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A Multi-Product Inventory Model for Selecting the First and Second Layers of Suppliers in a Supply Chain

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ABSTRACT

In recent years, Supplier evaluation and selection, an important element in supply chain management, has been gaining attention in both academic literature and industrial practice. The Mixed integer multi-Objective non-Linear programming model (MIMONLP) presented in this paper aimed to evaluate and select the appropriate set of suppliers considering quantitative and qualitative criteria and in addition to selecting the first layer's suppliers which relate directly to the organization, analyses the characteristics of second-layers suppliers, and design a network to determine the flow rate of products and materials between buyers and best suppliers in both layers. Another important feature of this model is considering holding costs of different products over the planning horizon and quantity discounts for the first layer's suppliers at the same time. Finally, the model is solved by using goal programming approach and numerical examples are presented to test the performance of proposed model.

1. Introduction

High competitive environment not only offers new business opportunities for companies but also challenges companies to optimize their business processes to remain competitive. Competition is not between individual organizations but between competing supply chains [1].

A supply chain is an interlinked network of suppliers, manufacturers, distributors and customers whereby materials or services flow from the suppliers through manufacturers and distributors to the customers.[7]

Several scholars have suggested that the use of economics methods can further increase the effectiveness of SCM [2, 3, and 4]

Outsourcing activities that are not core to the business could be one of these methods. Actually Outsourcing takes place when an organization transfers the ownership of traditional functions and value-added activities to a vendor. In general, it is particularly useful if (i) specialized skills are required, (ii) the organization is to focus on its core competencies [5,6], and (iii) the outsourcing partner is able to deliver products or services quicker and more reliably, at less cost, or at consistently better quality.

When an organization decided to outsource a part or parts of its services to other companies, one of the most critical steps facing with is supplier selection that is a key and strategic decision. This stage always prone to error. Selection of appropriate suppliers is one of the fundamental strategies for enhancing the output quality of any organization, which has a direct influence on the company's reputation [7].

For many manufacturing enterprises, supplier selection decisions, is an important part of supply management and production. Selecting appropriate suppliers will significantly reduce the costs of purchasing materials and improve competitive conditions. For this reason, experts believe that supplier selection is the most important activity of purchasing department [6].

This selection includes evaluating different criteria that has changed during the past 50 years (1966 onwards).

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Also various approaches and models have been used to solve the problem which always choose the first layer's suppliers and pay no attention to the second layer's suppliers. Although the academic studies have not paid to this issue, raw materials have an important influence on quality and price of final components and the suppliers of suppliers as one of supply chain's members can influence on effectiveness and competitiveness of supply chain.[8] So buyers can determine the best second layer's suppliers by evaluating them in various criteria and suggest them to their direct suppliers when contract them, or they can refer to this as one of the clauses in the contract.

In this paper, in addition to suppliers that relate directly to the company, providers of these suppliers are examined too and the best suppliers in both layers are selected. Also the model, considers the holding costs of different products over the planning horizon and the optimum order quantity supplied from each supplier to the buyer's plant in each sub-period and the optimum number of replenishment in the planning horizon will be obtained.

The remainder of this paper is organized as follows. Section 2 gives a literature review on supplier selection methods. Section 3 describes the proposed model. Solving model by using goal programming is presented in Section 4. In section 5 Numerical results are presented and analyzed. Finally conclusions and future research are given in Section 6.

2. Literature Review

Supplier selection is one of the most widely researched areas in purchasing with methodologies ranging from conceptual to empirical and modelling streams [9].

Supplier selection decisions are complicated by the fact that various criteria must be considered simultaneously in the decision-making process. The first publications can be traced back to the early 1960s. Dickson has identified 23 important criteria in the study of supplier decision making and those criteria still cover the majority of the criteria presented in the literature until today. But the evolution of the industrial environment has modified the degrees of the relative importance of them [10].

Also a classification of all published papers was presented by Weber et al. (1991) [11], based on 74 papers, shows that 'price', 'delivery', 'quality', 'production capacity and location' are the criteria most often treated in the literature.

