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The Development of a Multi-objective Model for Supplier Selection and Order Allocation in a Green Supply Chain under Uncertainty

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Abstract

In this research, the supplier selection problem and optimal order allocation considering environmental factors and uncertainties in demand are investigated. The objectives of the proposed problem include the minimization of environmental costs containing the costs of pollutants caused by any manufacturer and the costs of pollutants caused by transport, as well as the economic costs i.e. the costs of purchasing and transportation. In addition to the conventional constraints of supplier selection problem such as supply constraint, new constraints such as capacity constraint of shipping routes are considered. To solve the proposed problem, first using fuzzy chance−constrained programming model, mathematical model is transformed to a deterministic mathematical model. Then, to solve the deterministic mathematical model, the fuzzy multi-objective mathematical programming method is used. In this research, 18 problems are studied by considering a variety of suppliers, customers and transportation routes.

Keywords: Green Supply Chain, Supplier Selection; Fuzzy Chance Constrained Programming; Fuzzy Multi-objective Mathematical Programming

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Introduction

The supply chain is a system consisting of organizations, people, technology, activities, information and resources that like a chain rings, transfer a product or service from supplier to a customer. Therefore, the supply chain can be considered as a real system that transfers the raw materials and resources to the final customer. One of the most important issues in the supply chain that has always been considered by managers of organizations on the one hand and researchers on the other hand, is to select suppliers in the supply chain. The supply chain management always is seeking to optimize and manage the inventories, reduce risk, improve customers' satisfaction and higher profitability. Selecting suppliers play a major role in achieving these objectives. With globalization and the emergence of interdependent organizations, we are witnessed the increasing outsourcing of providing components and receiving services that this has led to more attention of mangers towards the practice of purchase. In today's highly competitive conditions that is defined by profit percentage of net sales, high customers' expectations for quality of products and low order processing time, companies have to take advantage of all opportunities to optimize their business processes (Aissaoui et al.,2007).

In achieving this objective, the researchers have obtained some results: to remain in the competition cycle and to improve supply chain performance, a company has to cooperate with its supply chain partners. One of the important tasks in this area that is on the responsibility of purchasing managers, is selecting appropriate suppliers (Aissaoui et al.,2007). Proper supplier selection will also result in added value (Khorasani, 2014).One of the areas that most companies have focused their attention to it, is the sourcing and purchasing management. The three important advantages of focusing on sourcing and purchasing management include: cost, quality and technology (Monczka, 1998). Given the importance of supplier selection in supply chain, this problem has been studied by many researchers. In the traditional approach for selecting suppliers that has been used for many years by various companies, only the economic measures are considered. Today with respect to trade globalization, a highly competitive market and the constantly changing demands of customers, the importance of focusing to other measures has become apparent. One of the issues that in recent years has been highly regarded, is the environmental factors. In the past two decades, the increasing attention is made to the importance of environmental impact and considering this impact along with traditional indices of supply chain. In this research, the suppliers selection problem and optimal order allocation with taking into account environmental factors is studied. Moreover, given that in the real world, demand is faced with uncertainty, in this research the uncertainty in demand with a fuzzy approach is considered. In order to close the proposed model with real-world situations, the capacity constraint of shipping routes is considered. Also in the proposed model in addition to the purchase and transport costs, the environmental costs including the cost of pollutants caused by any manufacturer and the cost of pollutants caused from transportation are also considered. In order to solve the proposed model, the fuzzy chance constrained programming and fuzzy multi-objective programming are used.

literature review

In the literature of suppliers selection problem in green supply chain, various methods such as statistical models, data envelopment analysis, hierarchical process, artificial intelligence and mathematical programming to select suppliers are used, but each of these methods have their own constraints. For example, one can say that the analytical hierarchy process (AHP) is widely used to solve multi-measures decision (Chan et al., 2008). However, this method is faced with a major limitation, and it is the lack of attention to problem constraints. The mathematical programming methods have the ability to consider the functional constraints and can achieve reliable solutions. However, the mathematical models that have been proposed so far to solve the supplier selection problem, do not consider many real-world situations.

