Supply Chain Expansion Using AHP, ILP and Scenario-Planning

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ABSTRACT

A strategic supply chain decision problem is solved and results are illustrated with an example. First, a mathematical model is formulated for selection of facility locations by minimizing various costs. Uncertainties in future demand and other parameters are dealt with using a scenario based planning method. Finally, an AHP method utilizes several non-cost criteria to produce an integrated decision. The results of this research can be considered as the groundwork for the design of a computer-based decision support system (DSS) that will be able to meet real world needs effectively.

INTRODUCTION

A supply chain is “an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to acquire raw materials/ingredients/components, convert these raw materials/ingredients/components into specified final products, and deliver these final products to retailers” (Beamon, 1998). At the end of the chain, the retailers sell the products directly to the customers. A supply chain is usually characterized by a forward flow of materials and a backward flow of information between the business entities. Managing a supply chain requires operational level decisions. A supply chain operates on its existing business entities, with their facility locations and the network connecting those locations. Designing a supply chain is an important strategic decision in all organizations. Its importance has increased further as more organizations have been realizing the possibilities of gaining additional value for their customers by restructuring the supply chain. In fact, the growing awareness of the positive impact of supply chain management on organizations’ competitiveness, profitability, and strategic advantage has made supply chain a truly strategic issue and thus it has received increased attention everywhere (O’Laughlin and Copacino, 1994; Clinton and Calantone, 1997). Strategic decisions require information projection for many years in to the future. Such information is not usually available with certainty at the time when decisions are made.

Decisions for new facility locations are crucial for supply chains operating under an uncertain environment. In this paper, we discuss a facility location problem for a supply chain serving different regional markets with possibilities for future demand, market, and cost changes which cannot be predicted with an acceptable level of accuracy at the time of planning. Where to locate and operate new distribution centres is an important decision to be made. In making such a decision, the trend is to develop a deterministic mathematical model and then solve the model for an optimal solution. The solution is optimal for one particular forecast of future market demand that may turn out to be far from optimal and very costly if the projected demand does not materialize. Usually sensitivity analysis is performed to show the effect of demand and other parameters change on the optimal solution. However, the sensitivity analysis may not provide any strong evidence for making a decision over the long term. Thus, in this paper, we introduce a methodology based on scenario planning and multi-criteria decision making to address the uncertainties of the future model parameters. The methodology is very challenging, and new in the literature, as it requires dealing with two different decision spaces namely location space and scenario space. In reality, the scenarios are non-comparable options. However it helps to incorporate the non-cost decision parameters and criteria in the decision process which are very common in any practical decision environment.

As outlined in Figure 1, the facility location problem will be solved using a scenario-based approach. To tackle the future market-demand uncertainties, first planners will generate a list of possible scenarios qualified by a set of parameters such as expansion models, demand and cost forecast, and other external factors. Since all scenarios cannot be exhaustively investigated, domain experts will select a set of most likely scenarios for further detailed analysis. Each of the selected scenarios will be formulated as a mathematical model that will be solved using a suitable optimization technique. Specifically, we use integer linear programming (ILP) techniques to minimize the total cost of expansion. A sensitivity analysis is performed to see the effect of different parameters. In most cases it is unlikely that the management would be able to make a decision with confidence when such deterministic outcomes are obtained by considering the cost alone. Therefore, a number of other criteria affecting the location decision will be considered and a multi-criteria decision model will be developed to rank the scenarios. For this we
specifically use the Analytic Hierarchy Process (AHP) (Saaty, 1980; Saaty and Vargas, 1994; Saaty, 1995) methodologies. The AHP is a popular multi-criteria decision model (MCDM) that allows both subjective and objective criteria in the same decision hierarchy. Finally, all this information will be combined before prescribing the final decision.

The relevant work in supply chain expansion is briefly reviewed in this section. Korpela and Lehmusvaara (1999) and Korpela et al (2001) considered a customer-service oriented supply chain design problem in which the AHP and mixed integer programming are used together. In any company, strategic decisions are made for the long term. Once a facility is established, it is not supposed to be relocated for many years. Thus, a thorough analysis based on both subjective and objective information is extremely important. In addition, the decision process must involve a good number of future years instead of the one period static model of Korpela and Lehmusvaara (1999). They considered an environment where the customers had access to a number of facilities implying that the facilities were closely located. In their approach, they first calculated customers’ priorities that are later used as inputs to the integer programming model. For long term survival, the installation and operating costs are important matters for customers. As it will be explained later, other non-cost factors are important as well. We address a strategic supply chain redesign problem by considering a multi-period planning environment and future uncertainties. However, as the facility locations considered in this research are geographically dispersed, the customers’ priorities that vary from location to location will not be considered in the model. Kengpol (2004) considered a problem for evaluating investment decisions for establishing a new distribution centre in Bangkok. His problem definition is similar to the

