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A multi-product model in green supplier selection with hard delivery time window

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Abstract

During recent years, supplier selection process in the supply chain has become a key strategic consideration. Increasing worldwide awareness of environmental protection and the corresponding raise in legislation and regulations, green purchasing has become an important issue for companies to gain environmental sustainability. This paper presents an interesting idea, proposing a multi-product model to solve the multiple sourcing green suppliers' problems. The goal of our model is minimizing the costs due to environmental pollutions, purchasing and transportation. Time window constraints which are assumed in this paper have lots of real world applications. However, in supply selection problems, it is given little importance. Thus, for on time delivery to customers, we use this constraint in our mathematical model. In this study, a nonlinear mixed integer programming model (MINLP) provided and has been resolved using by software GAMS. Finally, a numerical example is presented and its results are analyzed latter.

Keywords:
Supply chain, multi-product, green suppliers, time window.

1- Introduction

In a competitive environment, selection of suppliers represents one of the most critical issues that manufacturing firms have faced. Cost of various parts and raw materials in such industries comprises the major portion of a product's final cost, as well as purchasing costs that can significantly be reduced when appropriate suppliers are selected. Reduction of production costs is significant factor survived in today competitive environment [1-4]. Chai, Liu, and Ngai (2013) provided a systematic literature review on 123 journal articles published from 2008 to 2012 on the application of decision making (DM) techniques for supplier selection. They indicated that the most frequently used technique is AHP followed by linear programming (LP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [5]. Wu and Barnes (2011) reviewed the literature on supply partner decision-making published between 2001 and 2011 and concluded that the most famous combined approaches for the supplier selection problem are models that include mathematical programming, AHP/ANP, or fuzzy set approach [6].

Due to increasing awareness among people to protect the environment and governmental legislation, if firms want to maintain their competitive advantages in this globalization trend, they cannot ignore environmental issues. Growing environmental concerns means that it is necessary to consider environmental pollution issues including industrial development in supply chain management activities, leading to the emerging concept of green supply chain management (GSCM) [7-8]. In recent years, companies have implemented several regulatory checks and programs to ensure that suppliers would provide materials and services both with high quality and also dedicated to environmental standards [9]. GSCM is generally recognized as monitoring suppliers based on their environmental performance and having collaboration only with green suppliers that satisfy environmental standards [7]. Hence, studies that propose supplier selection based on the supplier's adoption of GSCM practices, a modern environmental sustainability concept, is yet to be done. GSCM offers an expanded perspective on environmental management that considers practices adopted both inside and outside the company [10], therefore this approach can generate more business opportunities for firms [11]. This new legislation requires firms and municipalities to adopt proactive green management values and practices, and companies are feeling pressured to enact these environmentally sensitive practices in a timely manner [12]. More authors have addressed supplier selection issues in green supply chain from environmental aspects increasingly [13-18].

Essentially, two types of supplier selection are prominent:

- ✓ In the first type (single sourcing), one supplier can satisfy the entire buyer's needs and the buyer needs to make only one decision, which supplier is the best.
- ✓ In the second and more common type (multiple sourcing), more than one supplier must be selected because no single supplier can satisfy all the buyer's orders.

Supplier selection process involves a set of activities such as identifying, analyzing, and choosing suppliers to become a layer of the supply chain. Suppliers who adopt GSCM practices can strengthen the environmental performances of companies throughout the entire supply chain. Addressing the environmental criteria during supplier selection process is even more important in developing countries because of the difficulties and barriers, companies in these countries face [19].

Moreover, due to the adverse environmental effects, many issues have been raised in the field of green supply chain improvement.

Green supply chain management is not a concept agreed by all researchers [20]. However, the majority of authors believe that it emerges from the ideas that companies must become greener [21], must try to reach a win–win perspective [22] and must link the supply chains and sustainable development [23]. The concepts of GSCM emerged from the realization that isolated implementations of environmental practices by companies are not as effective as collective actions that make the entire supply chain greener [10]. This broader systematic perspective of environmental management dispersed among all players in a supply chain has been called GSCM [24]. This concept is a part of the broad effort to align operations management with the goal of improving the quality of life in society and it is a theme that requires more attention and emphasis in future studies [25]. GSCM is, therefore, a part of the environmental dimension of the Sustainable Supply Chain Management (SSCM) concept [26]. SSCM can be defined as the management of materials, the distribution of information, the flow of capital, and cooperation among companies in a supply chain as they strive to improve their economic, environmental, and social performances while simultaneously considering the expectations of other stakeholders [26]. The interest of the scientific community in this subject is increasing quickly [23].

The increased inclusion of environmental considerations in the fields of operations management and supply chains has become a strong trend [27].