- Supply chain management

The supply chain consists a set of companies (loops) that cooperate with each other to transfer one or more products to the final customer, and their relationship with each other is in the form of customer and supplier. In other words, each company within the chain has at least one customer or at least one supplier. The chain consists of many tasks such as shopping, flow of funds, bearing of materials, planning and production control, inventory control and logistics, delivery distribution. In a chain the three main flows include the flow of materials, information and money there. In fact, the supply chain management in the sense of management of these three flows is in such a way that while customer satisfaction is maximized, the most value for the chain members is created.

- The supplier selection

The Suppliers are an important part of supply chain system. Since reliable suppliers enables manufacturers to reduce inventory costs and improve product quality, it is understandable that the manufacturers are increasingly concerned about the selection of suppliers and it is clear that the appropriate suppliers selection and effective management of relationships with supplier are the key factors in enhancing the company's competitiveness. The appropriate supplier selection for purchasing raw materials and assignment of some production operations to supplier constitutes an important part of this chain. De Boer et al. (2001) state that several steps form the supplier selection process. First the problem and different decision measures are designed. Then the suppliers who have the potential to become the best are selected and finally the best supplier is selected. In a study, they reviewed the literature of supplier selection problem in above four steps format. In addition to above the studies, one can point out to the study carried out in the field of green suppliers taking into account analytical tools (GDEA) by Kumar et al. (2014). He included a set of activities that are considered during the supplier selection process, containing identification, analysis and selection in three major categories.

- The supplier selection in the green supply chain

The main objective of green supply chain management, is to reduce environmental pollutions from upstream to downstream industries, which this chain includes all stages from purchasing the raw materials to delivering the final product to the customer. The harmful substances contained in parts provided by suppliers, cause the environmental impact. So organizations to increase productivity in this dynamic environment, need to pay more attention to their suppliers status that is one of the main elements; because the suppliers performance of each organization that can result in survival or destroying any organization or reducing the cost of organization. So far, many methods for evaluating and ranking suppliers in the green supply chain have been suggested that most of the methods have their own advantages and constraints.

The suppliers selection using multi-objective optimization methods

Ng (2008) used a linear mathematical programming model to evaluate suppliers.

The objective function considered by him, was a harmonious combination of suppliers number, quality, delivery lead time and price measures with the aim of maximization. The advantage of his proposed model was simplicity and efficiency that is proved by comparing the results obtained from the proposed model and data envelopment analysis. Also in the proposed model, the decisive role such as hierarchical analysis models and multi-objective models was not subjective. Ren et al. developed a multi-objective model for economic optimization of energy distribution systems that leads to reduce CO2 gases released

from fossil fuels (Ren et al., 2010). Yeh and Chuang (2011) in order to select green supplier, developed their model taking into account features such as capacity, productivity, cost, quality and ISO 14000 using genetic algorithms. Wang et al (2011) proposed a multi-objective mathematical model to optimize green supply chain. The variables that they used to develop their model include shipping cost, products flow during supply chain and investment to protect the environment.

Research method

The problem in this research can be presented in the form of a mathematical model. In this model, the cost function can be divided into two categories of environmental costs and supply chain costs. In the first category of costs, i.e. the environmental costs, two types of costs can be calculated that include the cost of pollutants caused by each manufacturer and the cost of pollutants caused by transport. The second category of costs include the costs of purchasing and transportation. The model that will be presented in this study, like all available models of supplier selection problem is based on the allocation models. The constraints of new model in addition to conventional constraints of the supplier selection problem such as supply constraint, include capacity constraint of shipping routes. Also, in addition to reducing the costs of purchase, the environmental objectives are also considered. The environmental objective function in the proposed model, minimizes the cost of pollutants, that contain pollutants caused by suppliers and pollutants caused by transport.