With the advent of supply chain management, much attention is now devoted to supplier selection. In the supplier selection process, there are four important phases: (1) problem definition (2) defining the criteria (3) pre-qualifying suitable suppliers (4) making a final choice. Most literature on supplier selection focuses on pre-qualifying suitable suppliers and making a final choice.

The three evaluation models for supplier selection feature prominently in the literature are MADM models, artificial intelligence models and mathematical programming models (Table I). Each of these is discussed below:

3. MADM Models

Multi-attribute decision making models such as AHP, ANP, TOPSIS, MAUT and …, evaluate potential suppliers using several weighted factors, and then allow the decision-maker to choose the supplier with the highest total score. [11]

3-1. Mathematical-Programming Models

Mathematical models can be used to formulate the supplier selection problem in terms of an objective function to be maximized (for example, profit) or minimized (for example, costs) by varying the values of the variables in an objective function.

Several papers have used MP techniques. These include linear Programming, goal programming, mixed integer programming and multi-objective programming to solve the supplier selection issue. Most of these MP models took cost as the objective function, with other Criteria (such as quality, capacity, delivery, and so on) being taken into account as constraints [12]. On the one hand, it may be argued that MP-models are more objective than rating models because they force the decision-maker to explicitly state the objective function and they often only consider the more quantitative criteria.

3-2. Artificial Intelligence Methods

The artificial intelligence (AI) methods can cope better with complexity and uncertainty than 'traditional methods', because they are designed to be more like human judgment functioning. In AI systems, users only have to provide the information on performance of a supplier on the criteria.

AI-based models are based on computer-aided systems that in one way or another can be trained by a purchasing expert or historic data. Subsequently, non-experts who face similar but new decision situations can consult the system.

Also researchers have used the combination of these methods to rank the suppliers. Table1 shows the supplier selection methods and examples.

Several researchers combine supplier selection and procurement lot-sizing by considering a multi-period planning horizon and defining variables to determine the quantity purchased in each elementary period [13]. In 2005, Basnet & Leung [14] proposed a mathematical model which ranked the suppliers considering inventory costs. The model was a multi-period problem with no limitation on storage capacity and of supplier's production capacity. In fact, the most important advantage of this model is the integration of inventory models and supplier selection. Erick Sucky

[15] presented a dynamic multi-period model which determined the best suppliers and the optimum order quantity product. Liao & Rittscher [16] integrated supplier selection, procurement lot sizing and carrier selection decisions for a single purchasing item.

In 2008, Rezaie & Davoodi proposed a multi-period model considering inventory costs and defective products. [17]

Demirtas [18] presented a multi-period inventory lot sizing scenario, where there is only single product.

Tab. 1. Supplier selection methods and examples

category	method	example
MP	LP	[19],[20]
	GP	[21],[22]
	Non-LP	[23]
	MIP	[24]
	MOP	[25],[26]
MADM	AHP	[27]
	ANP	[28]
	TOPSIS	[29]
	MAUT	[30]
AI	Neural network	[29],[31]
	Decision tree	[32]
	CBR	[33]
Hybrid methods	AHP+LP	[30]
	ANP+Fuzzy+MOLP	[34]
	ANP+MOP+MIP+GP	[35]
	Neural network+DEA	[36],[37]
	Neural network +Decision tree+DEA	[38]
	Fuzzy+AHP	[39]

