An Integrated Method for Supplier Selection in a multi-product and quantity discount environment

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Abstract: Supplier selection or vendor selection is a complicated multi-criteria decision-making including both quantitative and qualitative factors. In order to select the best suppliers it is important to make a trade-off among these factors, some of them may conflict. The buyer should determine two important variables: the number of best suppliers and the amount of purchasing from each selected supplier. In this paper an integrated approach of Multi-Attribute Utility Theory (MAUT) and Linear Programming (LP) is proposed for supplier selection problems when a buyer needs more than one product. Also, a Mixed Integer Linear Programming (MILP) approach is applied in a discount environment to determine the best suppliers and to place the optimal order quantities among them. Both cumulative and incremental discounts are taken into account in this study. Two numerical examples are presented for each discount policy to illustrate the application of the recommended models which in a reasonable time reach to an exact solution.

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1. Introduction

Today supplier selection decisions are important components of purchasing and logistics management. Such decisions involve the selection of individual suppliers and the determination of amount of purchasing with the best suppliers. We believe that one of the most important activities of a purchasing department is supplier selection, so that selecting right suppliers meaningfully decreases the raw material purchasing cost and enhances corporate competitiveness. The cooperation between buyer supplier helps to parties involved (Abolhasanpour et al. 2011).

Supplier selection is one of the most important components of production and logistics management for many companies. Selection of wrong suppliers could be enough to upset the companies' functional and operational position. Selecting the right suppliers significantly reduces purchasing costs, improves competitiveness in the market and enhances user satisfaction (Onut et al. 2009).

According to Sanayei et al. (2008) many factors are effective in measuring supplier performance. Many researchers have analyzed such criteria and supplier performance since the 1960s. Dickson (1963) identified 23 criteria that purchasing managers have been considered in supplier selection problems. Roa and Kiser (1980), Ellram (1990), Stamm and Golhar (1993) also mentioned several criteria for supplier selection. Weber et al. (1991) reviewed 47 articles that more than one criterion were considered in supplier selection models. One of the key area operations and supply chain management is inventory control (Hosseini and Hojangi, 2011). Azad et al. (2011) incorporate information flow in a supply chain model.

There are two approaches for supplier selection problems. The first is to select the best single supplier, which can fulfill all the demands (single sourcing). The second is to select a proper combination of suppliers in condition that no single supplier can meet all the demands. Correspondingly, management should divide order quantities among the attainable suppliers for various reasons such as making a firm environment of competitiveness (multiple sourcing).

Nowadays most companies in order to sell more and catch more proportion of market present discount for the customer with high demand. Furthermore in competitive environments there are two types of discount mechanisms: Cumulative and Incremental. In addition, several criteria are effective in supplier selection. Therefore we consider MAUT approach that is modeled by discount policy with multi product demand. In this paper the section 2 presents a brief literature review of the supplier selection problem and its models. Section 3 provides mathematical models for multi product and discounts. Then section 4 presents two numerical examples for cumulative and incremental discounts. After that section 5 included sensitivity analysis and proposed a formulation for computing purchase cost. Finally, section 6 is devoted to conclusions and recommendations.

2. Literature review

Many different methods are proposed for single sourcing supplier selection problems in the literature that one of them is data envelopment analysis (DEA). Data envelopment analysis is a mathematical programming technique that calculates the relative efficiencies of multiple decision making units (DMUs) based on multiple inputs and outputs (Liu et al. 2000). DEA was used in supplier selection evaluation for an individual product by Weber (1996). Liu et al. (2000), Forker and Mendez (2001) and Saen et al. (2005) used DEA to evaluate and select the most appropriate supplier.

Ghodsypour and O´Brien (1998) used the analytical hierarchy process (AHP) with linear programming model to consider both qualitative and quantitative factors in purchasing activity. Narasimhan (1983), Partovi and Banerjee (1989), Nydick and Hill (1992), Barbarosoglu and Yazgac (1997), Yahya and Kingsman (1999), Masella and Rangoue (2000), Tam and Tummeda (2001), and Lee et al. (2001) proposed to use this technique to cope with determining scores.

Analytic network process (ANP) is a multi-attribute decision making method that can be used to evaluate the most suitable suppliers systematically according to dependencies and feed backs (Onut et al. 2009). Also Lin et al. (2010) apply ANP for ranking the existing suppliers and calculate order quantity by linear programming (LP) in ERP environment.

