Proceedings of 2013 International Conference on
Technology Innovation and Industrial Management
29-31 May 2013, Phuket, Thailand

AN INTEGRATED OPTIMIZATION MODEL FOR DISTRIBUTION CENTER LOCATION WITH CONSIDERATIONS OF POPULATION AND INCOME

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ABSTRACT

This paper uses optimization technique and decision making method to find the optimum location for a group of distribution centers. Two levels of distribution center location have been found out. The first level uses set covering methodology to obtain the location which is the location for regional distribution center. The second level uses Analytical Hierarchy Process to obtain the location which is the location for local distribution center. This problem finds the location for two levels of distribution center for the state of Ohio considering various factors and conditions, primarily focusing on population and income.

Keywords: Two levels of distribution center location problem, location problem with population and income considerations

INTRODUCTION

Many models have been developed for the design of distribution center location which has provided valuable information about location problems, but this research offers a unique discernment for solving location problems as a completely distinct approach has been adopted. In this thesis, a multi-product single manufacturing facility is assumed. This facility wants to have two levels of distribution centers (DC); 1) Regional DCs (RDCs) 2) Local DCs (LDCs). The location of RDC is found out using set covering methodology and the location of LDC is found out using Analytical Hierarchy Process (AHP). A new modified model from the original model has been developed for set covering and AHP. Then some extension to both the models also has been discussed and evaluated. Set covering is a facility location problem which helps in determining the minimum number of facilities to cover maximum demand. The set covering formulation is given as [1]:

$$\textit{Minimize } z = \sum_{j=1}^{n} C_j X_j \qquad (1)$$

$$\text{Subject to} \quad \sum_{j=1}^{n} a_{ij} X_j \geq 1, \; i = 1 \ldots m \qquad (2)$$

$$X_j = \{0, 1\}, \; j = 1, \ldots\ldots, n \qquad (3)$$

Analytical Hierarchy Process is a decision making tool to solve multi-level hierarchical problems. It was introduced by Saaty [2]. The AHP divides the problem in picture into three levels [3]:

1) Define a goal for resolving the problem.
2) Define objectives for achieving the goal.
3) Determine evaluation criteria for each objective.

This research consists of two levels of distribution center, one at regional level and other at local level. The inspiration to have such a kind of system for distribution center was inspired by the theoretical concept of hub and spoke system. The very basic hub and spoke model is used as a prototype for the distribution network which is the most important part of this research work. A pure hub and spoke system consists of a hub and many spokes [4]. A hub usually performs activities like reassembling, and redirecting parts [4]. Spokes act as a connection between customers and hub [4]. In this research, for the first level of distribution system the manufacturing center is acting as a hub and RDC is acting as a spoke. For the second level of Distribution system the RDC is acting as a Hub and LDC is acting as a spoke.