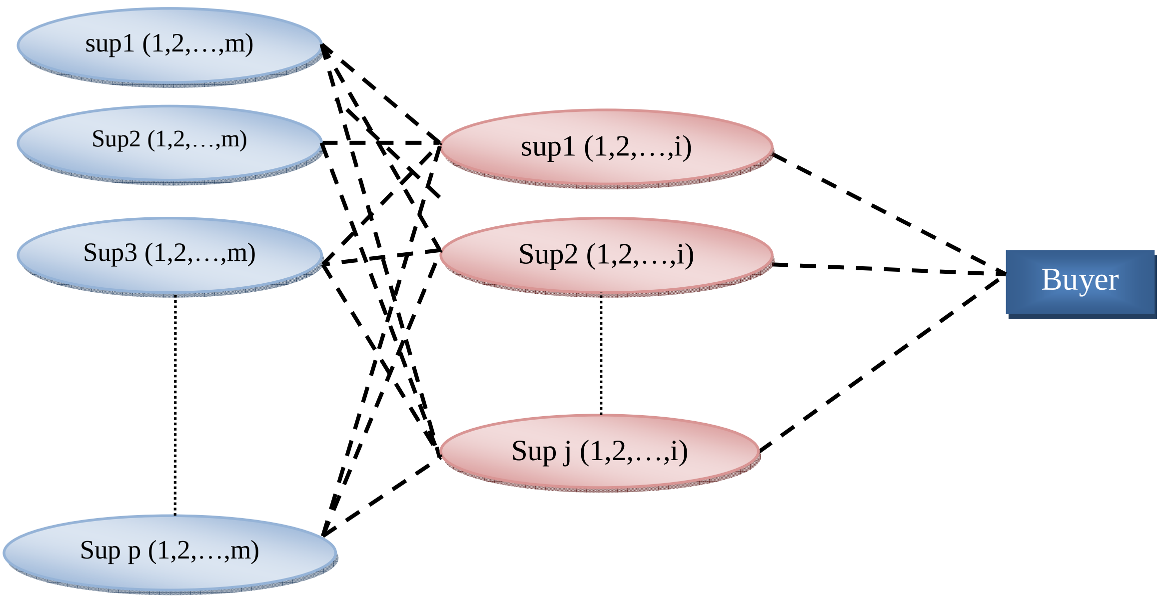

Fig. 1. First and second layers of a supply chain in a supply network

4. Formulation and Mathematical Modelling

In this paper we consider the case in which a set of J suppliers is available for a company and the buyer purchases different semi-products from them. As depicted in figure 1 those suppliers purchases their required materials from the second layer's suppliers too. Hence, the second layer's suppliers play an important role in supply chain's effectiveness and the quality of used materials will affect the final products.[40]

As mentioned in previous sections, supplier selection is a multi-criteria decision making problem and the decision maker wants to optimize different objective functions simultaneously. The proposed model aimed

at minimizing the total costs (purchase costs, inventory holding cost, ordering costs), the total quality rejected items and the total late deliveries in both layers and tries to design a network to determine the optimum order quantity of products to the selected suppliers in both layers.
In this section, we formulate a mathematical model of the supplier selection decision under the conditions of a multi-supplier quantity discount.

The supplier information is denoted as follows:
Indices:
J: set of first layer's suppliers
P: set of second layer's suppliers
I: set of product to be purchased
M: set of raw materials
K: set of price levels

4-1. Model Parameters:

A_{mi} = Consumption ratio of material m in product i

q_{ij} = quality that supplier j maintains for product i. (percent of defect products)

l_{ij} = lead time of supplier j to supply product i. (percent of late deliveries)

c_{ijk} = cost of buying one unit of product i from supplier j at price level k.

s_{ij} = supply capacity of supplier j for product i.

Q_{mp} = quality that supplier p maintains for material m. (percent of defect products)

L_{mpj} = lead time of supplier p to produce and supply material m to supplier j. (percent of late deliveries)

b_{ijk} = the kth price level from supplier j for product i.

C_{pm} = cost of buying one unit of material m from supplier p.

S_{pm} = supply capacity for supplier p for material m.

D_j = the buyer's demand for product i.

D_{jmi} = the jth supplier's demand for mth material to provide ith product.

f_j = fixed ordering cost associated with jth supplier

h_j = holding cost of ith product.

x_{ijk} = number of units of product i purchased from supplier j at price level k.

$z_{ijk} = \begin{cases} 1. & \text{if the jth supplier is selected for providing ith product at price level k.} \\ 0. & \text{Otherwise} \end{cases}$

ypmij = number of units of mth material supplied by vendor p to supplier j for providing product i.

n_{ij} = the number of replenishments of product i from supplier j in a planning horizon.

d_{ij} = total amount of product i supplied by supplier j in a time horizon.(a finite time horizon is consists of several periods.)

