Integrated model for Multi-criteria Supplier Selection and Order Allocation Problem

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Abstract. This paper discusses an integrated model of selecting suppliers and order allocation for a company that wishes to decide the quantity to be ordered from each supplier on the basis of some qualitative criteria. Since each supplier may have a different performance with respect to these criteria, an integration of analytical hierarchy process and linear program model is proposed to solve the problem in two stages. In the first stage, suppliers are evaluated based on qualitative criteria to consider both tangible and intangible factors in choosing the best suppliers. The output of this stage is the final score of each supplier. In the second stage, a linear programming model is proposed to placing the optimum order quantities among them such that the total final scores of suppliers become maximum. The mathematical programming model is validated through numerical analysis, and the computation result shows that the model is effective and applicable.

Keywords: supplier selection, order allocation, multiple criteria decision making, analytical hierarchy process, linear programming.

1. Introduction
To be able to survive the current business competition, supplier selection process is a very important issue to be well planned. This is because suppliers will not only determine the price of goods or materials needed, but also the time of delivery. In addition to the price and delivery time, supplier selection is generally based on other criteria, such as goods’ quality, after-sales service, response to order changes, supplier's financial condition, supplier location, etc. It is clear that the selection of supplier involves multi-criteria, both quantitative and qualitative. Since there are often conflicts between these criteria, supplier selection should be done by aligning both types of criteria.

Based on the ability of suppliers to meet the needs of buyers, supplier selection issues can be categorized into two types of issues [1]. If all buyers’ needs can be met by one supplier, the issue to be resolved is to choose one best supplier based on predefined criteria. If there is no single supplier can fulfill all of the needs of buyers, then the problem to be solved is to select some suppliers and at the same time specifying the number of items to be ordered from the selected supplier, so that the value of purchase can be maximized. Clearly, the second type of problem is more complex than the first one.

Some models and methods of supplier selection and order quantity allocation problem have been developed by many researchers, where mathematical programming models and approaches have been widely used. Among others is integer linear programming model with the objective of maximizing the preference weight of supplier [2], mixed integer programming (MIP) model with various objectives,
such as minimizing both the cost and the number of suppliers [3], minimizing the total of purchasing, inventory, transportation, and supplier management costs [4], minimizing the total of selecting, procuring, holding, and shortage costs [5]. Another methods considering multi-objective have also been developed, such as multi-objective mathematical model which minimize total cost and maximize total social, total environmental, and total economic qualitative scores [6], multi-objective mixed integer non-linear programming (MINLP) model which considered cost, quality and service level [7,8], and a hybrid of the DEA, fuzzy multi-objective programming and genetic algorithm [9].

The purpose of the study is to create an optimization model to determine the allocation of orders to a number of suppliers, where there are three important issues to be decided. These three issues comprise of determining the ability level of each supplier to meet the criteria set by the buyer, determining the quantities of material to be ordered, and determining the ordering time to fulfill the needs.

This paper is organized as follows. A brief review of the literature is presented in section 2, while section 3 contains the research methodology. Section 4 and 5 contain a numerical example, the results, and the discussions, while the conclusions is presented in section 6.

2. Methods

To solve the integrated problem of supplier selection and order allocation, a comprehensive framework is proposed. The proposed approach presents two-stage decision making procedure, where AHP is applied in the first stage to evaluate the weight of each supplier performance, and a linear programming model is applied in the second stage to allocates order quantities between the suppliers. The proposed algorithm consists of the following steps:

1. Constructing a hierarchical system
2. Preparing a pair-wise comparisons matrix and perform the synthesis process.
3. Calculating the weights and testing the consistency ratio.
4. Computing the overall performance score of each supplier.
5. Constructing the linear programming model

2.1 Constructing the hierarchical system

Structuring a hierarchy/decision model, i.e. to construct hierarchies based on the objectives, criteria, sub-criteria and alternatives, so that the overall structure/decision model is visible.