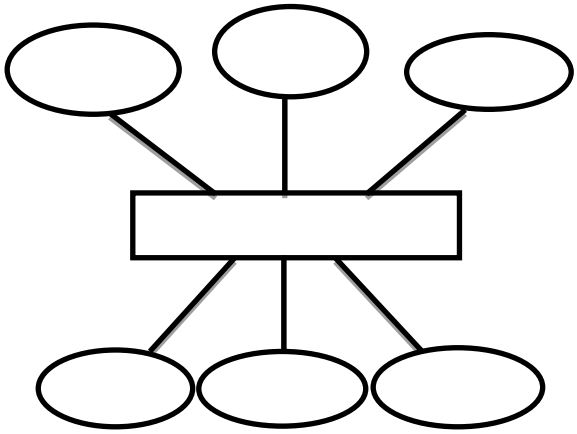

Figure 1: Hub and Spoke for the first level of distribution system

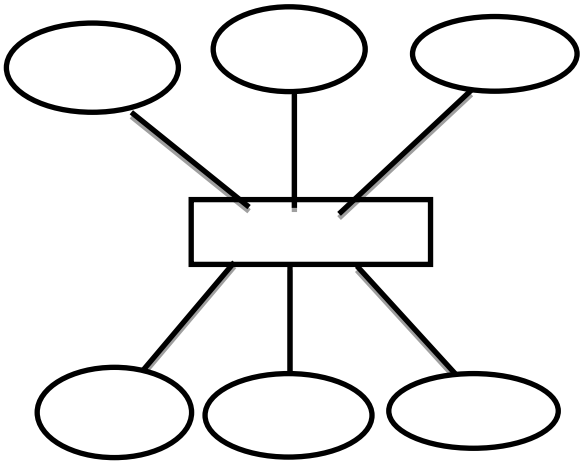

Figure 2: Hub and Spoke for the second level of distribution system

1. Objective

The main objective of this research is to determine two levels of distribution centers, one at regional level and the other at local level. The local distribution center (LDC) will assist regional distribution center (RDC) and will be located around the RDC. This problem is specifically a location and a selection problem where location of distribution centers and their number will be decided. This problem is inspired by a food company located in Jackson, Ohio which was looking to locate certain number of distribution centers nationwide, but this problem is limited to only in the state of Ohio.

2. Background

The two level arrangement of distribution center is usually observed in many distribution networks like a hub and spoke system where the mail is sent to some centralized system, and then from there they are dispatched to their destinations [5]. This type of system has been successfully implemented in the airline industry [5] and in various logistics network [4]. Big Corporations, like FedEx, have also implemented Hub and spoke type of model because of the various advantages that it has to offer [5].

Set covering focuses on covering all the demand with a minimum number of sites [1].Since the problem in this research is to cover the maximum area possible, set covering was thought to be an effective method, as this method assumes that there is some critical coverage distance or time within which demands need to be taken care of if they are counted as covered [1]. Set covering has numerous applications such as in locating emergency facilities, school, police station, distribution center etc. The location models are characterized into four types and one of them is discrete model[6]. Under discrete location model there are three more categories and one of the categories is Covering based models [6]. The covering based model is further divided into set covering, max covering and P-center [6]. Out of the three covering based models we are using

set covering model in this thesis which covers all the demands with minimum number of sites [6].

AHP is used for decision making in engineering applications, where both the quantitative and qualitative factors are taken into account and decision is made after evaluating a number of pertinent criteria [7]. The idea of using AHP for making decision for DC location came from the paper by Saaty [8]. The author describes AHP as a theory of measurement through pairwise comparisons and based on judgments [8]. According to the author it's the best tool for decision making. The ranking system for preference scale has been taken from this paper specifically. There are many papers on AHP using different preference scale, but the preference scale used in this paper has been used as Saaty has proved the validity of this scale in his paper.

Few studies have combined set covering and AHP to improve solutions. This research will use a unique approach to combine AHP and set covering to decide the best location of distribution center. The approach in this research is different from traditional approaches where either of the method is used to improve the solution, like in the research paper by Hwang, where public facility is located first by using AHP approach and then to improve this solution set covering is used [9]. However, in this research set covering will make sure that first whole region is covered and AHP will make sure that a certain region is covered.

3. Reasoning Behind The Three Way Methodology

The food company sells certain kinds of products which are affordable by all income groups. The Product line which is affordable can still be categorized in three income level groups. The categorization of the food products is a assumption for this research purpose.

a) Low priced products: These types of products are used by the lowest income group. The middle income can use these types of products and the highest level income may not use these types of products at all.

b) Mid-range priced products: The specialty of these types of products is that it can be used by all income groups.

c) High priced products: These types of products are usually used by high income groups.

For our research problem we will be dealing with Mid-range priced products which can be sold in each and every region and to all income groups. The following are the reasons for adopting the three way methodology for these types of problems:
1) Since we are dealing with mid-range price products which are affordable by all the income groups, therefore it is taken into consideration that such products can be sold in each and every region and so this reason forms the basis of clustering the Ohio state based on directions, so that a group of counties lies in the same direction.
2) Since in this research we are trying to sell mid-range priced products, which can be sold in every region, set covering is applied which will make sure that each and every region is covered

3) AHP is applied to locate LDCs around each RDC, since the coverage has already been taken care by set covering there may be other criteria which are required to be considered while setting up LDCs around each RDCs like cost, labor, distance so that not only every region is covered but certain conditions are also satisfied while setting up LDC taking local factors and characteristics into account.