4-2.Objective Function:

$$MIN\left[w_1\left(\sum_i\sum_j\sum_k q_{ij}\times x_{ijk}\right) + w_2\left(\sum_p\sum_m\sum_i\sum_j Q_{mp}\times y_{jipm}\right)\right] \quad (1)$$

$$MIN\left[w_1'\left(\sum_i\sum_j\sum_k l_{ij}\times x_{ijk}\right) + w_2'\left(\sum_p\sum_m\sum_i\sum_j L_{jpm}\times y_{jipm}\right)\right] \quad (2)$$

$$MIN\left[\left(\sum_i\sum_j n_{ij}\times\sum_k (c_{ijk}\times x_{ijk})\right) + \sum_i\sum_j (n_{ij}\times f_j) + \sum_i\left(\frac{v_i}{2}\times\sum_j\sum_k x_{ijk}\right)\right] + \sum_i\sum_j\sum_p\sum_m c_{pm}\times y_{jipm} \quad (3)$$

Subject to:

$$D_i = \sum_j d_{ij} \qquad \forall i \quad (4)$$

$$d_{ij} \leq \quad n_{ij} \times \sum_{k} x_{ijk} \quad \forall i, j \tag{5}$$

$$\sum_{p} y_{jipm} \geq \quad D_{jmi} \quad \forall i, j, m \tag{6}$$

$$D_{jmi} = A_{mi} \times d_{ij} \quad \forall i, j, m \tag{7}$$

$$d_{ij} \leq s_{ij} \quad \forall i, j \tag{8}$$

$$\sum_{j} \sum_{k} x_{ijk} \leq \quad S_{ji} \quad \forall i, j \tag{9}$$

$$\sum_{i} \sum_{j} y_{jipm} \leq \quad S_{pm} \quad \forall m, p \tag{10}$$

$$\sum_{p} \sum_{m} y_{jipm} \leq \quad M \times \sum_{K} z_{ijk} \quad \forall i, j \tag{11}$$

$$b_{ijk-1} \times z_{ijk} \leq x_{ijk} \leq b_{ijk} \times z_{ijk} \quad \forall i, j, k \tag{12}$$

$$\sum_{k} z_{ijk} \leq 1 \quad \forall i, j \tag{13}$$

$$x_{ijk}, y_{jipm} \geq 0 \quad , \quad z_{ijk} = 0,1 \quad n_{ij} \geq 0, \text{ integer} \tag{14}$$

The multi-objective problem includes a set of goals that should be a simultaneous trade-off. Objective function (1),(2) minimizes the number of rejected and late delivered products and materials from the both layer's suppliers. Objective function (3) minimizes the purchase costs for all products and materials and the holding costs.

Constraint (4, 5) puts restrictions due to the overall demand of products.

Constraint (6) puts restrictions due to the overall demand of materials.

Constraint (7) determine the demand of supplier j for material m to provide product i.

Constraint (٨, 9) puts restrictions due to the maximum capacity of the first and second layer's suppliers.

Constraint (10) ensures that if a supplier is not selected, the suppliers of that suppliers won't be selected.

Constraint set (11) is a quantity range constraint to meet the number of quantity ranges in a supplier's price level. Constraint set (12) represents the price level per supplier among which can be chosen only one or none.

Constraint set (13) is to prohibit negative orders. The proposed model is employed to rank suppliers and allocate orders.

5. Goal Programming

Goal programming is one of the widely used methods in solving multi-objective models. In 1985, Charles and Looper published an article about this method for the first time. Goal programming is concerned with the condition of achieving pre specified goals as closely as possible.

$$\min\ z = d_1^+ + d_2^+ + d_3^+ \tag{15}$$

$$MIN\left[w_1\left(\sum_i\sum_j\sum_k q_{ij} \times x_{ijk}\right) + w_2\left(\sum_p\sum_m\sum_i\sum_j Q_{mp} \times y_{jipm}\right)\right] + d_1^- - d_1^+ = qualitygoa \tag{16}$$

$$MIN\left[w'_1\left(\sum_i\sum_j\sum_k l_{ij} \times x_{ijk}\right) + w'_2\left(\sum_p\sum_m\sum_i\sum_j L_{jpm} \times y_{jipm}\right)\right] + d_2^- - d_2^+ = deliverygoal \tag{17}$$

$$MIN\left[\left(\sum_i\sum_j n_{ij} \times \sum_k (c_{ijk} \times x_{ijk})\right) + \sum_i\sum_j (n_{ij} \times f_j) + \sum_i\left(\frac{v_i}{2} \times \sum_j\sum_k x_{ijk}\right)\right] \tag{18}$$
$$+ \sum_i\sum_j\sum_p\sum_m c_{pm} \times y_{jipm} + d_3^- - d_3^+ = pricegoal$$

6. Numerical Example

Suppose a purchase manager would like to buy a set of products from four suppliers with information as given in Table2.

