The Suppliers Selection Problem: A Case Study

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Abstract. The effective supplier evaluation and purchasing processes are of vital importance to business organizations, making the suppliers selection problem a fundamental key issue to their success. We consider a complex supplier selection problem with multiple products where minimum package quantities, minimum order values related to delivery costs, and discounted pricing schemes are taken into account. Our main contribution is to present a mixed integer linear programming (MILP) model for this supplier selection problem. The model is used to solve several examples including three real case studies from an electronic equipment assembly company.

1 Introduction

The Suppliers Selection (SS) problem in Supply Chain Management represents one of the most critical tasks to be performed by the purchasing department of a business organization. The effective supplier evaluation and purchasing processes are of vital importance as the business organizations are becoming increasingly dependent on their suppliers. With the market globalization, the number of potential suppliers and the number of factors to consider when selecting suppliers increases. Therefore, an effective and efficient supplier selection process becomes very important to the success of any manufacturing or service organization [19].

We consider the supplier selection problem arising at an electronic equipment assembly company with multiple products, which is much more complex than the single product problem. For this reason, the majority of the published studies about this issue are very recent. Additionally we are considering minimum package quantities, minimum order values related to delivery costs and discounted pricing schemes. However, since we are dealing with electronic products stocking policies are not desirable.

A common approach to the SS problem with multiple products is a multi-objective approach. However, in this paper, we model the problem as a single objective optimization problem assuming price as the most important objective to the company. In [1, 5, 14, 17, 23, 24] multi-objective (mixed integer) programming approaches are proposed and frequently integrated with other approaches. Such approaches include the Analytic Hierarchy Process (AHP) ([21]), genetic algorithms ([4, 22]), the use of fuzzy concepts ([9, 12, 13, 16, 23]) including the Fuzzy TOPSIS method ([10, 11]). Together with these approaches several authors consider stochastic demands ([10, 22,

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24]). The most commonly used criteria are the products prices, the delivery date and the quality of products and services. Furthermore, suppliers capacity constraints, quantity discounts (frequently with cost level conditions), delivery costs and budget constraints are conditions generally considered. In [6, 14] lot-sizing and stock constraints are considered.

Our main contribution is to present a mixed integer linear programming (MILP) model to this complex SS problem with multiple products where minimum order values (MOV) related with delivery costs, minimum package quantities (MPQ) and discounted pricing schemes are taken into account. With the proposed model we aim to obtain the best supply condition for all the required products minimizing the total purchasing cost.

It is assumed that there is at least one supplier for each product and not all suppliers can supply all products.

Delivery costs are payable only in certain cases when the buyer order value does not reach certain minimum order value (MOV). In this case, if the total purchasing cost of the order to a supplier is less than its MOV, then the delivery cost, which is assumed to be fixed and not depending from the order value, has to be paid by the buyer.

The motivation for using discounted pricing schemes stems from the fact that it tends to encourage buyers to search for larger quantities and to reap operating advantages (such as economies of scale) for the buyer. From a coordination perspective, it has been shown that both the buyer and the supplier can realize higher overall profits if discounting schemes are used to set prices [18]. In [2] are listed several studies related with the SS problem when considering quantity discounts. Recently, other works were published [3, 5, 8, 15]. For each supplier and each product a set of product quantity levels is defined and each level is associated with a cost and offering some discount facility.

The remainder of the paper is organized as follows. In Section 2 we present a MILP model to the problem. In Section 3, two numerical examples and three real case studies are presented and the obtained computational results are discussed. Conclusions are drawn in Section 4.

2 Mixed Integer Linear Programming Model

In this section we present a MILP model to the SS problem with multiple products, minimum order values, discounted pricing schemes and minimum package quantities. The model presented here is similar to the model proposed in [17] however, here, conditions on the batches dimension (MPQ) are imposed and MOV related to delivery costs are considered. Furthermore, the model described herein has a single objective function minimizing the total purchasing cost.