2.2 Making pair-wise comparison and perform the synthesis process

As explained in Saaty [10], after the hierarchy has been structured, the next stage is to do a pair-wise comparison and provide judgement to the pair of criteria, sub-criteria, or alternatives using a basic scale (fundamentals scale) 1 to 9. This assessment is done by comparing a number of combinations of components that exist at each level of the hierarchy, so that the quantitative analysis to determine the magnitude of the weight can be done.

2.3 Calculating the weights and testing the consistency ratio

Perform the normalization process, i.e. making the unit of each criterion, sub-criterion, or alternative to be the same, so that we can compare each criterion, sub-criterion or alternative. Then calculate the Consistency Ratio (CR) to determine the level of consistency of the decision maker in providing judgement. If the CR is < 10% then the decision maker is already consistent in doing their judgement.

2.4 Computing the total performance score of each supplier

To determine the performance rating of each supplier, multiply the value of each sub criterion with the weight of that sub criterion, then sum that value to all criteria.

2.5 Building the linear programming model

Construct a linear programming model using the suppliers’ performance rating as the coefficient of the objective function to be maximized. The goal is to allocate the order quantities subject to some important constraints.
3. Results and Discussions

The following illustration is intended to explain how the proposed model is used. Suppose that the constraints of this linear programming are buyer’s demand, supplier’s capacity, supplier’s defect rate, and supplier’s delivery reliability, then the objective function and constraints of this linear programming are as follows.

3.1 Notations

- $S_j$: final score of supplier $j$
- $V_j$: maximum quantity that can be supplied by supplier $j$
- $L_j$: lot-size of supplier $j$
- $D$: buyer’s demand quantity
- $q_j$: percentage of defect rate of supplier $j$
- $Q$: buyer’s maximum acceptable defect rate
- $r_j$: percentage of late delivery of supplier $j$
- $R$: buyer’s maximum acceptable late delivery
- $X_j$: integer decision variable denoting the number of lots ordered from supplier $j$

3.2. The Objective Function

The objective function to maximize the total final scores of all suppliers can be shown as

$$\text{Max} \sum S_j X_j L_j \quad j = 1, 2, ..., n$$  \hfill (1)

3.3. The Constraints

The important constraints of the problem are buyer’s demand quantity, the quality, the delivery reliability, and the supplier’s capacity, which are formulated as follows:

**Demand constraint**

The total order quantity of the item from all suppliers must meet the demand quantity of the item. It can be stated as

$$\sum X_j L_j \leq D \quad j = 1, 2, ..., n$$  \hfill (2)

**Quality constraint**

The total defect quantity of the item cannot exceed maximum total acceptable defect quantity, therefore,

$$\sum q_j X_j L_j \leq QD \quad j = 1, 2, ..., n$$  \hfill (3)

**Delivery constraint**

The total late delivery cannot exceed maximum total acceptable lateness. It can be stated as

$$\sum r_j X_j L_j \leq RD \quad j = 1, 2, ..., n$$  \hfill (4)

**Supplier’s capacity constraint**

The order quantity of the item cannot exceed the supplier’s capacity. It can be stated as

$$X_j L_j \leq V_j \quad j = 1, 2, ..., n$$  \hfill (5)

**Non-negativity constraint**

$$X_j \geq 0, \text{ integer} \quad j = 1, 2, ..., n$$  \hfill (6)

3.4. Final Model

The final integrated linear integer programming model can be shown as

$$\text{Max} \sum S_j X_j L_j \quad j = 1, 2, ..., n$$  \hfill (7)

Subject to:

$$\sum X_j L_j \leq D \quad j = 1, 2, ..., n$$  \hfill (8)

$$\sum q_j X_j L_j \leq QD \quad j = 1, 2, ..., n$$  \hfill (9)

$$\sum r_j X_j L_j \leq RD \quad j = 1, 2, ..., n$$  \hfill (10)
\[ X_j L_j \leq V_j \quad j = 1, 2, ..., n \]  
\[ X_j \geq 0, \text{ integer} \quad j = 1, 2, ..., n \]  
(11)  
(12)