Tab. 2. Different kinds of products and materials each supplier produces.

First layer suppliers	products	Second layers suppliers	materials
1	1,4	1	2,3,4
2	1,2,4	2	1,4
3	3,4	3	2,3
4	1,2,3	4	1,3,4

Tab. 3. Consumption ratio of various raw materials in each product

	Material 1	Material 2	Material 3	Material 4
Product 1	0.3		0.7	
Product 2	0.2	0.2		**0.6**
Product 3		0.5	0.5	
Product 4			0.6	**0.4**

According to the objective function (14) and the constraints (4)-(13) and (15)-(17) the example is solved by Gams22 and the computational results, obtained by the designed mathematical model are reported in Tables 4.

Tab. 4. Computational results

n_{ij}	x_{ijk}	y_{jipm}
$n_{11} = 5$	$x_{111} = 1000$	$y_{1141} = 1500$, $y_{1133} = 200$, $y_{1143} = 3300$
$n_{41} = 5$	$x_{411} = 600$	$y_{1414} = 800$, $y_{1424} = 400$, $y_{1433} = 1800$
$n_{42} = 6$	$x_{422} = 833$	$y_{2433} = 1200$, $y_{2443} = 1800$, $y_{1424} = 2000$
$n_{33} = 5$	$x_{331} = 800$	$y_{3312} = 2000$, $y_{3333} = 2000$
$n_{24} = 10$	$x_{241} = 700$	$y_{4241} = 1400$, $y_{4214} = 4200$, $y_{4212} = 1400$

NO.	i	j	p	m	Optimum number of replenishment	Selected suppliers
1	3	3	3	4	$n_{11}=6, n_{12}=5$ $n_{21}=2, n_{22}=2$ $n_{23}=10, n_{32}=4$	$x_{112}=1000, x_{133}=800$ $x_{213}=1500, x_{223}=2500$ $x_{233}=700, x_{323}=2000$
2	3	4	4	3	$n_{11}=5, n_{13}=10$ $n_{21}=2, n_{22}=7$ $n_{32}=6, n_{33}=5$ $n_{34}=10$	$x_{113}=600, x_{133}=1000$ $x_{213}=1000, x_{223}=1000$ $x_{322}=700, x_{332}=1000$ $x_{343}=1400$
3	4	4	4	4	$n_{12}=5, n_{13}=7$ $n_{21}=10, n_{22}=7$ $n_{24}=5, n_{32}=4$ $n_{33}=10, n_{34}=4$ $n_{41}=7, n_{44}=4$	$x_{123}=700, x_{133}=500$ $x_{212}=650, x_{223}=500$ $x_{243}=400, x_{323}=1250$ $x_{333}=1500, x_{343}=1250$ $x_{412}=1000, x_{442}=500$
4	3	3	5	5	$n_{11}=5, n_{12}=10,$ $n_{13}=5, n_{21}=10,$ $n_{22}=2, n_{31}=1,$ $n_{32}=2, n_{33}=4$	$X_{113}=600, X_{123}=700,$ $X_{133}=1000, X_{213}=650,$ $X_{222}=1250, X_{311}=2500,$ $X_{321}=1250, X_{333}=1250$
5	4	4	5	5	$n_{12}=5, n_{14}=2$ $n_{21}=5, n_{23}=10$ $n_{24}=1, n_{31}=2$ $n_{32}=7, n_{41}=5$ $n_{43}=3, n_{44}=10$	$x_{123}=700, x_{143}=750$ $x_{212}=1000, x_{233}=850$ $x_{243}=2500, x_{313}=2000$ $x_{323}=1000, x_{413}=300$ $x_{433}=500, x_{441}=700$
6	5	5	6	6	$n_{12}=6, n_{14}=9$ $n_{21}=2, n_{23}=10$ $n_{31}=4, n_{35}=10$ $n_{32}=7, n_{41}=5$ $n_{43}=3, n_{44}=10$ $n_{55}=10$	$x_{121}=500, x_{143}=500$ $x_{212}=1250, x_{233}=650$ $x_{313}=1250, x_{353}=650$ $x_{423}=1000, x_{433}=550$ $x_{511}=300, x_{531}=350$ $x_{552}=1000$