Consider the set $S=\{1,\dots,m\}$ of m suppliers and the set $P=\{1,\dots,r\}$ of r products. For each supplier $s\in S$ define the set P_s of available products and for each product $p\in P$ consider the set S_p of available suppliers. To define discounted pricing schemes, define, for all $s\in S$ and all $p\in P_s$, the set $N_{sp}=\{1,\dots,\lambda_{sp}\}$ of cost level conditions. To each cost level condition in set N_{sp} corresponds a product quantity level, a product unit cost and a discount facility offered by supplier s to product p when its ordered quantity ranges from the product quantity level up to the product quantity level of the next cost level condition (infinity, if last cost level condition). The λ_{sp} represents the last cost level condition and is the total number of cost level conditions that supplier s offers to product p. Therefore the total number of supplier conditions is $SC = \sum_{s\in S, p\in P_s} \lambda_{sp}$ and this number corresponds to the overall total number of possible price choices.

Consider the following parameters:

c_{spn}: unit cost of product p from supplier s at cost level condition n, for all $s \in S$, $p \in P_s$, $n \in N_{sp}$;

d_s: delivery cost associated with supplier s, for all $s \in S$;

mov_s: minimum order value (MOV) for supplier s, for all $s \in S$;

q_{spn}: product quantity level corresponds to the minimum quantity order of product p to supplier s in cost level condition n at which price c_{spn} can be considered, for all $s \in S$, $p \in P_s$, $n \in N_{sp}$. Notice that $q_{sp1} = 0$;

$pack_{sp}$: minimum package quantity (MPQ) of product p for supplier s, for all $s \in S$, $p \in P_s$;

Q_p: demand quantity of product p, for all $p \in P$.

To obtain a formulation consider the following variables:

x_{spn}: integer variables indicating the number of packages of product p ordered to supplier s in cost level condition n, $s \in S$, $p \in P_s$, $n \in N_{sp}$;

w_{spn}: integer variables indicating the number of units of product p ordered to supplier s in cost level condition n, $s \in S$, $p \in P_s$, $n \in N_{sp}$;

y_{spn}: binary variables with value 1 if cost level condition n associated with product p and supplier s is used, $s \in S$, $p \in P_s$, $n \in N_{sp}$, value 0 otherwise;

z_s: binary variables with value 1 if supplier s is used, and value 0 otherwise, $s \in S$;

t_s: binary variable with value 1 if the delivery cost associated to supplier s is supported by the buyer, 0 otherwise, $s \in S$.

To minimize the overall cost, including the total products cost and any delivery costs associated with the suppliers, the objective function of the SS model is as follows

$$Z = \sum_{s\in S,\ p\in P_s,\ n\in N_{sp}} w_{spn} c_{spn} + \sum_{s\in S} t_s d_s \ .$$

To satisfy all the products demand, the following constraint is considered

$$\sum_{s\in S_p,\ n\in N_{sp}} w_{spn} \geq Q_p, \qquad p\in P\ . \tag{1}$$

To guarantee that each product is supplied by only one supplier using only one cost level condition we have

$$\sum_{s\in S_p,\ n\in N_{sp}} y_{spn} = 1, \qquad p\in P\ . \tag{2}$$

The following constraint guarantees that in the case a product is supplied by a supplier using some cost level condition the quantity order should be superior to the minimum order quantity of that product necessary to qualify it for the conditions established by the cost level condition.

$$w_{spn} \geq q_{spn} y_{spn} \qquad s\in S,\ p\in P_s,\ n\in N_{sp}\ . \tag{3}$$

Most of the products are provided in batches, therefore the quantity order of each product should be multiple of the batch size. Thus we have

$$w_{spn} = x_{spn}\, pack_{sp} \qquad s\in S,\ p\in P_s,\ n\in N_{sp}\ . \tag{4}$$

The following constraints relate the delivery costs with the MOV. The value $\sum_{p\in P_s,\ n\in N_{sp}} \left(w_{spn}\times c_{spn}\right)$ is the total order value for supplier $s\in S$. When for a selected supplier $s\in S$, we have $z_s = 1$ the following holds. When delivery costs are to be paid by the buyer, $t_s = 1$, constraints (5) are redundant, therefore no constraints exists for the corresponding order value. Otherwise, when there are no delivery costs, $t_s = 0$, its order value (if it exists) must be greater or equal than its MOV:

$$\sum_{p\in P_s,\ n\in N_{sp}} \left(w_{spn}\times c_{spn}\right) + t_s \times mov_s \geq z_s \times mov_s \qquad s\in S \tag{5}$$