Multi-attribute utility theory (MAUT) is used by Min (1994) in international supplier selection in a single sourcing environment in which there is one decision maker. Sanayei et al. (2008) used MAUT and LP to rate and choose the best suppliers and define the optimum order quantities. In multiple sourcing, different methods have been used. LP models were used by Pan (1989) and Ghodsypour and O´Brien (2001) in supplier selection problems. They combined AHP and LP as a hybrid model to optimize order allocation among suppliers. Multi objective programming (MOP) was used by Current and Weber (1994) in a vendor selection problem. Weber et al. (2000) used DEA and MOP in multiple sourcing environment and order allocation.

Goal programming technique combined with AHP, was used by Buffa and Jackson (1983) and Wang and Huang (2004) to solve purchase planning and supplier selection problems. Xia and Wu (2007) proposed an integrated approach of analytical hierarchy process improved by rough sets theory and multi objective mixed integer programming to simultaneously determine the number of suppliers to employ and the order quantity allocated to the suppliers.

According to Min (1994) MAUT does not have any constraints, has less computational difficulty and requires more data in comparison with other similar methods of decision-making. In addition, MILP model can find the solution exactly that is valuable in real world problems. Therefore, in this paper an integrated MAUT approach and an MILP model are proposed for rating and choosing the best suppliers and identifying the optimum order quantities. Our research work is distinguished from researches done so far by considering following new aspects that makes the problem more realistic:

- To fulfill multi criteria condition, we apply MAUT approach to select the best supplier.
- There is more than one product prepared by each supplier and each supplier is not necessary to produce all of product types.
- Both cumulative and incremental discount policies are considered.

A mathematical programming model is proposed for the supplier selection problem in which the buyer needs more than one product and the suppliers are not bounded to produce all kinds of products that the buyer needs. The proposed model determines the best suppliers and the optimal order quantities for each supplier under some constraints such as demand, capacity, budget and quality. Then, the model is extended to consider the discount cost constraints-cumulative and incremental quantity discount. The objective function is to maximize utility.

3. Mathematical Modeling

Supplier selection is a complex decision-making problem. The complexity origins from the uncertain nature of the decision-making process, a plenty of quantitative and qualitative components affecting supplier choices as well as the natural difficulty of making several balancing among these components. One analytical approach often suggested for solving such complex problems is MAUT. We used MAUT method because is more applicable and easier than other methods. The main steps of algorithm are illustrated in Figure. 1. For more information about MAUT refer to section 2 of Sanayei et al. (2008).

According to Wang and Yang (2009) supplier selection is more complicated when quantity discount is incorporated. So we apply cumulative and incremental discount for supplier selection and gain exact solution.

3.1. Multi-Product Model

In this section an LP model is formulated for multi-product supplier selection problem to determine the best suppliers and allocate optimal order quantities to suppliers. There are two constraints for each supplier including capacity and quality. Here it is assumed that each supplier is not bounded to produce all products the buyer needs. The supplier's ratings are used as coefficients of the LP objective function for each product. As a result, the TAU becomes maximized while purchasing as much as we can from the most desirable suppliers. The notations, objective function and constraints of this LP model are explained as follows:

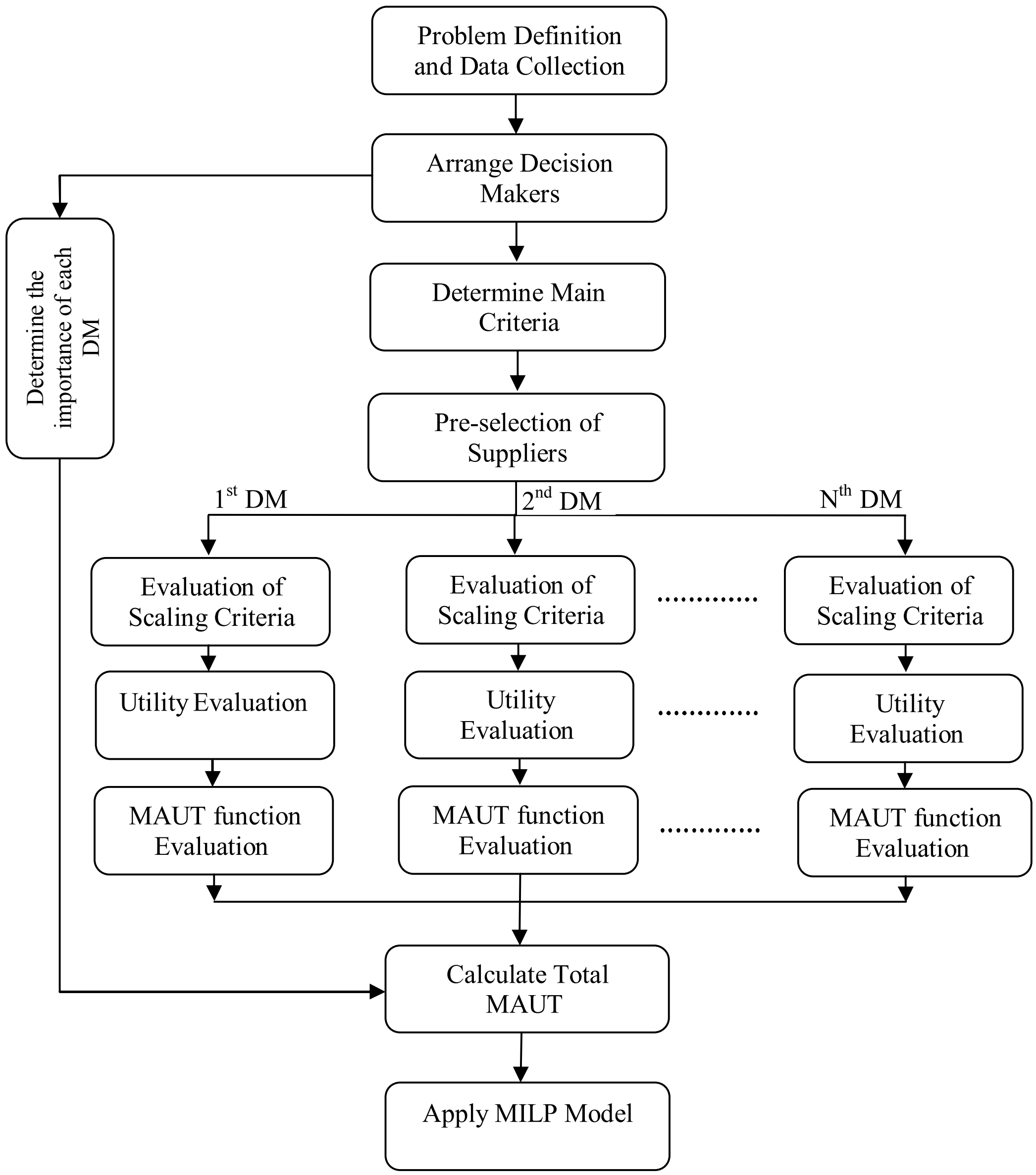

Figure 1. The overall framework of proposed model in supplier selection

3.1.1. Notations

Three mathematical models are constructed using the following notation:

U_{ij} Final utility (rate) of i^{th} supplier for j^{th} product

X_{ij} Order quantity for i^{th} supplier for j^{th} product

V_{ij} Capacity of i^{th} supplier for j^{th} product

C_{ij} Total logistic of i^{th} supplier for j^{th} product

D_j Demand of j^{th} product for the period

q_{ij} Defect percent of i^{th} supplier for j^{th} product

Q_j Buyer's maximum of acceptable defect rate for j^{th} product

B Total budget

F_i Budget of i^{th} supplier

3.1.2. Objective Function

As U_{ij} and X_{ij}, respectively, denote the ratings for and the number of purchased units for j^{th} product that can be produce from the i^{th} supplier and maximizing the TAU as the objective function of desired purchasing as follows:

$$Max(TAU) = \sum_{j \in J} \sum_{i=1}^{n} U_{ij} X_{ij} \quad (1)$$

3.1.3. Constraints

$$X_{ij} \le V_{ij} \quad For\ i = 1,2,...,n \ \& \ j \in J \quad (2)$$

$$\sum_{i=1}^{n} V_{ij} \ge D_j \quad For \quad j = 1,2,..., m \quad (3)$$

$$\sum_{i=1}^{n} X_{ij} = D_j \quad For \quad j = 1,2,..., m \quad (4)$$

$$\sum_{i=1}^{n} X_{ij} q_{ij} \le Q_j D_j \quad For \ j = 1,2,...,m \quad (5)$$

$$\sum_{j \in J} \sum_{i=1}^{n} C_{ij} X_{ij} \le B \quad (6)$$

$$\sum_{j \in J} C_{ij} X_{ij} \le F_i \quad For \ i = 1,2,..,n \quad (7)$$

Eq. (2) demonstrates as vendor i for j^{th} product can provide up to V_{ij} units of the product, the order quantity X_{ij} should be equal or less than the vendor capacity. Eq. (3) shows the aggregate suppliers' capacity should be equal or greater than the demand. The sum of the assigned order quantities to n vendors should meet the buyer's demand for each product is manifested in Eq. (4). Since Q_j is the buyer's maximum acceptable defect rate for j^{th} product and q_{ij} is the defect rate for j^{th} product of the i^{th} vendor, the quality constraint can be expressed in Eq. (5). Cost plays an essential criterion in the supplier selection problems. Budget allocated for outsourcing or buying all products that needed is not unlimited. Consider B as total allocated budget and C_{ij} total logistic cost of i^{th} supplier for j^{th} product in Eq. (6) which involves products cost, ordering cost and shipping cost. Eq. (7) exhibits constraint of i^{th} vendors for producing all j products can be produced.

3.2. Cumulative Discount Model

Cumulative quantity discounts (also called accumulation discounts) are price reductions based on the quantity purchased over a set time periods. The expectation is that they will impose an implied switching cost and thereby bond the purchaser to the seller. The main focus of the formulation discussed here is on modeling the discount behavior of the suppliers and buyer reaction to this discount policy. For that reason, a single product is assumed in order to simplify the problem, plain the details and remain the focus of the model on discount behavior. Although such an extension poses no increased difficulties beyond notation. At first we determine some notations as follows:

C_{ir} r^{th} price of supplier i

q_{ir} r^{th} break point for supplier i

α_{ir} Buying amount of supplier i in the r^{th} level of discount

$y_{ir} = \begin{cases} 1 & \text{If buyer buys from supplier } i \text{ in the } r^{th} \text{ level of discount} \\ 0 & \text{Otherwise} \end{cases}$

M A huge number

Purchase costs for each level of discount are as follows:

$$C_{ir} = \begin{cases} C_{i1} & 0 \le x < q_1 \\ C_{i2} & q_1 \le x < q_2 \\ \vdots & \vdots \\ C_{iR} & x \ge q_R \end{cases} \quad (8)$$

Here we change the budget constraint of the single product model in order to consider cumulative quantity discount behavior of suppliers. Then, the new non-linear budget constraint is made linear and takes the place of the old budget constraint. Since the purchase cost in each level of discount is different, we define decision variable α_{ir} to determine the amount of purchase from supplier i as follows:

$$X_i = \sum_{i=1}^{R} \alpha_{ir} \quad For \ i = 1,2,....n \quad (9)$$

At most one of the α_{ir}'s is non-zero for each supplier *i*. Therefore we can define a set of constraints as follow:

$$\begin{cases} 0 \le \alpha_{i1} \le q_{i1}y_{i1} - \frac{y_{i1}}{M} \\ q_{i1}y_{i2} \le \alpha_{i2} \le q_{i2}y_{i2} - \frac{y_{i2}}{M} \\ \vdots \\ \alpha_{iR} \ge q_{iR}y_{iR} \end{cases} \quad (10)$$

Since the upper bounds of these constraints are not equal to exact numbers, we subtract a small amount from the right hand side of the equations so that we are able to solve the model. Because in Eq. (10) at most one of the α_{ir} s should be non-zero, we define a constraint as follow:

$$\sum_{r=1}^{R} y_{ir} \le 1 \qquad For\ i = 1, 2, \dots, n \quad (11)$$

where y_{ir} is a binary variable. We mentioned at most, because we do not have to buy from all suppliers and in some cases all of the y_{ir} variables is zero for all discount level.