7	**4 5 6 6**	$n_{11} = 7$, $n_{13} = 4$	$x_{113} = 500$, $x_{133} = 1250$
		$n_{22} = 5$, $n_{24} = 10$	$x_{223} = 1250$, $x_{241} = 550$
		$n_{31} = 8$, $n_{35} = 10$	$x_{311} = 500$, $x_{352} = 6500$
		$n_{42} = 5$, $n_{43} = 1$	$x4_{323} = 700$, $x_{433} = 2500$
		$n_{44} = 7$	$x_{443} = 500$
8	**6 6 7 6**	$n_{11} = 7$, $n_{16} = 5$	$x_{113} = 500$, $x_{162} = 900$
		$n_{22} = 10$, $n_{25} = 5$	$x_{223} = 550$, $x_{251} = 600$
		$n_{33} = 10$, $n_{34} = 9$	$x_{333} = 550$, $x_{343} = 500$
		$n_{41} = 4$, $n_{46} = 5$	$x_{412} = 1500$, $x_{462} = 700$
		$n_{52} = 9$, $n_{55} = 5$	$x_{523} = 500$, $x_{553} = 1000$
		$n_{63} = 10$, $n_{64} = 10$	$x_{633} = 550$, $x_{643} = 500$
9	**7 7 8 8**	$n_{13} = 2$, $n_{17} = 5$	$x_{133} = 650$, $x_{172} = 900$
		$n_{22} = 5$, $n_{25} = 8$	$x_{223} = 400$, $x_{257} = 500$
		$n_{31} = 3$, $n_{36} = 9$	$x_{313} = 1000$, $x_{363} = 600$
		$n_{41} = 6$, $n_{44} = 4$	$x_{412} = 500$, $x_{442} = 1000$
		$n_{52} = 7$, $n_{55} = 5$	$x_{523} = 550$, $x_{553} = 400$
		$n_{63} = 10$, $n_{66} = 9$	$x_{633} = 1000$, $x_{663} = 500$
		$n_{74} = 1$, $n_{77} = 10$	$x_{742} = 2000$, $x_{771} = 450$
10	**8 8 9 9**	$n_{11} = 10$, $n_{14} = 8$	$x_{113} = 250$, $x_{142} = 400$
		$n_{22} = 1$, $n_{28} = 4$	$x_{223} = 1500$, $x_{283} = 1250$
		$n_{33} = 9$, $n_{35} = 3$	$x_{333} = 500$, $x_{353} = 1000$
		$n_{41} = 5$, $n_{47} = 5$	$x_{412} = 600$, $x_{473} = 600$
		$n_{56} = 5$, $n_{58} = 10$	$x_{561} = 700$, $x_{583} = 400$
		$n_{62} = 10$, $n_{67} = 7$	$x_{623} = 550$, $x_{673} = 500$
		$n_{73} = 10$, $n_{74} = 1$	$x_{731} = 250$, $x_{741} = 2000$
		$n_{93} = 6$, $n_{96} = 6$	$x_{833} = 500$, $x_{862} = 500$

7. Conclusions

Supplier selection problems have been solved by several methods. The main ones are MP, AI, and MADM and…. This paper studies the integration of the supplier selection and inventory problem. A mathematical programming model is developed to determine the best suppliers, when and how much to order.

Being different from previous studies, this paper presents a non linear multi-objective model which considers multi-products and several suppliers in first and second layers of supply chain and allocates the optimum order quantity to them. Also, due to considering inventory costs for different products the model can be assumed as a multi-period one and according to storage space limitation and suppliers limited capacities in both layers, the buyer can receive products from selected suppliers in several sub-periods. The model is useful for solving supplier selection problem in a supply chain or logistic management when the quality of products is very important and the company care about the second layer's suppliers. As a future research the integration will be extended under stochastic demand conditions.

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