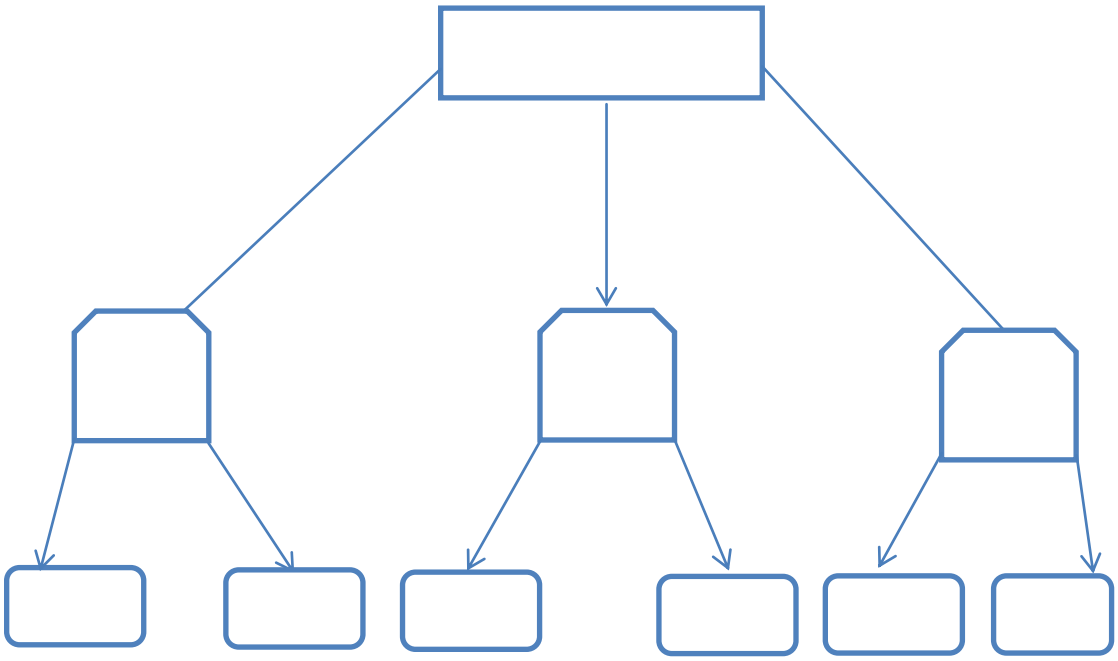

Figure 3: Hierarchical representation of the problem.

METHODOLOGY

The following methods will be adopted to solve this problem. The methods are summarized in the following steps:

1) The two level hierarchy of distribution center is inspired by hub and spoke model. The regional distribution center and local distribution center consists of two level of distribution center.

2) The very first step would be to divide the state of Ohio into certain number of regions based on geographic directions and population.

3) The Step # 2 will divide the state of Ohio into some number of regions.

4) After regional division, set covering methodology would be applied to locate a RDC in each of these regions.

5) Once the location of RDC is determined, the next step would be to determine some number of LDC around each of RDC using AHP.

6) The methodology can be described in more detail in the following way:

a) The map of Ohio state is used for this research purpose which is divided into counties. Regional division is done for the map.
b) The state of Ohio is divided in such a way that each region has a population range between 1.5 million to 3 million as it is assumed that each RDC or group of RDCs can serve at the most population in the above defined range.
c) The regional division is done based on population and considering adjacent counties and nearby counties. If the population for a group of counties together lies in the range between 1.5-3 million then that group forms one region.
d) After the regional division, set covering is used in that particular region to find RDC or groups of RDC. Population, income and distance are the deciding factors to obtain the location of RDC which is incorporated in the set covering formula.
e) After obtaining the location for RDC, LDC is found out using AHP technique which will be the interface between RDC and customers. Various factors are taken into consideration while solving AHP.