Finally, the budget constraint is changed to:

$$\sum_{i=1}^{n}\sum_{r=1}^{R} C_{ir}\alpha_{ir} \le B \quad (12)$$

3.3. Incremental Discount Constraints

Incremental discounts (Non-cumulative quantity) are price reductions based on the quantity of a single order. The expectation is that they will encourage larger orders, thus reducing billing, order filling, shipping, and sales personal expenses. Here all constraints are similar to cumulative discount model except the budget constraint which is changed as follows:

$$\sum_{i=1}^{n}\sum_{r=1}^{R} y_{i\,r+1}[\sum_{r=1}^{r-1} C_{ir}(q_{ir} - q_{i\,r-1} - 1)] + \sum_{i=1}^{n}\sum_{r=1}^{R} \quad (13)$$

Eq. (13) consists of two parts. The first part shows the purchase cost for discount levels before the last interval in which the order quantity is. The second part shows purchase cost for remained order quantities.

4. Numerical example

In this section we use the numerical example presented by Sanayei et al. (2008) to apply our proposed model and illustrate the implementation of both discount models- Cumulative and Incremental discounts. The criteria used in numerical example are shown in Figure. 2.

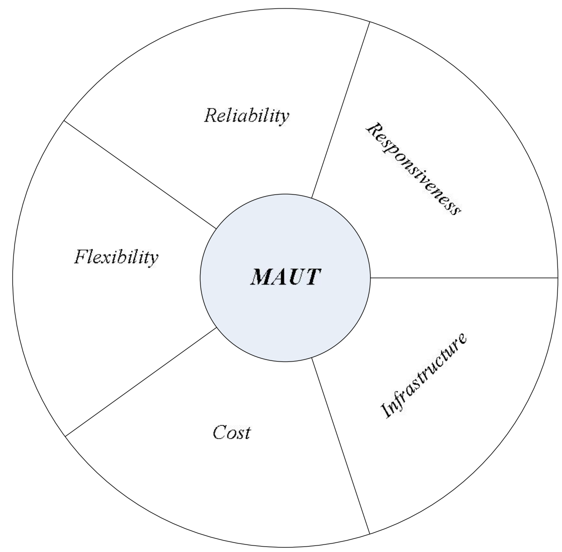

Figure. 2. Supplier Selection Criteria

Since the multi-product model is a simple LP model we do not show any example for it. Table 1 represents assumptions of the problem and table 2 contains levels of discount for each supplier and parches cost for each unit of product.

Table 1. The parameters of the MILP model

Supplier index	Utility value	Capacity	Quality	Total demand	Total budget
1	0.447	650	0.99	1200	$35000
2	0.457	650	0.98		
3	0.323	550	0.96		

Table 2. Levels of discount for each supplier

Supplier	Order of Quantity	Cost ($)
S1	$0 \le x < 20$	30
	$20 \le x < 100$	29
	$100 \le x < 200$	27
	$200 \le x < 400$	26
	$400 \le x \le 650$	24
S2	$0 \le x < 20$	60
	$20 \le x < 100$	58
	$100 \le x < 200$	55

	$200 \le x < 400$	52
	$400 \le x \le 650$	49
S3	$0 \le x < 20$	35
	$20 \le x < 100$	33
	$100 \le x < 200$	31
	$200 \le x < 400$	29
	$400 \le x \le 550$	26

This problem is formulated for both Cumulative and Incremental discounts environment. Then the problem is formulated as an ILP problem in Lingo 8.0 software. The time for solution was less than one second on a Pentium 4 desktop with 2 GB of RAM. The solution outputs, the order quantities from each supplier, are displayed in Table 3.

Table 3. Final result of solving the model

Supplier	Cumulative Discount	Incremental Discount
S1	650	650
S2	65	400
S3	485	150

5. Discussion

Purchase cost is one of important criterion which used in objective function to maximize the utility. We propose below a relationship to obtain average purchase cost with the aim of determining coefficient of objective function (MAUT):

$$C^* = \frac{C_1 q_1 + C_2(q_2 - q_1) + \cdots C_n(q_n - q_{n-1})}{q_n} \quad (13)$$

Using Eq. (14) is a simple and appropriate way to obtain average purchase cost. Sensitivity analysis has been done for the coefficients in objective function, where if values of coefficient of each supplier vary and the others remained fixed for both of models we can see that the amounts of optimal solution will not change.

Table 4 shows the amount of variation in coefficients of objective function to extent that the optimal solution be fixed.