![Figure 1. A Problem Solving Approach](image-url)
The problem considered in this paper. However the methodologies are significantly different. We have used a combined integer-linear programming model for the location and transportation decisions simultaneously. Kengpol (2004) first used a standard linear programming model for evaluating the total transportation costs alone and then a simple logic-based (implemented in a DSS) methodology for determining the locations. Such a sequential approach may provide suboptimal solutions. Besides this, the criteria used by Kengpol for the associated AHP model are all different from our model. In addition, we considered a scenario based planning process to tackle long-term uncertainties.

The problem is defined in the second section; the mathematical formulation is presented in the third section; the scenario planning is discussed in the fourth section; a numerical example is illustrated in the fifth section; and conclusions are drawn in the last section.

**PROBLEM DEFINITION**

Consider a supply chain as shown in Figure 2. There is only one manufacturing unit that supplies goods to a number of geographically dispersed regional retailers in the country. The retailers are responsible for meeting the field/market demand in their localities. The management realizes that the demand has been increasing for the last few years and will continue to grow in the future. Therefore, the organization is planning to establish new distribution centres instead of supplying from the present small centre located next to the manufacturing unit. As the manufacturing unit may not be centrally located relative to the current regional retailers, management is interested in exploring two major options in their expansion program. These are:

I. Expanding the existing distribution centre, which is next to the manufacturing unit, and constructing at least one distribution centre in a new location,
II. Constructing two or more distribution centres in new locations.

We may generate many sub-options such as a number of possible locations for the new distribution centre. The new problem is presented in Figure 3 where a manufacturing unit delivers goods to the regional retailers via two or more distribution centres. One of the distribution centres can be located either next to the manufacturing unit or at a new location. The other distribution centres will have to be located at new locations.

![Diagram](image)

The suppliers of raw materials to the manufacturer are excluded from our consideration, as they would not affect the decision process underlying the problem being considered in this paper. In Figure 3, the distance between distribution centre 1 and the manufacturing unit is assumed to be zero in order to imply their concurrent location. The bold lines in the figure represent the existing structures. Similarly, if the new distribution centre is located at an existing retailer, the distance between these two facilities will be considered zero. Management wishes to have at least two distribution centres. However, if two facilities (manufacturing unit and distribution centre) are located in one location there may be some advantages in terms of operations and cost savings that have to be included in the model. As in Figure 3, we need to select at least two locations out of I possible locations for the distribution centres. We must emphasize that once the locations for
the distribution centres are determined, they will not be changed in the near future. As demand at the retailers and other cost parameters change over time in the uncertain and dynamic market environment, and the establishment of distribution centres is a strategic decision (once established, they would be used for many years), we need to consider a number of future periods in developing any decision model. For a fair comparison with alternatives, all costs must be converted to their net present values in this multi-period planning problem.

**MODEL FORMULATION**

To determine the locations of the distribution centres at the minimum cost, we adopt a mathematical programming approach as presented below.

**Variables:**

\[
x_i(t) \quad \text{Amount shipped from the manufacturing plant to a distribution centre } i \text{ in period } t
\]

\[
y_{ij}(t) \quad \text{Amount shipped from a distribution centre } i \text{ to a retailer } j \text{ in period } t
\]

\[
z_i = \begin{cases} 
1 & \text{if a distribution centre is located in location } i \\
0 & \text{otherwise}
\end{cases}
\]

**Index:**

\[I = \text{number of distribution centres}; J = \text{number of retailers}
\]

\[T = \text{number of time periods considered in the planning problem}
\]

**Data:**

\[P_{cap}(t) \quad \text{Plant capacity in period } t
\]

\[D_{jt} \quad \text{Demand at retailer location } j \text{ in period } t
\]

\[F_{C}(i) \quad \text{Fixed cost for distribution centre } i
\]

\[T_{CMD}(i) \quad \text{Total transportation cost per unit for transporting between the manufacturing unit and distribution centre } i \text{ in period } t
\]

\[O_{CD}(i) \quad \text{Total operating cost for a distribution centre } i \text{ in period } t
\]

\[T_{CDR}(i,j) \quad \text{Transportation cost per unit for transporting between the distribution centre } i \text{ and retailer centre } j \text{ in period } t
\]

\[C_{A}(i) \quad \text{Any cost advantage in period } t \text{ if a distribution centre is located in location } i
\]

For simplicity, we assume that all costs defined above are given in present values (at \(t = 0\)) taking into consideration the discount factor or interest rate.