So, it is attributed to every supplier and every means of transport, a parameter of pollutant cost. In the mathematical model it is assumed that these parameters are preset as the other parameters of model such as the cost of purchase are preset. In fact, the method of determining parameters is so that the amount of pollutant produced (usually greenhouse gas) per unit of product manufacturing by for suppliers or per unit distance for vehicles is determined and then, with respect to various factors influencing in the community, the imposed cost of produced pollutant percentage are estimated. Given that the cost of environmental pollutants in different situations, are different in different times and societies, these costs are included in the model as parameters so that model can be used in any situation. So determining the cost of these pollutants, is like determining the cost of purchase. It requires that when the model is used by an organization, these costs are determined according to special requirements of the organization. Taking into account the environmental objectives can be the most important step in selection of supplier in a green supply chain. Given that the most important purpose of green supply chain is reducing environmental pollutants, taking into account the objectives set out in the supplier selection problem, closes this problem to the green supply chain objectives. The innovation of the presented approach in this study, is using the fuzzy chance constrained programming method to deal with uncertainty in the demand which for the first time is used in solving supplier selection problem and optimal order allocation in a green supply chain. According to the above description, an objective function related to the cost of pollutants caused by suppliers and transportation and an objective function related to the cost of purchasing and shipping the product for mathematical model are considered. In order to provide a precise formulation of the problem, the variables and parameters as well as the mathematical model of the problem are expressed as follows.

Parameters

p_j : the cost of pollutants caused by the supplier j th for production of a single product.

d_{ijk}: the route distance k th for transportation of the product from supplier j to the customer i

r_{ijk}: the Costs of pollutants caused by transport per unit of distance for every single product delivery from supplier j to customer i through k th path

c_j: The cost of purchasing product from supplier j

T_{ijk}: the Cost of delivery of single product from supplier j to customer i through k th path

Cap_k: The maximum transferable amount of product through the k path

A_j: the capacity of Supplier j

D_i : the demand of customer i that can be expressed in the form of triangular fuzzy number

Decision variables

x_{ij}: The products purchased by customer i from supplier j

q_{ijk}: If the k th path for product transport from supplier j to customer is selected to takes the value 1, and otherwise it is zero.

The objective functions

$$\text{Min} \sum_{i=1}^{m}\sum_{j=1}^{n} p_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \sum_{k=1}^{K} q_{ijk} d_{ijk} r_{ijk} \quad (1-3)$$

$$\text{Min} \sum_{i=1}^{m}\sum_{j=1}^{n} c_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K} x_{ij} T_{ijk} q_{ijk} \quad (2-3)$$

Given that the product transport from any supplier to each customer can be done only through one path the following constraint should be included in the model

$$\sum_{k=1}^{K} q_{ijk} = 1 \quad (3-3)$$

In addition, each patch has its constraint to transport a product that should be considered in the model. The constraint of each route can be modeled as follows.

(4-3)

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} q_{ijk} \le Cap_k$$

In the above expression, $Cap_{k\ shows}$ the maximum amount of transportable product through path k. As previously mentioned, in addition to the objective functions and above constraints, other constraints common in the supplier selection problem also will be considered in the model. In the present problem it is assumed that each supplier has specified capacity equal to A_j that can not produce the excess of this amount in each period. Thus, capacity constraint of suppliers is expressed as follows.

$$\sum_{i=1}^{m} x_{ij} \le A_j \qquad (5-3)$$

This constraint ensures that the total product supplied by supplier j does not exceed the Aj . Another key constraint that is considered in the model is demand constraint. In most models available on supplier selection problem, the demand is considered to be definitive. However, in the real world, demand for products is always faced with uncertainty. In our model, utilizing the concepts of fuzzy sets theory, the fuzzy demand is defined. In fact, it is assumed that demand for triangular fuzzy numbers is expressed. The following constraint, shows the constraint to meet the demand.

$$\sum_{j=1}^{n} x_{ij} \ge D_i \qquad (6-3)$$

In the above expression, D_i shows the customer demand i which is indicated as fuzzy and finally with respect to the definition presented for decision variables we have,

(7-3)

$$x_{ij} \ge 0, \quad q_{ijk} = 0 \text{ or } 1$$

As mentioned, in the proposed model in constraint (6-3), to get closer to real-world situations, the demand for product is considered to be fuzzy. So by taking into account such assumptions, the proposed mathematical model for this problem is a fuzzy multi-objective mathematical model which one of its constraints is expressed as fuzzy. To solve this problem, first using fuzzy chance constrained programming, the proposed mathematical model is transformed to a deterministic mathematical model. Then, in order to solve this deterministic mathematical model, the fuzzy multi-objective programming method is used.

