

An integrated Multi-objective Decision Making Process For Supplier Selection with Volume Discounts

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Abstract

Nowadays, purchasing decisions are increasingly considering both tangible and intangible factors that in supplier selection. If suppliers have capacity or other different constraints, the problem is to identify the potential suppliers and to allocate the optimal order quantity among the selected suppliers. In this paper an integrated model of analytic hierarchy process (AHP) and preemptive goal programming (PGP) is proposed. The model attempts to incorporate volume discount in a conflicting multi-objective scenario wherein one needs to maximize the total purchase value and minimize the total cost. The framework of the model will be illustrated by means of a numerical example.

Keywords

Supplier Selection, volume discount, analytic hierarchy process, preemptive goal programming

1. Introduction

Most manufacturing enterprises are organized as networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers. Supply chain management administers these networks which require tight coordination both within the organization and outside the organization. Since this coordination with supplier is outside the organization it is not easy unless systems for cooperation are integrated properly. Therefore, this makes supplier selection a very important facet that contributes to the long term growth of the company. In general, supplier selection is not based on a single universal criterion; instead it is the result of a multi-criteria decision [1]. Practically, every company has a policy to short list the suppliers so as to make sure they meet the minimum qualification criteria as deem fit for the industry of business. Some of these supplier selection methodology could be very subjective in nature and the others have a more structured and scientific objective approach towards the selection process. The methodology for the solving such problem is primarily based on multiple and conflicting objectives [2]. As no individual method can solve this type of problem to our satisfaction it is best to come up with a concoction that would eventually bring in the best in each of the individual methods. The significance that is attributed to the supplier selection is evident based on the sheer number of research papers that address this topic over the years.

It is evident from the literature that supplier selection criteria and the methods to solve the supplier selection problem are going to evolve over time. Among the factors, quality, cost, problem solving capability, expertise, delivery lead time, experience, service and reputation are the key tangible and intangible factors that are recently addressed by most authors [3, 1]. In terms of the solution methodology, it is also evident from the literature that supplier selection problem is a multi-objective problem. There is a wide reference of AHP technique that has been used as a solution in combination with other techniques such as MCDM methods to address supplier selection problems [4, 5]. The goal programming (GP) is an important technique to find as a satisfying solution to MCDM problems [6]. AHP and GP were both integrated in order to take into account intangible and intangible factors to optimize order allocation among suppliers (7, 8, 2]. This paper presents a solution methodology in the context of a situation where vendors offer discounts on total amount of sales volumes and not on the quantity or variety of products. The paper attempts to use a combination of AHP and GP so as to incorporate volume discount in a conflicting multi-objective scenario wherein one needs to maximize the total purchase value and minimize the total cost. Although volume

2. Using AHP and PGP as an Integrated Approach

Given the evaluation criteria, we need to adopt a method that could prioritize the relative importance of the supplier. This is normally achieved by assigning weight factors so as to define the importance degree to each supplier criterion. But, the importance degree that is associated to each supplier criterion cannot be assigned arbitrarily because it might then lead to biases in the final decision. For this purpose, AHP is employed in the process for which the priorities are converted into ratings with regard to each criterion using pairwise comparisons and the consistency ratio.

AHP is a multi-attribute, decision-making approach based on the reasoning, knowledge, experience, and perceptions of experts in the field. It is a robust technique that allows managers to determine preferences of criteria for selection purposes, quantify those preferences, and then aggregate them across diverse criteria. Typically, AHP enables the decision maker to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria [9]. This method utilizes pairwise comparisons of the multiple criteria. The use of such pairwise comparisons to collect data from the decision-maker offers significant advantages. It allows the decision maker to focus on the comparison of just two objects, which makes observation as free as possible from extraneous influences. Additionally, pairwise comparisons generate meaningful information about the decision problem, improving consistency in the decision making process, especially if the process involves group decision-making [10].