Table 4. Percentage of variation in coefficient of objective function

Supplier	Decreasing coefficient of objective function	Increasing coefficient of objective function
S1	28%	Unlimited
S2	29%	Unlimited
S3	Unlimited	38%

Consequently, above results confirm that purchase cost criteria despite its importance do not have high effect on optimal solution therefore we can use Eq. (14) as an estimation of purchase cost without facing any problem.

In Cumulative Discount, global optimal solution found at 111 iterations and in less than one second, and in Incremental Discount, global optimal solution found at 2283 iterations and in one second. By the same token there is not problem in large scale problems, for example in Xia and Wu (2007) paper their solution gain global optimum in 67 seconds, if there are four supplier and five level of discount, but our solution because of ILP model found global optimum in one second for incremental discount and less than one second for cumulative discount, too.

Figure. 3 shows how the quantity of purchase of supplier 1, 2 and 3 is changing when the coefficient of S1 changes. As it can be seen there is a little change for order of quantity of S2 and 0.28 is a critical point so that order of quantity is constant when the coefficient of S1 is less than 0.28 and as the coefficient reaches to 0.28 and above this value order of quantity of S3 is decreased and order of quantity of S1 is increased. Noteworthy, for values of coefficient of S1 that are greater than 0.32, order of quantity remains constant.

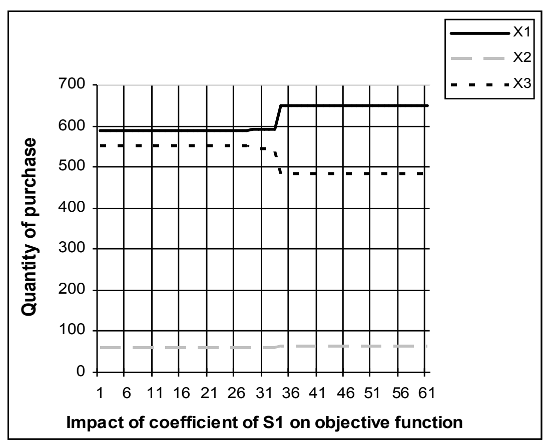

Figure. 3. Cumulative Discount

Figure. 4 is for values of coefficient that are greater than 0.32, order of quantity from each supplier remains constant. Also the values of order of quantity are constant at 400 for S2.

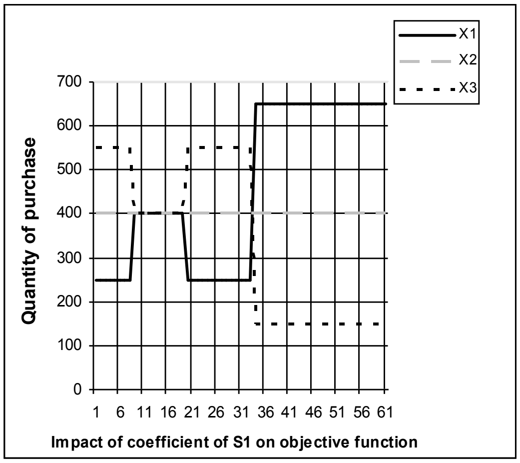

Fig. 4. Incremental Discount

6. Conclusion

Today increasing attention toward supplier partnership raises the importance of supplier selection. However, little concentration is given in the literature to decisions on the appropriate supplier selection, and on allocating lot sizes to these suppliers in discount environment. Supplier selection is a complicated multi-criteria decision-making problem contains factors which are often evaluated in an uncertain environment and by human judgments. Taking into account discounted cost in addition to demand, supplier's and manufacturer's capacity and quality limitations makes the supplier selection process more complicated.

We suggested an effective integrated MAUT and LP model for solving the supplier selection problem in multi-product environment and two effective integrated MAUT and ILP models for solving the problem in both Cumulative and Incremental discount environment. MAUT which is well suited to deal with multi-criteria decision problems include uncertainty, determines the supplier's utility from the decision makers' viewpoints. Then the LP model is used for multi-product problem and ILP model is used for discount problems to determine the order quantities to be purchased from each supplier to maximize the quantity of purchase from the most desired suppliers.

The integrated models presented in this paper are simple to use and more efficient in running time for large scale problems. However, the models would be restructured by considering the existing constraints according to the specific needs and the desirable requirements, such as minimum order quantity and limitation on the number of selected suppliers. Supplementary factors such as lot sizing and logistic costs would be taken into account to improve the models. Furthermore, stochastic and fuzzy extensions of demand can be considered as a future research.

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