solution method

- transforming the proposed mathematical model to a deterministic mathematical model

In the fuzzy chance constrained programming, different measures can be used. In this study the validity measure is used. Using validity measure, the constraint is expressed as follows.

$$Cr\left(\xi \le r\right) \ge \lambda$$

In the above expression λ is the level of confidence that is determined by the decision maker. $\xi = (a,b,c)$ is a triangular fuzzy number and Cr represents validity of holding the fuzzy equation that for triangular fuzzy numbers is calculated as follows.

$$Cr\left(\xi \le r\right) = \begin{cases} 0 & if \quad r \le a, \\ r-a \big/ 2(b-a) & if \quad a \le r \le b \\ c-2b+r \big/ 2(c-b) & if \quad b \le r \le c \\ 1 & if \quad r \ge c \end{cases}$$

In the proposed mathematical model, the demand constraint is considered as follows

$$\sum_{j=1}^{n} x_{ij} \ge D_i$$

Which using fuzzy chance constrained planning approach is expressed as follows.

$$Cr\left(\sum_{j=1}^{n} x_{ij} \ge D_i\right) \ge \lambda$$

And with respect to definition of validity measure and the fact that in this study, the demand is considered as triangular fuzzy numbers, is calculated as follows

$$Cr\left(\sum_{j=1}^{n} x_{ij} \geq D_i\right) = \begin{cases} 0 & if \quad \sum_{j=1}^{n} x_{ij} \leq a_i, \\ \dfrac{\sum_{j=1}^{n} x_{ij} - a_i}{2(b_i - a_i)} & if \quad a_i \leq \sum_{j=1}^{n} x_{ij} \leq b_i \\ \dfrac{c_i - 2b_i + \sum_{j=1}^{n} x_{ij}}{2(c_i - b_i)} & if \quad b_i \leq \sum_{j=1}^{n} x_{ij} \leq c_i \\ 1 & if \quad \sum_{j=1}^{n} x_{ij} \geq c_i \end{cases}$$

As can be seen in the above expression if $a_i \leq \sum_{j=1}^{n} x_{ij} \leq b_i$ holds , the value of validity measure is in the range of 0 to 0.5 and if $b_i \leq \sum_{j=1}^{n} x_{ij} \leq c_i$ holds, value of validity measure will be in the range of 0.5 to 1

However, it can be used the above equations to calculate the validity according to the confidence level. If the confidence level is in the range of 0 to 0.5, the following equation is used.

$$\frac{\sum_{j=1}^{n} x_{ij} - a_i}{2(b_i - a_i)} \geq \lambda$$

Which after simplification becomes

$$\sum_{j=1}^{n} x_{ij} \geq 2\lambda(b_i - a_i) + a_i \qquad (1-4)$$

In contrast, if the confidence level in the range of 0.5 to 1, the following equation is used.

$$\frac{c_i - 2b_i + \sum_{j=1}^{n} x_{ij}}{2(c_i - b_i)} \geq \lambda$$

which it can also be expressed as:

$$\sum_{j=1}^{n} x_{ij} \geq 2\lambda(\mathrm{c}_i - b_i) + 2b_i - c_i \qquad (2-4)$$

The equations (1-4) or (2-4) are used in the model and these equations are replaced (6-3) in the previously proposed mathematical model .

- The Linearization of mathematical model

The previously proposed model is a non-linear model. The nonlinearity of this model results from the multiplication of decision variables in objectives and and constraints (1-3), (2-3), (4-3). In objectives of model, the variables Xij and qijk have been multiplied to each other.

$$\text{Min} \sum_{i=1}^{m}\sum_{j=1}^{n} p_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \sum_{k=1}^{K} q_{ijk} d_{ijk} r_{ijk}$$

$$\text{Min} \sum_{i=1}^{m}\sum_{j=1}^{n} c_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K} x_{ij} T_{ijk} q_{ijk}$$

Also in the constraint (4-3) the variables xij and xij also have multiplied to each other.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} q_{ijk} \leq Cap_k$$

