	1, 10	1, 8

As seen, by assuming a high importance for objective function 2 (i.e. defective items) to increase the product quality, the model is trying to increase the number of suppliers. This result suggests that quality is a highly important factor in the importance of the product (which is a drug). Figures (1) and (2) depict the graphic views of changes made in the sensitivity analysis section.

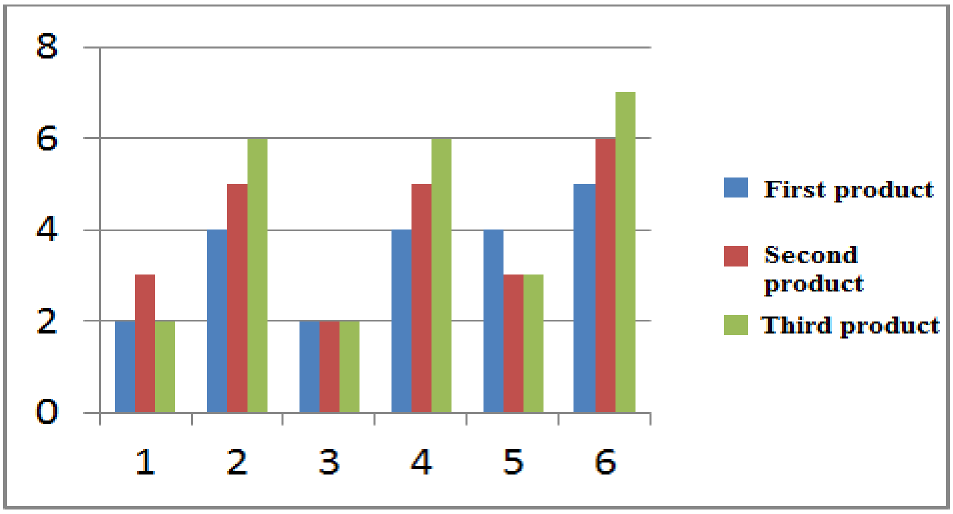

Figure 1: The number of selected suppliers for each product in each state.

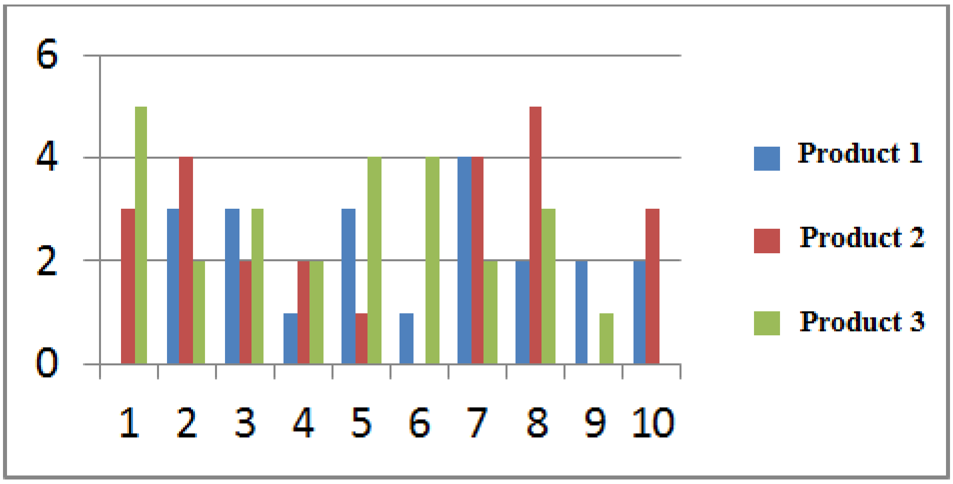

Figure 2: The number of selected suppliers for each product in each state.

5- Results and Future Work Recommendations

This paper presents a multi-product model for supplier selection and allocation of orders in the supply chain. All of the quantitative, qualitative, and environmental factors were taken into account. The proposed model is an integrated model, which is similar to real models. This model was solved using the epsilon-constraint algorithm and was coded in Lingo. A sensitivity analysis was conducted on the weights of objective functions and the results were reported. It is recommended to add other objective functions in accordance with the conditions. Changing constraints, considering fuzzy objective functions, and solving the model with meta-heuristic algorithms are also recommended for future research. We hope our integrated systematic model is utilized by pharmaceutical companies.

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Corresponding Author:

Ali Nazeri*,

Email: *nazeri@damavandiau.ac.ir*