**Objective Function**

The objective is to minimize the sum of all fixed and variable costs.

\[
\min \sum_i F_{C}(i)z_i + \sum_t \sum_i O_{CD}(i)z_i + \sum_t \sum_i T_{CMD}(i)x_i(t) + \sum_t \sum_j \sum_i T_{CDR}(i,j)y_{ij}(t) - \sum_i \sum_t C_{A}(i)z_i
\]

\[i \in I, j \in J \text{ and } t \in T \quad (1)
\]

The first and second terms represent the fixed cost and operating cost for the distribution centres respectively. The third term calculates the transportation cost from the manufacturing unit to the distribution centre. The fourth term represents the transportation cost from the distribution centres to all retailers. The fifth or last term is for any cost savings if any facility is located in any particular location and therefore is subtracted from others.

**Constraints**

The number of distribution centres should be at least two.

\[ \sum_i z_i \geq 2 \]  
(2)

The amount shipped from the manufacturing plant to all distribution centres must be equal to or less than the plant’s capacity.

\[ \sum_i x_{it} \leq Pcap_t \quad \forall t \]  
(3)

The amount shipped from the manufacturing plant to any established distribution centre i must be equal to or less than the plant’s capacity and zero for other locations. This condition will ensure that supply will be made only to the distribution centres to be established.

\[ x_{it} \leq Pcap_t \times z_i \quad \forall i,t \]  
(4)

The amount shipped from the ith distribution centre to all retailers must be equal to or less than what the ith distribution centre receives from the manufacturer.

\[ \sum_j y_{jit} \leq x_{it} \quad \forall i,t \]  
(5)

The amount a retailer j receives from all distribution centres must be equal to or greater than the retailer’s sales demand.

\[ \sum_i y_{jit} \geq D_j \quad \forall j,t \]  
(6)

**Non-negativity constraints:**

\[ x_{it} \geq 0, y_{jit} \geq 0, \text{ and } z_i \in \{0,1\} \quad \forall i,j,t \]  
(7)

Total number of variables = \( I^* (I + J + J^* T) \)

Total number of constraints = \( I^* (I + 2I + J^* T) \)

**SCENARIO PLANNING**

An optimal solution of the mathematical programming model presented in the previous section may not be valid if parameters in any or all of the future periods change with time. To tackle this problem, we define a set of future possible scenarios \( PS = \{ 1, 2, \ldots, S \} \) (Harries, 2003; Krause, 2001). For each scenario \( s \in PS \), we fix a set of parameters for the associated mathematical model. It is unlikely that a solution for the above model would provide the same optimal solution for each scenario \( s \in PS \). We also consider a number of measurable decision factors to finally make a decision for a particular scenario. As mentioned earlier, we use the AHP for planning the scenarios as a multi-criteria decision problem.

To demonstrate the use of the methodologies being developed here, we consider the following five short-listed scenarios:

- **Scenario I:** Base scenario: based on general situation of the problem
- **Scenario II:** Demand increase: possible high increase of demand in certain retailers
- **Scenario III:** Demand decrease: possible demand decrease in certain retailers
- **Scenario IV:** New market: possible new market creation
- **Scenario V:** Cost change: possible changes in cost structure

Any future demand variation in any retailer centre would change the cost pattern significantly. So it is important to consider the future demand changes in the scenario planning. With the population growth and movement, it is not unusual to create new markets in the future. With possible changes in infrastructure and technology, some retailers may even enjoy cost advantages in the future. For each scenario, the ILP-based optimization as discussed above will generate the minimum-cost solution and the corresponding project cost. However, in reality, project cost I is not the only attribute or criteria to be considered. There are other attributes that can be collectively called “Other than Cost” (OTC) play a significant role in decision making. In this paper OTC is broken down into the following three sub-criteria for the sake of model development. In reality there can be many other sub-criteria and their inclusion is straightforward.
Environmental Impact (EI): infrastructure, local community support, job creation, pollution, etc. of the locations selected.