The objective function (7) is to maximize the total final scores of all suppliers. The constraint (8) stating that the total order quantity of the item from all suppliers must meet the demand quantity of the item. The constraint (9) stating that the total defect quantity of the item cannot exceed maximum total acceptable defect quantity. The constraint (10) stating that the total late delivery cannot exceed maximum total acceptable lateness. The constraint (11) stating the supplier’s capacity constraints, while constraint (12) stating that the number of lots ordered has to be integer and non-negative value.

3.5. Numerical Example

Suppose a company wishes to place an order of 1200 pieces of particular item, for which four suppliers are available. Each supplier accepts orders in lot-sizes that vary from supplier to supplier. The lot-size for supplier A, B, C, and D is 40, 70, 60, and 50, respectively. Each supplier can supply only a maximum quantity given by 800, 500, 600, and 900 units for supplier A, B, C, and D respectively. The previous record shows that the defect rate for supplier A, B, C, and D is 3%, 5%, 1%, and 6% respectively, while the record of on-time delivery for supplier A, B, C, and D is 93%, 98%, 85%, and 92% respectively. The company’s maximum acceptable defect rate is 4% and the maximum acceptable lateness is 8%.

3.5.1 Supplier Selection. Suppose the company have found five most important criteria and 11 sub-criteria as shown in Table 1, that leads to the hierarchy structure of the problem as shown in Figure 1.

| Main-criteria         | Sub-criteria                          | Description                                      |
|-----------------------|---------------------------------------|--------------------------------------------------|
| Purchasing Cost       | Product price                         | Price offered by supplier                        |
|                       | Condition of payment                  | Date of maturity of the invoice                  |
| Product Quality       | Defect ratio                          | Defective percentage rate                        |
|                       | Supporting document                   | All important documents are available            |
| Delivery Reliability  | On-time delivery                      | Goods are delivered as per PO date               |
|                       | Delivery accuracy                     | Goods are delivered in accurate quantities       |
|                       | Delivery time                         | Total time since order to delivery               |
| Service               | Responsiveness to request for quotation | Supplier promptly submits quotation after receiving a request for quotation |
|                       | Responsiveness to claim/problem resolve | Supplier quickly responds back when claim/problem is reported |
| Flexibility           | Inventory availability                | Supplier’ ability to fulfill customer’s demand   |
|                       | Negotiability                         | Supplier’ willingness to negotiate on price and delivery schedule |

**Figure 1.** The hierarchical structure for supplier selection
The input data consisting of pair-wise comparison matrix of the suppliers for the five main criteria is given in Table 2.

Table 2. The pair-wise comparison for the five main-criteria

| Criteria          | Purchasing Cost | Product Quality | Delivery | Service | Flexibility |
|-------------------|-----------------|-----------------|----------|---------|-------------|
| Purchasing Cost   | 1               | 1               | 3/2      | 2       | 2           |
| Product Quality   | 1               | 1               | 3/2      | 2       | 2           |
| Delivery          | 2/3             | 2/3             | 1        | 3/2     | 3/2         |
| Service           | 1/2             | 1/2             | 2/3      | 1       | 3/2         |
| Flexibility       | 1/2             | 1/2             | 2/3      | 1       | 3/2         |

For simplicity, let say that the sub-criteria product price is twice more important than the condition of payment, the defect ratio is three times more important than the supporting document, the responsiveness for quotation is 1.5 times more important than the responsiveness to claim resolve, and the inventory availability is twice more important than the negotiability, and the pair-wise comparison matrix for the sub-criteria of delivery is shown in Table 3.