Having arrived at the weight factor for each of the selection criteria, the final stage would be to use these weighted supplier selection criteria to evaluate and select the supplier who passes through to satisfy all these required criteria. But we again have multiple-objective criteria such as maximizing value and minimizing the cost in the presence of constraints (quality, demand and capacity) using the goal programming approach.

Goal programming is a procedure for handling multiple-objective situations within the general framework of linear programming, where each objective is viewed as a goal. Then given the usual resource limitations or constraints, the decision-maker attempts to develop decisions that provide the best solution in terms of as close as possible to reaching all the goals [11]. Along with the constraints such as suppliers' capacity, quality and demand, we use the suppliers rating as coefficients of multi-objectives functions in preemptive goal programming to allocate order quantities to the most favorable suppliers with relative portion of the orders. Such that the total value of purchasing is maximized as the first priority, the total cost of purchasing is minimized as the second priority. In general, it can be said that first the AHP ratings are used to prioritize the set of criteria and then this resulting prioritization information is used as ranking scheme within the framework of the Preemptive Goal Programming (PGP) model. Thus the preemptive goal programming model not only considers the relative importance or priority of the selection criteria but also considers the other important resources limitations faced by the organization when making the supplier selection decisions as well [12].

3. Framework of Model

The following steps are used in order to formulate the problem:

- Given the tangible and intangible factors for supplier, the relative importance of supplier evaluation is determined by using the AHP method.
- The consistency indexes are computed and compared to the random index. If the consistency is not satisfactory then the pairwise comparisons are again done and the consistency indexes are recomputed. The process will continue to iterate until the degree of consistency is found to be satisfactory.
- The overall score for each supplier is computed as part of the PGP model.
- The objective functions of the model are structured. The objectives are to maximize the value and minimize the cost. The primary goal of value proposition is derived based on the overall score for each supplier as computed by AHP. The secondary goal of minimizing the cost is also defined.
- A number of constraints that is applicable to the model such as demand of the product, capacity of the suppliers, and quality of the product are considered in the model.
- The PGP model is then solved by using appropriate software and finally the results are examined to see whether the goals are satisfied.

4. Assumptions

The following assumptions were made so as to arrive at the framework detailed below:

- There is no restriction on the market share from any of the suppliers.
- There is no limitation on the business volume that could be awarded to any single supplier.
- There is no limit on the number of suppliers that could fulfill the demand on hand.
- Volume discount are applicable based on the cumulative orders placed during the study period and the ordered quantity will not impact the costs involved.
- Ordering costs, inventory holding costs are not considered as part of the model.
- The volume discount slabs are constant throughout the study period.
- The demand is constant for the study period.
- The model assumes that there is only one product for which allocation has to be made.
- Quality of the item procured from the supplier will be constant throughout the study period.

5. PGP Model Formulation

We consider a situation where there are some constraints such as suppliers' capacity, quality, demand and we use the suppliers rating as coefficients of multi-objectives functions in preemptive goal programming to allocate order quantities to the most favorable and with relative portion of the orders, such that the total value of purchasing is maximized as the first priority and the total cost of purchasing is minimized as the second priority.

5.1 Notation

The following notation was used to construct the model:

- Q_i : quantity of item ordered from the i^{th} supplier
- N : total number of suppliers
- D : demand of the item
- w_i : weight factor derived from AHP for the i^{th} supplier
- c_i : capacity of the i^{th} supplier
- x_i : percentage of defect items rejected from the i^{th} supplier
- X : maximum defect rate acceptable by the buyer
- uc_i : unit cost of item from the i^{th} supplier
- W : expected average value of the business done with the suppliers
- TC : total cost of the purchase
- v_{ij} : volume of business awarded to the i^{th} supplier in the j^{th} discount bracket
- m : total number of discount brackets
- u_{ij} : upper cut-off point of the j^{th} discount bracket of the i^{th} supplier
- d_{ij} : percentage discount associated with j^{th} discount bracket of the i^{th} supplier
- $y_{ij}=1$, if volume of business awarded to the i^{th} supplier with the j^{th} discount bracket
- $y_{ij}=0$, otherwise
- P_1, P_2 : Priority 1 goal and Priority 2 goal respectively
- d_1^-, d_1^+ : Deviation variables on purchase value
- d_2^-, d_2^+ : Deviation variables on purchase cost