Zonal Advantage (ZA): the future tax and financial advantages and the condition of the road network may be different for different zones, which may save substantial costs and delivery time for certain locations. So the relative advantages for different scenarios must be compared.

Company Preference (CP): the company-preferred locations for social and/or political commitments.

C and OTC may have different weights depending on the decision maker. Cost could be a less important factor as compared to the other criteria for some planning environments such as defence. Each scenario may result in different locations. Even if two scenarios provide the same location, their initial costs plus operating costs could be different. That means that the total cost (i.e., the objective function value) of a scenario is the optimal cost for a given instance of the problem and thus the cost figures are not costs for alternative locations under similar situations. Each scenario represents a different situation that may occur in the future. Once we know the situation, we can easily find the optimal cost as well as its corresponding locations. The use of cost as the only decision criterion under the multi-criteria method cannot be justified from a decision-making point of view. So we would use the other criterion OTC in the AHP to compare the scenarios and analyse the problem by assigning different weights to them. In other words, the AHP will evaluate the optimal location of each scenario generated by the ILP. Costs from the ILP model’s objective values will be used to produce relative priorities of the scenarios with respect to cost alone and the AHP will generate another set of relative priorities for them with respect to OTC (see the example below). Then finally, a weighted aggregate ranking will be produced that combines the two sets of relative priorities and the chosen weights for C and OTC. Let \( P_C^i \) and \( P_{OTC}^i \) be the relative priorities of the \( i \)th scenario for C and OTC respectively, and \( w_C \) and \( w_{OTC} \) be the weights for C and OTC respectively (note that \( w_C + w_{OTC} = 1 \)). The weights are expected to be provided by the domain experts. The aggregate relative priority \( A_i \) for the \( i \)th scenario is,

\[
A_i = w_C P_C^i + w_{OTC} P_{OTC}^i
\]

The decision maker then would choose the one that suits his or her organization’s overall goal based on these aggregates. The AHP hierarchy for prioritizing the scenarios with respect to OTC is given in Figure 4.

SOLVING THE PROBLEM: AN EXAMPLE

Let us consider a problem with five distribution centres, five retailers, and five time periods. There will be 155 variables and 81 constraints in the mathematical model. In the base scenario, the demand and cost figures are forecast from the historical data and any other additional information currently available. The domain experts will generate many more scenarios and finally will select a set of them for further analysis after assessing their likelihoods. The ILP model for each selected scenario is solved using LINGO (a well-known optimization package) in a PC environment. The solution of the mathematical model for each scenario provides optimal locations for the distribution centres and their long-term minimum costs. In order to illustrate the methodology, we provide the summary of data used for different scenarios just for the sake of guidance. Wide variations in the demands may sound unrealistic but they are considered for representing extreme conditions that may happen in reality. That is why sensitivity analysis is not enough for decision-making. Complete data can be obtained from the authors for replicating the results.

Scenario I (SCI): The base scenario data are considered as follows. The initial costs for the five locations are \( 500k, 550k, 600k, 650k \) and \( 850k \) (here \( k \) denotes thousand). The demands for the five retailer locations are generated arbitrarily in the ranges of 1,000 to 2,000; 5,000 to 6,000; 10,000 to 15,000; 20,000 to 21,000; and 8,000 to 9,000. Both types of transportation costs are generated randomly in the ranges \( 40 \) to \( 50 \), \( 30 \) to \( 40 \), \( 20 \) to \( 30 \), \( 15 \) to \( 25 \) and \( 5 \) to \( 15 \) per unit.

Scenario II (SCII): Same as base scenario but retailer 2 has higher demand in future periods in the range of 70,000 to 80,000.

Scenario III (SCIII): Same as base scenario but retailer 4 has lower demand in future periods in the range of 2,000 to 3,000.

Scenario IV (SCIV): Same as base scenario but there is a new market close to retailer 1 with higher demand than any other existing retailer.

Scenario V (SCV): Same as base scenario but lower costs for distribution centre 3.

Figure 4. AHP Hierarchy for the Decision under OTC Attribute

The resulting locations and corresponding minimum costs for the scenarios are obtained after solving the ILPs applicable to each scenario and are given below.