We must guarantee that when the ordered number of packages of a product to a supplier for a certain cost level condition is zero, then the corresponding cost level condition is not used.

$$y_{spn} \leq x_{spn} \qquad s\in S, p\in P_s\ , n\in N_{sp} \tag{6}$$

To guarantee that the corresponding cost level condition is used, when the ordered number of packages is non null, we have

$$My_{spn} \geq x_{spn} \qquad s \in S, p \in P_s, n \in N_{sp} \tag{7}$$

with M being the maximum number of packages that can be ordered. We can use $M = \left\lceil \max\left\{ Q_p, \frac{mov_s}{c_{spn}}, q_{spn} \right\} / pack_{sp} \right\rceil, \quad \forall s \in S, p \in P_s, n \in N_{sp}$.

Next we establish that if a cost level condition is used for a supplier, then the corresponding supplier must also be used:

$$\sum_{p \in P_s, n \in N_{sp}} y_{spn} \leq SC \times z_s \qquad s \in S. \tag{8}$$

If no cost level condition is used for a supplier, then this supplier is not the solution:

$$\sum_{p \in P_s, n \in N_{sp}} y_{spn} \geq z_s \qquad s \in S \tag{9}$$

Finally we have the constraints on the variables values. For the integer variables

$$x_{spn},\ w_{spn}\ \ integer \qquad s \in S, p \in P_s, n \in N_{sp} \tag{10}$$

and for the binary variables

$$z_s, t_s, y_{spn} \in \{0, 1\} \qquad s \in S, p \in P_s, n \in N_{sp}. \tag{11}$$

The MILP model for the SS problem is as follows: min Z subject to (1)-(11).

The number of constraints and variables in the model can be expressed according to the number SC and the cardinality of sets S and P. The model uses $2|P|+3|S|+4SC$ constraints and $2|S|+3SC$ variables.

3 Numerical Examples and Case Studies

In this section we describe and analyze two small examples and three real case studies from an electronic equipment assembly company. With the small examples we explore and describe characteristics of the problem. The case studies help to validate the model tailored for the assembly company. We use the software Xpress-Ive 64 bits, version 7.6., to solve the examples by using the model and we run the software on a personal computer with Intel(R) Core(TM) i5-2410M CPU @ 2.30 Ghz and 6 GB of RAM.

The first example has four suppliers, four products and eighteen cost level conditions. The characteristics of this example are displayed in the Table A1 presented in Appendix. The required quantities for the products are 100, 135, 129 and 115 units, respectively and the obtained solution is displayed in Table 1.

Table 1 Summary of the results of the first example

Supplier	Product	Quantity	Order Value	Delivery cost
1	-	-	-	-
2	4	120	108	no
3	1,3	100,150	100	no
4	2	150	45	yes

The ordered quantities of the products 1, 2, 3 and 4 are, respectively, of 100, 150, 150 and 120 units which are higher than the required quantities for products 2, 3, and 4 to satisfy the MPQ quantities. Supplier 1 receives no order, therefore is not used. Products 1 and 3 are provided by supplier 3 and the total order value for this supplier is greater than its MOV. For this reason, there is no delivery cost associated to this supplier. The same happens for supplier 2, where product 4 is ordered. The reverse situation occurs for supplier 4, as the total order value is less than its MOV thus the buyer has to pay delivery costs. Notice that 120 units of product 4 are ordered at cost 0.9. The order quantity of this product allows a unit cost of 0.8 corresponding to the next cost level condition, however, in this case, the MOV would not be achieve, the buyer would have to pay the delivery cost and the total cost would be higher. On the other hand, the ordered quantity of product 2 to supplier 4 is lower than its MOV, however there is advantage on paying the delivery cost instead of reaching its MOV. This would imply the order of 250 units of product 2 at a higher cost. The total cost for this example is of 268.

The second example has three suppliers and five products. The table with the specifications of this example is Table A2 in Appendix. The required quantities for the products are 988, 480, 670, 200 and 775, respectively. The solution is displayed in Table 2.