6. Complete Model

The multi-objective preemptive goal programming model can be shown as: Preferably, they should be prepared with an Equation Writer. See Equation (1) below for the demonstration.

$$\text{Min } Z = P_1 d_1^-, P_2 d_2^+ \quad (1)$$

Subject to:

$$\sum_{i=1}^n \left(\frac{w_i Q_i}{D} \right) + d_1^- - d_1^+ = W \quad (2)$$

$$\sum_{i=1}^n Q_i = D \quad (3)$$

$$Q_i \leq c_i \quad (4)$$

$$\sum_{i=1}^n \sum_{j=1}^m (1 - d_{ij}) v_{ij} y_{ij} + d_2^- - d_2^+ = TC \quad (5)$$

$$\sum_{i=1}^n \frac{x_i Q_i}{D} \leq X \quad (6)$$

$$\sum_{j=1}^m v_{ij} y_{ij} = uc_i Q_i \quad (7)$$

$$v_{ij} \leq u_{ij} y_{ij} \quad (8)$$

$$v_{ij+1} \leq u_{ij} y_{ij+1} \quad (9)$$

$$\sum_{j=1}^m y_{ij} = 1 \quad (10)$$

Constraint (2) specifies the average value proposed by the supplier, which should at least meet the expected average value (W) of the business done with the suppliers. The demand constraint is formulated by constraint (3), since sum of the assigned order quantities to all vendors should meet the buyer's demand. Constraint (4) ensures that ordered quantity for each supplier is less than or equal to its capacity. Constraint (5) makes certain that the aggregated total cost after accommodating for discounts will not exceed the budgeted total (TC) of the company. Constraint (6) ensures that the product quality of each supplier is accordance with the requirement. Since the volume is based on the number of units purchased and the unit cost associated with each unit purchased, the appropriate discount slab is formulated in constraint (7). Finally, the discount slabs are structured based on the volume of purchase, which are formulated in constraints (8), (9), and (10).

7. Numerical Example

To illustrate the model, in this section a numerical example has been used to demonstrate the combined methodology of AHP and PGP in order to solve the problem of supplier selection for a company located in Los Angeles area given a number of tangible and intangible criteria. The company employs four different suppliers with seven criteria including low initial price, cost reduction activities, conformance quality, consistent delivery, delivery speed, product volume changes and short setup times. The volume discount schedule is shown in Table 1. Other pertinent information including supplier capacity, average defect ratio and unit cost of the product are shown in Table 2.

Table 1: Volume discount schedule

Sales Volume	Discount (%)
0-100	0
100-250	5
250 and over	10

Other pertinent information including supplier capacity, average defect ratio and unit cost of the product are shown in Table 2.

Table 2: Pertinent data for each supplier

	Supplier			
	S1	S2	S3	S4
Capacity	200 units	500 units	400 units	800 units
Defect Ratio %	1%	2.2%	1.5%	2.5%
Unit Cost	\$1.2	\$0.9	\$1.1	\$1.0

The demand for the product is 1000 units per unit time and the average defect ratio should not be less than 2%. The company wants to ensure that the average value proposition the suppliers bring to the business must not be less than 0.25 and at the same time they would like to fulfill the demand without exceeding the budget of \$925.

7.1 Application of AHP

AHP technique was used to compute the evaluating score for each candidate supplier. Due to limited space, the pairwise comparison among the evaluating criteria is omitted and only the final result is shown in Table 3. If there

were no other constraints other than selecting the supplier with the highest rating, then supplier 4 with the maximum rating would have been chosen and all demanded units would have been purchased from this supplier. But as indicated in the problem, there are two major goals that need to satisfy as well as the merit of using volume discounts. The goals are to maximize the total value and to minimize the total cost in the presence constraints, such as supplier's capacity, quality, unit cost, and demand.