In order to linearize these equations, a new variable y_{ijk} is replaced the the product of variables x_{ij} and q_{ijk} and the objective functions are expressed as

$$\text{Min} \sum_{i=1}^{m}\sum_{j=1}^{n} p_j x_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K} y_{ijk} d_{ijk} r_{ijk} \qquad (3-4)$$

$$\text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} c_j x_{ij} + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{K} y_{ijk} T_{ijk} \quad (4\text{-}4)$$

Also the following constraint is replaced the constraint (4.3)

$$\sum_{i=1}^{m} \sum_{j=1}^{n} y_{ijk} \leq Cap_k \quad (5\text{-}4)$$

In addition, the following restrictions must also be added to the GPA.

$$y_{ijk} \leq M q_{ijk} \quad (6\text{-}4)$$

$$y_{ijk} \geq x_{ij} - M\left(1 - q_{ijk}\right) \quad (7\text{-}4)$$

$$y_{ijk} \leq x_{ij} + M\left(1 - q_{ijk}\right) \quad (8\text{-}4)$$

In the above equations, M is an large arbitrary number. The above constraints ensure that variable yijk is equal to the product of variables xij and qijk. Considering the fact that qijk is a binary variable, the first constraint ensures that if the variable q_{ijk} is equal to 0, the variable yijk is also equal to 0. In contrast if the variable qijk is equal to 1, the second and third constraints ensure that variable yijk is equal to the xij.

Calculation Results

In this research, the Lingo software for solving the linear programming problem is used. For this purpose, various problems with different number of customers, suppliers and transport routes are solved and their results are analyzed. In this problems, the number of customers 2 to 4, the number of suppliers from 3 to 5 and the number of routes 2 or 3 are considered. A total of 18 problem taking into account the different number of customers, suppliers and transport routes at a confidence level of 0.9 are solved. Information related to these problems and the obtained results are shown in the table below.

Table1: the results of solving problems with different dimensions

Total cost	The cost of purchase and transport	The cost of environmental pollutants	Routes number	Suppliers number	Customers Number	No.
209449.8	100957.7	108492.1	2	3	2	1
199823.5	97446.0	102377.5	2	4	2	2
176508.6	84571.2	91937.4	2	5	2	3
253308.4	123902.7	129405.7	2	3	3	4
232355.0	112043.8	120311.2	2	4	3	5
221332.9	107438.9	113894.0	2	5	3	6
272991.1	128402.8	144588.3	2	3	4	7
271913.2	132901.4	139011.8	2	4	4	8
258215.9	126312.5	131903.4	2	5	4	9
189315.83	90671.93	98643.9	3	3	2	10
180141.1	87001.4	93139.7	3	4	2	11
159065.6	76325.0	82740.6	3	5	2	12
250165.5	122512.4	127653.1	3	3	3	13
207929.4	100749.4	107180.0	3	4	3	14
200298.6	96884.0	103414.6	3	5	3	15
257610.9	126572.5	131038.4	3	3	4	16
243521.8	117501.2	126020.6	3	4	4	17
233386.2	115772.2	117614.0	3	5	4	18

The above table represents information about the change trend of costs based on the number of customers, suppliers and transport routes. It can be seen from the above table that the cost is increased as the number of customers is increased. This is evident because with increasing the number of customers, the total demand will be increase and results in increased costs of environmental pollutants, and transport costs. The following figure shows the trend of increased total costs per customer if the number of suppliers is equal to three and the number of routes is equal to 2.