Table 2 Summary of the results of second example

Supplier	Product	Quantity	Order Value	Delivery cost
1	2, 3, 4	520, 720, 200	50	no
2	-	-	-	-
3	1,5	1000, 805	80.25	no

The ordered quantities of the products 1, 2, 3, 4 and 5 are, respectively, of 1000, 520, 720, 200 and 805 units which are higher than the required quantities for products 1, 2, 3, and 5. There are different reasons for this fact. Product 5 has to satisfy the MPQ quantity. For products 1, 2 and 3 the reason is to satisfy MOV. Supplier 2 is not used. The products 2, 3 and 4 are provided by supplier 1 and the total order value for this supplier is equal to its MOV. For this reason, there is no delivery cost associated to this supplier. The same happens with supplier 3, where products 1 and 5 are ordered. The total cost is 130.25.

Next we present three real case studies, named projects 1, 2 and 3, of the SS problem from an electronic equipment assembly company. In this company, once for each project, the SS process is manually performed by workers. The supply conditions for which the unit price is the smallest possible are chosen, whereby the process time is slow. For the three case studies the number of available suppliers, the number of required products and the number of available supply conditions (related with quantities discounts) are displayed in Table 3.

Table 3 Number of suppliers, products and supply conditions for the case studies

	Suppliers	Products	Supply Conditions
Project 1	48	106	616
Project 2	40	35	275
Project 3	49	58	445

In Table 4 we display the project cost obtained manually by the company in column "**Cost reference**". The remaining columns refer to the application of the MILP model to solve the problem. The obtained total cost of the project is displayed in column "**Model cost**", the computational time used in column "**Execution Time**" and the number of constraints and variables are displayed in columns "**Constraints**" and "**Variables**", respectively.

Table 4 Results for three real case studies

	Cost Reference	Model Cost	Execution time	Constraints	Variables
Project 1	39309	39299	0.025	2820	1944
Project 2	24319,2	24206,7	0.008	1290	905
Project 3	27044,2	26623,8	0.012	2043	1433

From Table 4 we conclude that the results obtained by using the proposal model are better than the results obtained manually by the company. Moreover, we may conclude that the execution time of the model increases slightly with the number of available supply conditions, although, these times are much smaller than the times used by the workers of the company to obtain the solution manually.

4 Conclusions

We address the supplier selection problem for several products considering minimum order values (MOV) related with delivery costs, minimum package quantities (MPQ) and discounted pricing schemes. A mixed integer linear programming model is proposed that minimizes the total cost, the criteria elected as the most important. We present two small examples to describe and analyze some characteristics of the problem and three case studies.

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Appendix

Table A1. Delivery costs and MOV associated with suppliers, list of product for each supplier, quantities discounts and MPQ for these products, relatively example 1.

Supplier s	d_s	MOV_s	Product p	$pack_{sp}$	q_{spn}	c_{spn}
1	10	50	1	20	0	0.2
					200	0.15
					400	0.1
			2	40	0	0.5
					200	0.4
			4	100	0	0.8
2	20	100	2	1	0	0.6
			4	20	0	0.9
					100	0.8
					300	0.7
3	10	60	3	30	0	0.5
			1	50	0	0.25
					250	0.175
					500	0.1
4	15	65	3	25	0	0.6
					250	0.5
					500	0.4
			2	50	0	0.3

Table A2. Delivery costs and MOV, MPQ associated with suppliers, list of product for each supplier and quantities discounts for this products, relatively example 2.

Supplier s	d_s	MOV_s	Product p	$pack_{sp}$	q_{spn}	c_{spn}
1	10	50	1	20	0	0.1
					1000	0.08
			2	40	0	0.01
					500	0.007
			3	30	0	0.04
			4	100	0	0.08
			5	1	0	0.09
					500	0.07
2	20	80	2	20	0	0.015
					400	0.01
			3	10	0	0.05
					500	0.04
			4	50	0	0.085
					300	0.06
					700	0.04
3	15	60	1	25	0	0.5
					750	0.04
			2	20	0	0.02
					1000	0.005
			5	35	0	0.095
					300	0.05