Table 3. The pair-wise comparison for the five main-criteria

| Sub-criteria          | On-time Delivery | Delivery Accuracy | Delivery time |
|-----------------------|------------------|-------------------|---------------|
| On-time Delivery      | 1                | 3/2               | 2             |
| Delivery Accuracy     | 2/3              | 1                 | 3/2           |
| Delivery time-cost    | 1/2              | 2/3               | 1             |

The pair-wise comparison matrices for each of 11 sub-criteria are shown in Table 4 to Table 8.

Table 4. Pair-wise comparison for the sub-criteria of purchasing cost

| Supplier | Product price of supplier | Condition of payment of supplier |
|----------|---------------------------|----------------------------------|
|          | A  | B  | C  | D  | A   | B   | C   | D  |
| A        | 1  | 2  | 3/2| 3  | 1   | 2/3 | 1/2 | 1/2|
| B        | 1/2| 1  | 3/2| 3  | 2   | 1   | 2/3 | 1/2|
| C        | 2/3| 2/3| 1  | 2  | 2   | 3/2 | 1   | 3/2|
| D        | 1/2| 2/3| 1/2| 1  | 2   | 2   | 2/3 | 1  |

Table 5. Pair-wise comparison for the sub-criteria of product quality

| Supplier | Defect ratio of supplier | Supporting document of supplier |
|----------|--------------------------|---------------------------------|
|          | A  | B  | C  | D  | A   | B   | C   | D  |
| A        | 1  | 4/3| 3/2| 2  | 1   | 1   | 1   | 1  |
| B        | 3/4| 1  | 2  | 5/2| 1   | 1   | 1   | 1  |
| C        | 2/3| 1/2| 1  | 3/2| 1   | 1   | 1   | 1  |
| D        | 1/2| 2/5| 2/3| 1  | 1   | 1   | 1   | 1  |

Table 6. Pair-wise comparison for the sub-criteria of delivery

| Supplier | On-time delivery of supplier | Delivery accuracy of supplier | Delivery time of supplier |
|----------|-------------------------------|-------------------------------|----------------------------|
|          | A  | B  | C  | D  | A   | B   | C   | D  |
| A        | 1  | 2  | 2  | 3/2| 1   | 1/2 | 2/3 | 1/3|
| B        | 1/2| 1  | 1  | 2/3| 2   | 1   | 3/2 | 2/3|
| C        | 1/2| 1  | 1  | 2/3| 3/2 | 2/3 | 1   | 1/2|
| D        | 2/3| 3/2| 3/2| 1  | 3   | 3/2 | 2   | 1  |
Table 7. Pair-wise comparison for the sub-criteria of service

| Supplier | Responsiveness for quotation of supplier | Responsiveness to claim resolve of supplier |
|----------|------------------------------------------|---------------------------------------------|
| A        | 1/2                                      | 1/3                                         |
| B        | 1/3                                      | 2/3                                         |
| C        | 1/4                                      | 2/3                                         |
| D        | 2/3                                      | 1/4                                         |

Table 8. Pair-wise comparison for the sub-criteria of flexibility

| Supplier | Inventory availability of supplier | Negotiability of supplier |
|----------|-----------------------------------|---------------------------|
| A        | 1/3                               | 1/2                       |
| B        | 1/2                               | 3/2                       |
| C        | 2/3                               | 1/2                       |
| D        | 3/2                               | 1/4                       |

In order to determine the final score of each supplier, the AHP model is performed using *Expert Choice* software, where the result is given in Figure 2.

Figure 2. The final score of each supplier

3.5.2 Order Allocation

In order to find the best order quantities, the total final scores of suppliers should be maximized. The model formulation is as follows.