1. Formulation

Set covering formulation: The new set covering Formulation was derived. The formulation is as follows:

$$\text{Minimize } z = \sum_{j=1}^{n} F_{ij}X_j + \sum_{j=1}^{n} C_jX_j \qquad (1)$$

$$\text{Subject to} \quad \sum_{j=1}^{n} P_{kj}X_j + \sum_{j=1}^{n} I_{kj}X_j + \sum_{j=1}^{n} D_{kj}X_j \geq 1, \qquad (2)$$

$$k = 1..m$$

$$X_j = \{0, 1\}, j=1, \ldots\ldots, n \qquad (3)$$

Equation (1) minimizes the total cost.

Equation (2) describes the constraints. These constraints make sure that each of the counties is at least covered by one occupied county where RDC will be located.

Equation (3) is the decision variable which takes the value 1 or 0.

If a county is satisfying a given condition, which is also a potential RDC site then its value will be 1 else 0 where

F_{ij} : (Distance × Cost required needed to cover that distance). The distance would be from manufacturing facility to potential RDC site. Thus F_{ij} is basically the cost associated

to cover the distance between manufacturing facilities located in Jackson to the potential RDC site. This is a fixed cost and not a one-time cost.

C_j : The fixed cost associated to operate the RDC. This cost is also not a one-time cost. The cost may include electricity cost, labor cost, taxes, maintenance cost etc.

i : Manufacturing Site

j : Potential Distribution Center location

The explanation for equation (2) is explained below:

$$\sum_{j=1}^{n} P_{kj}X_j + \sum_{j=1}^{n} I_{kj}X_j + \sum_{j=1}^{n} D_{kj}X_j \geq 1,$$

$k = 1..m$

k: county
j: potential RDC site

Here, P is population of the county k that can be covered by potential distribution center j if a condition is satisfied. Conditions for different regions will be different. Here the county itself is the potential RDC site too. Therefore k and j both are counties except for the fact that j is the county which will be acting as a potential RDC site.

If population lies within a certain range for the particular region then the condition will be satisfied if

$\underline{P_{kj}} = 1$
Else
$\underline{P_{kj}} = 0$

I is Income of county k such that the income lies within a certain range so that it can be covered by potential distribution center j. Conditions for different regions will be different. Here the county itself is the potential RDC site too. Therefore k and j both are counties except for the fact that j is the county which will be acting as a potential RDC site.

If the income lies within a certain range for the particular region,

then $I_{kj} = 1$
Else
$I_{kj} = 0$

D is the distance between a county k and potential distribution center j such that the distance lies within a certain range so that it can be covered by potential distribution center j. Conditions for

different regions will be different. Here the county itself is the potential RDC site too. Therefore *k* and *j* both are counties except for the fact that *j* is the county which will be acting as a potential RDC site.

If the distance lies within a certain range,

then $D_{kj} = 1$
Else
$D_{kj} = 0$

1) Analytical Hierarchy Process: The hierarchical diagram is created in this process.