<table>
<thead>
<tr>
<th>Scenario Number</th>
<th>Objective value (Cost in $/million)</th>
<th>Location decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>6.54</td>
<td>4 &amp; 5</td>
</tr>
<tr>
<td>II</td>
<td>12.2</td>
<td>2 &amp; 5</td>
</tr>
<tr>
<td>III</td>
<td>4.68</td>
<td>1 &amp; 5</td>
</tr>
<tr>
<td>IV</td>
<td>13.62</td>
<td>3 &amp; 5</td>
</tr>
<tr>
<td>V</td>
<td>6.35</td>
<td>3 &amp; 5</td>
</tr>
</tbody>
</table>
As indicated earlier, the scenarios are non-comparable options. The ILP is providing the best choice of 2 locations under each scenario defined. In reality, one of these scenarios is expected to occur but is unknown at this stage. To simplify the process, one may assume equal probability of occurrence for each of the scenarios. The probabilities can be revised as additional information is available and the relative priorities (calculated below) can be revised accordingly following some expected value approach. To obtain the relative priorities of the scenarios with respect to cost, we generate the pairwise comparison matrix as follows. The lower the cost, the more preferred it is. For example, as the cost of Scenario I and Scenario II are 6.54 and 12.2 million dollars respectively, then under cost criterion, Scenario I is 12.2/6.54 times preferred compared to Scenario II. Using this approach the resulting reciprocal pairwise comparison matrix \([a_{ij}]\) is,

<table>
<thead>
<tr>
<th></th>
<th>SCI</th>
<th>SCII</th>
<th>SCIII</th>
<th>SCIV</th>
<th>SCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCI</td>
<td>1</td>
<td>1.87</td>
<td>2.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCII</td>
<td>1</td>
<td>1.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIII</td>
<td>1.4</td>
<td>2.61</td>
<td>1</td>
<td>2.91</td>
<td>1.36</td>
</tr>
<tr>
<td>SCIV</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCV</td>
<td>1.03</td>
<td>1.92</td>
<td>2.15</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

These ten entries are sufficient since the remaining ones can be readily obtained by using the reciprocity relation \(a_{ij} = 1/ a_{ji}\). In general, in the AHP, an \(n \times n\) pairwise comparison matrix, requires \(n(n-1)/2\) entries. Using the Expert Choice™, the relative priorities with respect to cost are obtained as (inconsistency ratio = 0.0)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>SCI</th>
<th>SCII</th>
<th>SCIII</th>
<th>SCIV</th>
<th>SCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>0.225</td>
<td>0.121</td>
<td>0.315</td>
<td>0.108</td>
<td>0.232</td>
</tr>
<tr>
<td>Scenario II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario IV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Comparing the Sub-Criteria (numbers in parentheses are the local priorities)

It is difficult to decide locations based on the solutions of the mathematical models alone as they represent different scenarios or situations. So we consider the OTC criterion to analyse these situations. We use Expert Choice™ to determine the relative priorities of the scenarios with respect to OTC as per the decision hierarchy of Figure 4. Figures 5 – 8 show the results that are supposed to represent the inputs from a domain expert. Here we are comparing the preferences of the optimal locations obtained from the ILP under the five scenarios considered (e.g., locations 4 & 5 of Scenario 1, vs. locations 2 & 5 of Scenario 2). Figure 4 deals with the OTC attributes for the resulting locations of each scenario. We kept C and OTC separate, as they refer to distinct decision domains. Here C is based on different scenarios (scenario space) involving uncertain parameters and OTCs are based on known locations (location space) resulting from optimal solution of scenarios. Later, we can present either relative priorities of C and OTC or aggregate relative priorities (as in Table 1) to management for final decision-making. The expected priority can be calculated if the probabilities for each scenario are known (i.e., problem under risk). However the problem we consider is defined as problem under uncertain environment implying that no information on probabilities is available.