One of the most important GSCM practices is to choose environmental considerations in supplier selection, maintenance, and development [28].

There are many others studies that discuss green supplier selection. For example, Large and Thomsen (2011) utilized data from more than 100 German companies and discovered that the degree of green supplier assessment and the level of green collaboration directly influence a company's environmental performance [29]. These two practices are driven at the strategic level by the purchasing department and through the firm's level of environmental commitment. Other researchers have consistently indicated that including environmental considerations in supplier selection is a fundamental practice among organizations that strive for sustainability [30].

Growing urbanization, industry (especially supporting industry) make good and human transportation complicated. Moreover, urban growth increases the demand and distribution companies in transportation industry one the one hand, each distributor seek maximum profit and on the other hand, they face problems such as traffic congestion, wasting time in daily trips, increasing fuel consumption and depreciation of vehicles. Thus, a system will be efficient, if it can achieve customer satisfaction by providing timely service [31].

One of the important factors in supply selection is product delivery time. In the researches, this factor was considered qualitatively and solved by decision methods. In this article by using time window constraint in the proposed mathematical model, Product delivery time is limited and suppliers have to deliver products to customers at the specified time.

Time window models is divided into three general kinds:

Hard time window: In this time window, Distribution network requires to serve the customer in a given time period. There exists a service time period $[e_i, l_i]$ for each customer i which represents e_i and l_i as allowed earliest and latest starting time of serving customer i respectively. Service must be done necessarily in this particular time interval and the services beyond the provided time interval has infinite cost.

Soft time window: in this time window, there is a possibility to serve customers beyond the specified time interval, but the penalty assigned for each unit of violation in the time window must be paid. Feasible solution space in this case is greater than hard time window.

Hard and soft time window: it's a combination of both hard and soft time window. So that each time window involves a soft interval and a hard interval; but the hard one must not be violated [32].

In the following section, the considered problem is described in detail and a mixed-integer nonlinear programming model (MINLP) is represented afterwards. In the third section, a numerical example is represented to evaluate the accuracy of the mathematical model and sensitivity analysis of this model is also described. Some conclusions and recommendations are given in the final section of this article.

2- The proposed MINLP green model

The aim of this study is to improve product quality, reduce supply chain and reduce environmental effects. The objective function for this research is to minimize costs (environmental cost, purchasing cost and transportation cost). Environmental dimensions in supplier selection problem in green supply chain is taken into account from two perspectives: Costs caused by pollutants of each supplier and costs caused by pollutants of each transportation vehicle. Time window constraint in order to timely product access to customer is also considered.

Assumptions

- ✓ The problem is single period.
- ✓ The objectives of the model includes minimization of costs (transportation cost, the purchase good and environmental costs).
- ✓ The suppliers are independent and each supplier can provide all or a part of buyers' demand.
- ✓ Each supplier has a limited production capacity.
- ✓ The problem is considered as a multi-product one and there is the possibility of ordering a combination of different products simultaneously.
- ✓ Buyer's demand for each product (good) is determined and predefined.
- ✓ Greenhouse gas emissions are considered as an environmental problem due to economic aspects in the chain.
- ✓ Hard time window is considered in constraints.
- ✓ Vehicle's velocity is determined based on types of product (less time for perishable products).

Indexes

Suppliers	i
Transportation routes	j
Product	m

Parameters

Pollutant production cost by supplier i for a unit of product m	o_{im}
Pollutant production cost by transportation facilities for a unit of product m by supplier i	f_{im}
Transportation cost per unit of product m in route j from supplier i to purchaser	t_{imj}
Cost of purchasing a unit of product m from supplier i	c_{im}
Capacity of supplier i for product m	ca_{im}
Capacity of route j	a_j
Customer demand for product m	D_m
Distance between supplier and customer in route j	DI_j
Transportation vehicle speed	V
Maximum time for product delivery	B
Large enough arbitrary number	M

Decision variables

Amount of product m delivered from supplier i to customer in route j	x_{imj}
Binary variable is equal to 1 if route j is selected	y_j

Mathematical formulation

The proposed mathematical model is defined as follows:

$$\min Z = \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{j=1}^{J}(o_{im}+f_{im})x_{imj}$$

$$+\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{j=1}^{J} t_{imj}y_j \times x_{imj} + \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{j=1}^{J} c_i x_{imj}$$

st:

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{imj} \geq D_m \qquad \forall\, m \qquad (1)$$

$$\sum_{j=1}^{J} x_{imj} \leq ca_{im} \qquad \forall\, i, m \qquad (2)$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} x_{imj} \leq a_j \qquad \forall\, j \qquad (3)$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} x_{imj} \leq M \times y_j \qquad \forall\, j \qquad (4)$$

$$DI_j \times y_j \leq V \times B \qquad \forall\, j \qquad (5)$$

$$y_j = [0,1], x_{imj} \geq 0 \qquad (6)$$

In this model, the objective function minimizes environmental costs, transportation cost and purchasing cost.
Constraint 1 guarantees that customer demands of different products should be provided from suppliers.
Constraint 2 assures that the amount of products delivered from every supplier should be less than the capacity of that supplier.
Constraint 3 shows that each delivery route has limited delivered product from each route and it should not be more

than the specified capacity.
Constraint 4 assures that if a route is selected, product should be transported from that route
Constraint 5 shows the hard time window. Vehicle can be used only in specified time interval.
Constraint 6 identifies types and non-negativity of variables.

3- Computational experiment

In this section in order to evaluate the proposed mathematical model, a small-scale numerical example is generated randomly which involves two suppliers, different product and three different routes for product delivery. Table 1 shows customer demands for every product, Table 2 shows the capacity of supplier i for product m, Table 3 shows the capacity of route j. Also, the vehicle speed is 80 km/h and maximum time for product delivery is assumed to be 4 hours. The presented mathematical model was coded with GAMS software using BARON solver.

Table 1 - Demands

Customer demand for product 1	120
Customer demand for product 2	170

Table 2 - Capacity of supplier i for product m

Product		
1	2	
100	150	Supplier 1
70	100	Supplier 2

Table 3 - Capacity of route j

route j	Capacity
1	100
2	150
3	200

The optimal objective value for this example is 49700 and the variable values are shown in table 4.

Table 4 – Variable Values

$x_{111} = 60$	$x_{112} = 40$	$x_{122} = 50$
$x_{123} = 100$	$x_{211} = 20$	$x_{221} = 20$

In order to verify and validate the model, sensitivity analysis is done on the supply chain model. For this purpose, the buyer demand parameters for the product is defined in four applicants and the behavior of this model is checked applying these changes. According to the obtained results, the changes are shown on the graph and their process can be easily followed.
The following table 5 and figure 1 shows the objective function values changes by four buyer scenarios for products.

Table 5 – Result of Sensitivity Analysis

The first objective function	Demand for products		Different values
	2	1	
52000	200	100	Scenario 1
52500	240	120	Scenario 2
52666.667	400	340	Scenario 3

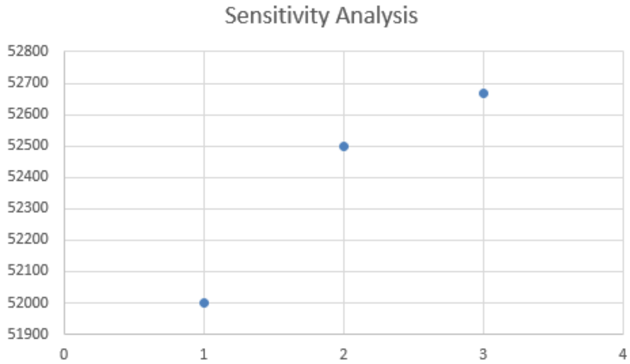

Figure 1- Sensitivity Analysis Chart

As we can see, increasing demand due to increasing purchasing cost, increasing environmental pollutants and transportation cost cause objective value to increase.

4- Conclusion and recommendations

It has been considered as a strategic factor in the supply chain how researchers can determine the most suitable supplier in recent years. The nature of these types of decision is usually complex and have no specific structure. Therefore, many qualitative and quantitative performance criteria such as quality, price, flexibility, delivery time and the green factor should be taken into consideration in order to determine the most appropriate supplier. It seems necessary to have a long-term relationship between suppliers and buyers in order to create an efficient and competitive supply chain.
In this study, the supplier selection in green supply chain is investigated by considering cost related to goals and environmental impact reduction. Environmental impacts from two perspectives is evaluated, which include reduction of gases produced by transportation facilities, depending on the circumstances of each track. Hard time window is also considered in order to in order to deliver timely product to the customer.
One of the main factors that makes model more realistic is the contribution of inventory costs that should be considered in future studies as well as parameters like demand that its uncertainties can be characterized by fuzzy numbers. For further validity, the model can be examined using other data related to industry, especially automotive industry.
Sustainability is also another important factors that can be considered in future model development and conducts subsequent researches. This factor have been introduced in the supply chain topics recently.

Social issues such as social justice and human rights should be contributed in future models as well as economic and environmental issues. Considering the social aspects in supply chain decisions allows us to better assess the effects of supply chain on stakeholders and shareholders (including employees, customers and local communities)

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