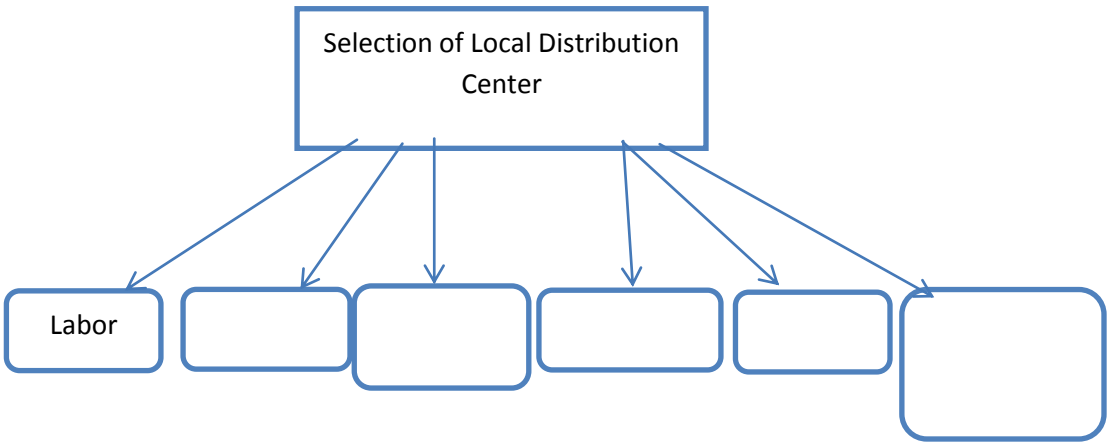

Figure 4: Criteria Level Representation

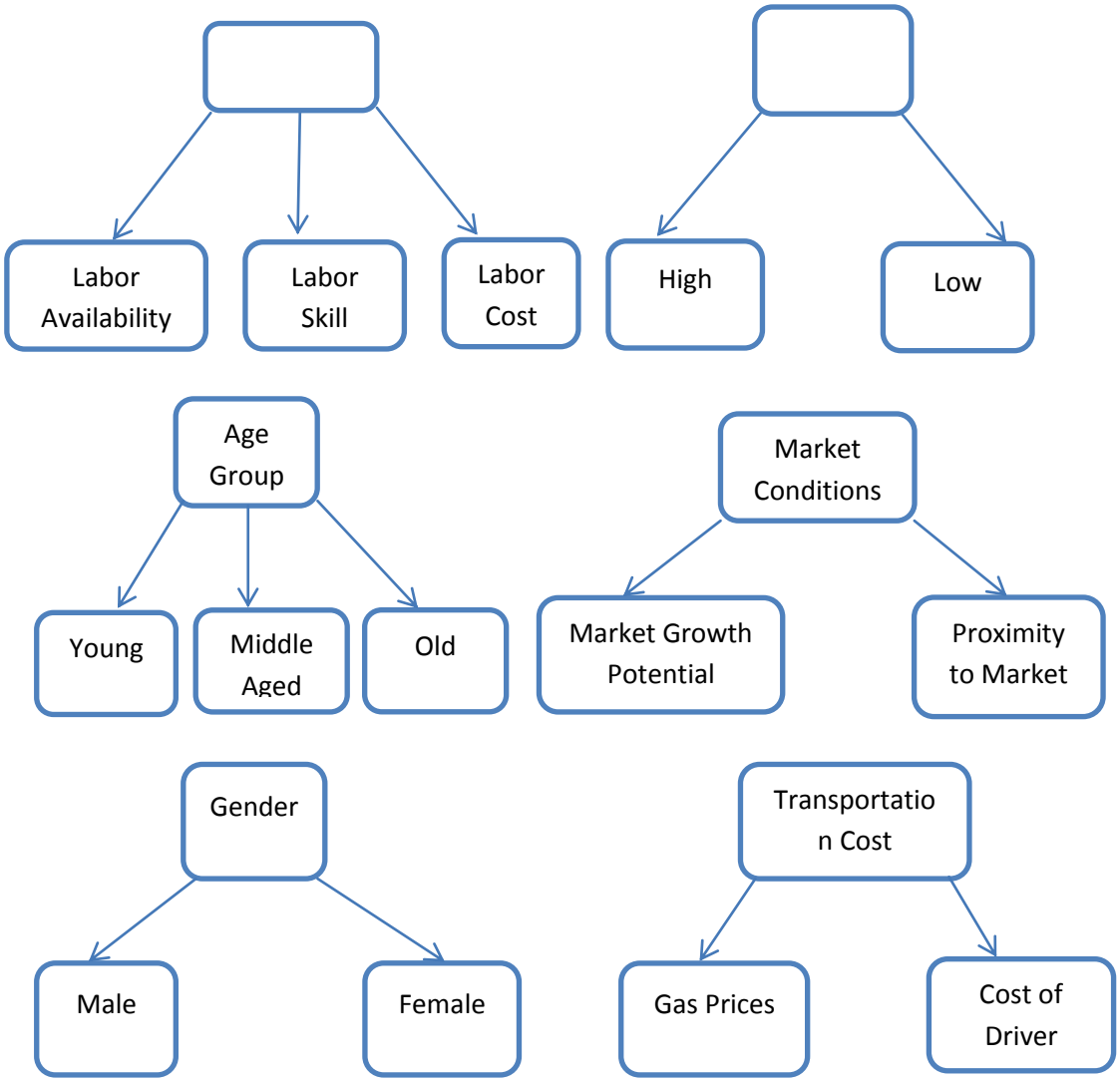

Figure 5: Sub-Criteria Level Representation.

The following steps will be implemented to solve AHP:

a) Calculate weight for each criteria w.r.t each DC and then calculate final composite rank for each of the DC's.
b) Calculate weight for each sub-criteria w.r.t each DC and then calculate final composite rank for each of the DC's.
c) Add the composite scores for criteria and sub criteria level to get the final rankings for the LDC
d) Add the composite scores for criteria and sub criteria level to get the final rankings for the LDC.

2. Extension for set covering model

The new set covering formulation can still be modified to have one more additional constraint

$$\text{Minimize } z = \sum_{j=1}^{n} F_{ij}X_j + \sum_{j=1}^{n} C_jX_j \quad (1)$$

$$\text{Subject to} \quad \sum_{j=1}^{n} P_{kj}X_j + \sum_{j=1}^{n} I_{kj}X_j + \sum_{j=1}^{n} D_{kj}X_j + \sum_{j=1}^{n} M_{kj}X_j \geq 1 \quad (2)$$

$$k=1\ldots m \quad (3)$$

$$X_j = \{0, 1\}, j=1, \ldots, n$$

As can be seen in equation (2), a new constraint was introduced M_{kj} which is market conditions.

The data was obtained for the following:

a) Investment climate
b) Number of business starts
c) New & Expanding facilities.

The data for the above three information were combined together to obtain the final Market condition situation for each of the county. The above mentioned data was obtained for each of the counties from Ohio Department of development website[10].

3. Weight Based Set Cover Model

The formulation will be modified to the following:

$$\text{Minimize } z = \sum_{j=1}^{n} F_{ij}X_j + \sum_{j=1}^{n} C_jX_j$$

$$\text{Subject to} \quad w1 * \sum_{j=1}^{n} P_{kj}X_j + w2 * \sum_{j=1}^{n} I_{kj}X_j + w3 * \sum_{j=1}^{n} D_{kj}X_j + w4 * \sum_{j=1}^{n} M_{kj}X_j \geq 1$$