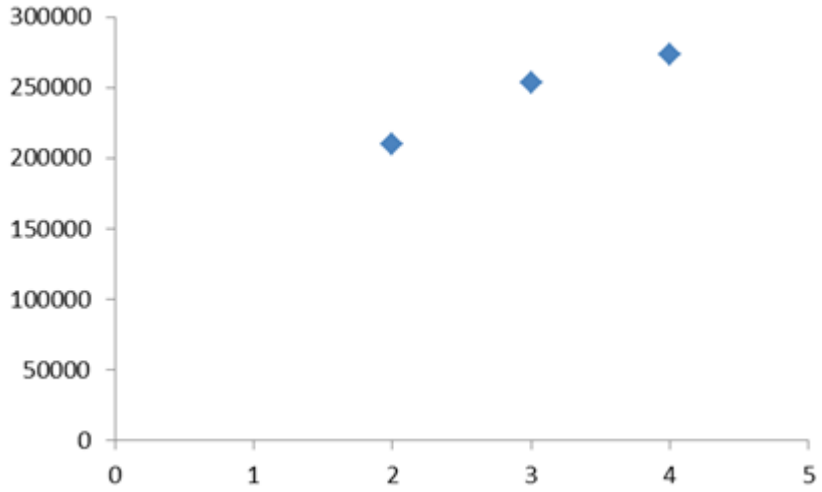

Fig 1: The trends of increased costs versus the number of customers with three suppliers and two routes.

The data in table 1 also shows that with increasing the number of suppliers if the number of customers and the routes are constant, the costs will be reduced. For example, when the number of customers is equal to 2 and the number of transport routes is also equal to 2, with an increase in the number of suppliers, the costs are reduced. This example is shown in the following figure.

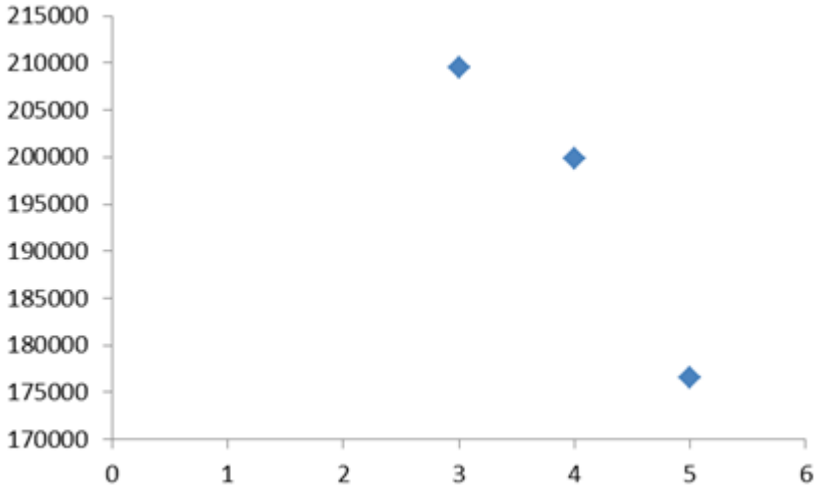

Fig 2. The trend of reducing the costs versus the number of supplies with two customers and two routes.

The reason for this is due to the constant in the number of customers and their demand, by increasing the number of suppliers, each customer has the possibility to meet his demand from more options. This more flexibility leads to better choices that impose lower costs. This also applies to the number of transit routes. In other words, by increasing the number of transport routes, the costs are reduced. For example, in the case where the number of customers is equal to 2 and the number of suppliers is equal to 3, with the increasing number of transport routes from 2 to 3 the costs will be reduced from 98,643.9 108,492.1. The reason is that with the increasing number of transport routes, there will be more options for transportation. This allows greater flexibility to choose better options that lead to lower costs.

Conclusion

The results indicate that lack of attention to environmental costs in the supplier selection problem and to determine optimal order allocation can lead to significant increases in environmental costs. As can be expected, the cost of purchasing and shipping when the environmental objectives are not considered, are reduced cost of environmental pollutants will be increased significantly. Therefore, the simultaneous attention to the cost of purchasing and shipping and costs of environmental pollutants can have a significant impact in reducing total supply chain costs. Considering the multi-objective approach and attention to environmental objectives, the cost of purchasing and transport are increased, while the environmental costs are significantly reduced. The comparison of multi-objective (economic and environmental objectives) approach and traditional (economic) approach helps managers to make better decisions in selecting suppliers and allocating order. In other words, in comparing the two approaches it is clear that with a certain amount of increase in the cost of purchasing and transportation, how the cost of environmental pollutants can be reduced.

According to studies carried out in the current research, the following areas will be considered as interesting areas for future research:

- Considering new assumptions on the supplier selection problem and optimal order allocation
- considering other objective functions
- proposing different problem -solving approaches

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