3.5.2.1 Objective function

The objective to maximize the total final scores of all suppliers is expressed as:

\[
\text{Max} \quad 0.280 X_1 + 0.245 X_2 + 0.235 X_3 + 0.240 X_4
\]

3.5.2.2 The demand constraint

The total order quantity of the item from all suppliers must meet the demand quantity of the item, therefore:

\[
40 X_1 + 70 X_2 + 60 X_3 + 50 X_4 \leq 1200
\]

3.5.2.3 The quality constraint

The total defect quantity of the item cannot exceed maximum total acceptable defect quantity, therefore:
(0.03 x 40) \( X_1 \) + (0.05 x 70) \( X_2 \) + (0.01 x 60) \( X_3 \) + (0.06 x 50) \( X_4 \) ≤ (0.04 x 1200)  
or  
1.2 \( X_1 \) + 3.5 \( X_2 \) + 0.6 \( X_3 \) + 3 \( X_4 \) ≤ 48 

### 3.5.2.4 The delivery constraint

The total late delivery cannot exceed maximum total acceptable lateness. It can be stated as: 
(0.07 x 40) \( X_1 \) + (0.02 x 70) \( X_2 \) + (0.15 x 60) \( X_3 \) + (0.08 x 50) \( X_4 \) ≤ (0.08 x 1200)  
or  
2.8 \( X_1 \) + 1.4 \( X_2 \) + 9 \( X_3 \) + 4 \( X_4 \) ≤ 96

### 3.5.2.5 The supplier’s capacity constraint

The order quantity of the item cannot exceed the supplier’s capacity. It can be stated as 

- 40 \( X_1 \) ≤ 800  
- 70 \( X_2 \) ≤ 500  
- 60 \( X_3 \) ≤ 600  
- 50 \( X_4 \) ≤ 900

The problem is then solved using Linear Interactive Discrete Optimizer (LINDO) software, where the report is shown in Figure 3, where the solution gives an optimal order of 20 lots with supplier A and 8 lots with supplier D, and the total final scores is 7.52. No orders are placed with the supplier B and C.

![LINDO Report](image)

**Figure 3. Problem and solution report for the example**

The numerical example demonstrates that the model offers a reasonable and realistic solution based on the imposed objective and constraints. The optimum solution shows that to obtain 1200 units of the demanded product, the company has to order 20 lots of product from supplier A which means that the quantity of product ordered from supplier A is (20 x 40) = 800 units. In addition, the company has to
order 8 lots of product from supplier D, which means that the quantity of product ordered from supplier D is \( (8 \times 50) = 400 \) units.

Since the company’s maximum acceptable defect rate is 4% and the maximum acceptable lateness is 8%, then the total defect product has to be less than \( (0.04 \times 1200) = 48 \) units and the total product with late delivery has to be less than \( (0.08 \times 1200) = 96 \) units. From the optimum solution it can be resumed that the total number of defect products from both suppliers A and D is \( (0.03 \times 800) + (0.06 \times 400) = 48 \) units, which is equals to the company’s maximum acceptable defect rate. The total unit of product that will be late delivered both from supplier A and D is \( (0.07 \times 800) + (0.08 \times 400) = 88 \) units, which is less than the company’s maximum acceptable lateness.

4. Conclusion
The overall supplier selection problem of multiple sourcing is not only to select the right suppliers, but also to allocate optimal order quantity among the selected suppliers, based on a number of key criteria such as costs, quality, delivery reliability, supplier’s capacity, etc. For these purposes, the two-stage decision making procedure was developed in this paper. Firstly, a hierarchical structure for supplier selection was developed through the analytical hierarchy process, in consideration of both quantitative and qualitative criteria, in order to identify a set of candidate suppliers. Secondly, to help management allocate the optimum order quantities to the candidate suppliers, a linear programming model was formulated such that the total final score of suppliers becomes maximum.

The advantage of this proposed model is that it can deal with multiple criteria, both qualitative or quantitative, such as cost, quality, delivery reliability, customer services, and many other criteria in supplier selection problems. For future research, this model can be extended by considering uncertainties, since many parameters may not be estimated certainly, such as customer demand and supplier’s capacity.

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