<table>
<thead>
<tr>
<th></th>
<th>SCI</th>
<th>SCII</th>
<th>SCIII</th>
<th>SCIV</th>
<th>SCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCI</td>
<td>(0.260)</td>
<td>2.0</td>
<td>0.5</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>SCII</td>
<td>(0.268)</td>
<td>2.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>SCIII</td>
<td>(0.279)</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>SCIV</td>
<td>(0.084)</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCV</td>
<td>(0.109)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Comparing Scenarios under EI (local priorities in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>SCI</th>
<th>SCII</th>
<th>SCIII</th>
<th>SCIV</th>
<th>SCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCI</td>
<td>(0.142)</td>
<td>0.5</td>
<td>4.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SCII</td>
<td>(0.152)</td>
<td>3.0</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>SCIII</td>
<td>(0.053)</td>
<td>0.2</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIV</td>
<td>(0.404)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCV</td>
<td>(0.250)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Comparing Scenarios under ZA (local priorities in parentheses)
The aggregate relative priorities under OTC are (overall inconsistency ratio = 0.06)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>P^TC</th>
<th>SCI (0.171)</th>
<th>SCII (0.320)</th>
<th>SCIII (0.094)</th>
<th>SCIV (0.338)</th>
<th>SCV (0.076)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>0.214</td>
<td>3.0</td>
<td>3.0</td>
<td>0.25</td>
<td>3.0</td>
<td>0.212</td>
</tr>
<tr>
<td>Scenario II</td>
<td>0.265</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>1.0</td>
<td>0.122</td>
</tr>
<tr>
<td>Scenario III</td>
<td>0.187</td>
<td>0.33</td>
<td>0.33</td>
<td>2.0</td>
<td>0.33</td>
<td>0.188</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>0.212</td>
<td>0.33</td>
<td>0.33</td>
<td>2.0</td>
<td>0.33</td>
<td>0.210</td>
</tr>
<tr>
<td>Scenario V</td>
<td>0.122</td>
<td>3.0</td>
<td>3.0</td>
<td>0.25</td>
<td>3.0</td>
<td>0.122</td>
</tr>
</tbody>
</table>

Figure 8. Comparing Scenarios under PC (local priorities in parentheses)

The priority scores in C versus OTC scales for all the scenarios are shown in Figure 9. As per our ranking definition, a higher score indicates a favourable scenario for decision making. Here SCI, SCII and SCIII are on the Pareto frontier dominating SCIV and SCV by a wide margin. Out of the first three scenarios, SCI is slightly off the linear combination of SCII and SCIII. So the decision maker would choose either SCII or SCIII to maximize his/her priority scores. We have also calculated the aggregate relative priorities of the scenarios under various weighting schemes for the Cost (C) and Other than Cost (OTC) attributes as given in Table 1. It is obvious that unless the Cost weight is too small (i.e., less than 0.4), the third scenario remains preferred option under the consideration of both the attributes C and OTC. Therefore, in this example Scenario III is the best choice considering both Cost and other criteria together. For Cost weight less than 0.4, Scenario II is favourable which is consistent with the Pareto frontier in Figure 9. Also, it should be noted that their relative priority is substantially greater than its nearest neighbour second level choice, Scenario I.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Weight of Cost (w_C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Scenario I</td>
<td>0.216</td>
</tr>
<tr>
<td>Scenario II</td>
<td><strong>0.236</strong></td>
</tr>
<tr>
<td>Scenario III</td>
<td>0.213</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>0.191</td>
</tr>
<tr>
<td>Scenario V</td>
<td>0.144</td>
</tr>
</tbody>
</table>

Table 1. Aggregate Relative Priorities of the Scenarios for Various Values of w_C

It is difficult to suggest a particular set of weights for w_C and w_OTC because a decision-maker may not have one in reality. Instead, the decision-maker may have a range of values for them. That is why we presented the outcome as a type of sensitivity table. In case the aggregate relative priorities do not indicate a clear winner, the decision makers must re-evaluate the problem both in terms of Cost and non-Cost attribute plus sub-attributes until a clear winner emerges.

Figure 9. Pareto Frontier in C and OTC Scale
CONCLUSIONS

We have presented a scenario-based approach to a time-dependent supply chain problem and described a methodology for finding an acceptable solution that would enable operations managers to make improved strategic decisions. We not only minimized the cost by formulating an ILP-based mathematical model, but also integrated such a solution with possible solutions recommended by considering other subjective criteria through a multi-criteria decision analysis. The AHP was found ideally suited for the latter part of the approach. The integrated approach is prescribed as a practical method for tackling real-world situations in supply chain expansion decisions. Despite the subjectivity about the likelihood analysis for scenario selection and the AHP analysis with respect to OTC, the solutions obtained this way are not rigid because decision makers are free to incorporate possible variations of the scenarios by interactively changing the decision parameters.

The methodology can be used in many other practical strategic decision processes. In a bidding process, it is well known that the minimum cost bidder may not be the winner. In such a problem, the bidding cost along with other non-cost factors can be combined using a similar methodology discussed in this paper to make a rational decision. The methodology can be used for long term decision making such as deciding on new businesses, expansion plans, new facilities and others. The results of this research can be considered as the groundwork for the design of a computer-based decision support system (DSS) that will be able to meet real world needs effectively. This method also needs to be extended by analyzing the risk involved in selecting a certain scenario or location because of wrong design of scenarios.

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