$k = 1, \ldots, m$

$X_j = \{0, 1\}, j=1, \ldots, n$

where w1+w2+w3+w4=1

w1, w2, w3, w4: weights allotted to each of the constraint.

4. Extended AHP Model:

The three extended models are developed for AHP, they are:

1) Model 1: Multiplying weights for criteria, sub-criterion and county w.r.t sub-criterion to obtain final composite scores for each region.
2) Model 2: Adding the weights for each county w.r.t sub-criterion to obtain the final ranking in each region.
3) Model 3: Add the composite scores for criteria and sub-criteria to obtain the final ranking.

RESULT

The map of Ohio is shown below with all the eighty eight counties and division into five regions after the regional division. The counties in red are RDC and the counties in yellow are LDC for that particular region. The location for RDC and LDC are obtained after solving the set covering and AHP formulation in section 2.1.

The following conclusions can be drawn from the results obtained by solving different set cover models:

The answers obtained by the new model and the model consisting of M_{kj} constraint gave more or less the same answer. However, when weights were introduced the answers differed to some extent from the previous two models.

The following conclusion can be drawn after solving four different AHP models

1) The answers obtained by the AHP model and Model 1 are to some extent similar, though not completely.
2) The answer given by Model 2 largely differs from the AHP model and Model 1. The county location obtained seems to be unreasonable as the locations are almost near to each other which won't be able to cover the complete region.
3) The answer given by Model 4 is different from all the models.

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