Table 3: AHP result and the overall score for each supplier

Evaluating Criteria	Evaluating Weight	S1	S2	S3	S4	Consistency
Low Initial Price	10.296	0.356	0.194	0.325	0.125	Passed
Cost Reduction Activities	21.158	0.244	0.099	0.244	0.413	Passed
Conformance Quality	4.102	0.477	0.351	0.114	0.058	Passed
Consistent Delivery	6.216	0.094	0.248	0.456	0.202	Passed
Delivery Speed	15.210	0.140	0.081	0.260	0.519	Passed
Product Volume Changes	30.108	0.360	0.258	0.142	0.240	Passed
Short Setup Time	12.909	0.147	0.090	0.065	0.699	Passed
Overall Scores		26.229	17.233	20.880	35.658	
Value		0.262	0.172	0.209	0.357	

7.2 PGP Model Formulation and solution interpretation

Given the two major goals and the pertinent data, the PGP model was constructed and solved using the LINGO software. By solving the model, we got the results that are summarized and indicated in Table 4. As one can see from Table 4, the total value (priority 1 goal) has been maximized with a value of 0.2532, which is well beyond of the given threshold requirement of 0.25 and the total cost (priority 2 goal) has not been achieved and exceeds the given threshold of \$925.

Table 4: Solution interpretation at the first stage

Solution Results	Value	Comments
Supplier 1	200 units	Within the capacity of 200
Supplier 2	277 units	Within the capacity of 500
Supplier 3	227 units	Within the capacity of 400
Supplier 4	296 units	Within the capacity of 800
Average Value	0.2532	Better than the expected value of 0.25
Total Cost	\$968.45	Not satisfy priority goal 2 of \$925
Average Defects	1.89%	Better than the expected value of 2.0%

But it can also be noted that the goal of minimizing the Total Cost has not been achieved and exceeds the given threshold of \$925. There is a potential for saving costs if we could exploit the volume discounts provided. This relationship is depicted in Figure 1.

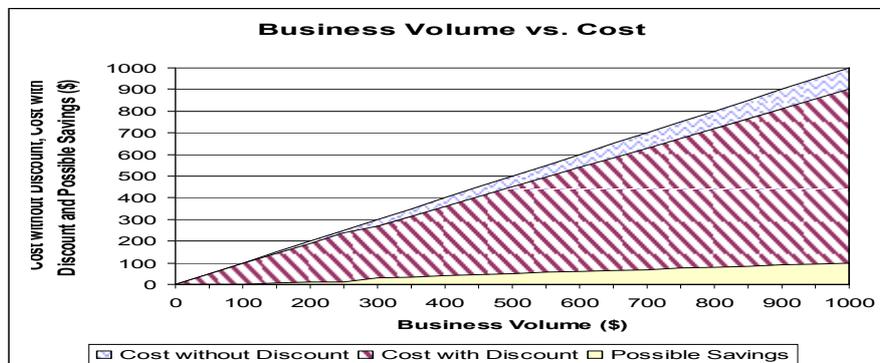


Figure 1: Relationship between business volume and cost

Not achieving both goals at the first stage, we did proceed to the next step of adding additional constraints to the model based on the values for the deviational variables for the priority one goal. After adding the new constraint and including the priority 2 goal in the objective function, the interpretation of the solution is summarized and shown in Table 5.

Table 4: Solution interpretation at the second stage

Solution Results	Value	Comments
Supplier 1	89 units	Within the capacity of 200
Supplier 2	278 units	Within the capacity of 500
Supplier 3	297 units	Within the capacity of 400
Supplier 4	336 units	Within the capacity of 800
Average Value	0.2532	Better than the expected value of 0.25
Total Cost	\$923.07	Better than the expected value of \$925
Average Defects	1.99%	Better than the expected value of 2.0%

Table 4 shows that the total value is now 0.2532, which is the same as obtained at the first stage and at the same time the total cost, which now is \$923.07. Thus this is an overall more efficient model compared to previous one which brings in both better value and better cost savings as well.

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