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A non-linear program to find an approximate location of a second warehouse: A case study

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ABSTRACT

A mathematical model was developed to estimate the location of a second warehouse for a case study in Bangkok. A non-linear program was developed based on the Load Distance Technique. The objective function was to minimize the sum of weighted straight-line distances from the first or second warehouse to either vendors or customers. The straight-line distance was determined using the principle of Pythagorean triples and was weighted by the shipment frequency and the shipment cost rate. The model was then solved using the Microsoft Excel Solver upgraded to the Premium Solver Platform. The starting solutions were randomly set within a specified range to obtain different local optimal solutions. The best one was finally selected to be the approximate location of the second warehouse. Sensitivity to customer demands was conducted and some useful recommendations are provided.

Introduction

This paper extends the study of Monthatipkul (2012). That author determined a location of a second warehouse for a case study (a paper wholesaler in Bangkok). The goal was to decrease the total transportation cost in the long run. A non-linear model was first formulated and then solved using the Premium Solver Platform V11. By diversifying initial solutions, the author obtained the best local optimal solution representing the approximate location of the second warehouse. Even though the author ran some simulations and concluded that opening the second warehouse using the proposed solution could save transportation costs in the long run compared to using only the first warehouse to supply all customers, that research ignored the transportation costs from the supply side. In reality, transport costs from suppliers have significant effects on the selection of a facility's location. A site far away from suppliers invariably results in high transportation costs. Using the same case, this paper strengthens the model proposed in Monthatipkul (2012) to cover the supply side issue.

The problem description explained in Monthatipkul (2012) can be re-summarized as follows. The case study purchases products from many suppliers and distributes them to customers using various types of trucks. The head office is located in the middle of Bangkok, but its warehouse is in southern Bangkok at latitude 13.65841 and longitude 100.47126 (N13.65841, E100.47126). There are almost 1,000 customers (printing, retailers, copier centers, and companies, among others) whose sites are dispersed around Bangkok and the city perimeter. The last three years of records indicate that the sales volume has reached roughly 50 million kilograms of paper. The biggest customer from the west buys 1.7 million kilograms, while the smallest customer in the middle of Bangkok buys only

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45 thousand kilograms. Daily, the case study receives customer orders by telephone and has a cutoff time of 4 p.m. All pre-loading jobs must be performed and the truck schedules/routes must be prepared by 7 p.m. The trucks are loaded the next morning and depart from the warehouse before 8:30 a.m., making a round trip with from 5 to 15 destinations before returning to the warehouse. A second round trip seldom happens.

The main concern of the case study was to reduce the total distribution cost in the long run. Despite determining suitable daily routes by considering related costs and truck capacities, high transportation costs are a major problem due to the inappropriate location of the current warehouse. One possible solution to the problem selected by top management was to open a new warehouse (the second warehouse), in the most suitable location. Some customers would be served by the new warehouse, while the remaining customers would still receive deliveries from the old one. Thus, the main questions in this research were where to locate the second warehouse and how to allocate customers to each warehouse, so that the total transportation cost in the long run was reduced.

To simplify the analysis without loss of generality, the following assumptions were made:

1) Geographical coordinates are used for location identification. They were sourced from the company database (for example, the most significant customer is at N13.77165, E100.39584). However, due to confidentiality requirements, the coordinates of some major customers have been modified for this exercise.

2) The total transportation cost in the long run depends on the actual distances. However, actual determination is cumbersome because of unpredictable factors such as future road construction and traffic conditions, among others. Thus, this research used the straight-line distance instead because this research focused on long-term planning. The result was to used to indicate an approximate location of the new warehouse, with a real-world survey being conducted prior to implementation.

3) The straight-line distance was calculated using Equation (1):

$$\text{Straight}-\text{line distance} = \left\{ (\text{diff\_N})^2 + (\text{diff\_E})^2 \right\}^{1/2} \quad (1)$$

where, diff_N and diff_E are the differences between the latitudes/longitudes of any two points.

4) The straight-line distance was weighted by the shipment frequency and the shipment cost rate. The shipment frequency equals the expected overall demand divided by the shipment size. The shipment cost rate is a multiple of fuel price (baht/liter) and the average fuel consumption rate of vehicles (liter/kilometer).

5) The expected overall demand of each customer was forecast by experts from the marketing department. They used historical data and other necessary parameters from marketing plans and economic growth estimates. The forecast was required to cover a particular period, such as three years.

6) All expected customer demands must be fulfilled by one of the two warehouses, which in turn, are supplied by company vendors. The material balance principle must apply and no shortages are allowed. A customer cannot be assigned to both warehouses simultaneously.

7) Despite many types of papers being traded in practice, this research assumed a single sales unit (kilogram).

8) This paper considered various types of trucks—ten-wheels, six-wheels, and four-wheels. Their fuel consumption rates varied; however, their capacities were ignored.

9) Each vendor can supply every type of paper and has sufficient capacity. Both warehouses must be supplied by at least one vendor.

The remainder of the paper is organized as follows. The next section contains a literature review. Section A Mathematical Model proposes a model for estimating a location of the second warehouse. A solution approach and an illustrative example are then given in the subsequent section. The next section provides an application of the proposed model and some sensitivity analysis. The last section gives a summary.

Literature Review

The facility location problem mainly concerns selecting or placing facilities to serve customer demands efficiently. The following review concludes a literature survey which mainly focused on the continuous facility location problem.

The continuous facility location problem can be briefly stated as: Given n-dimensional points (vertices) P_1, P_2, …, P_p in $\mathbb{R}^n$ and positive multipliers (weights) ω_1, ω_2, …, ω_p $\in \mathbb{R}_+$, find a point P^* that minimizes $\Sigma_p\ \omega_p\ ||P^* - P_p||$, where $||P^* - P_p||$ denotes the Euclidean norm of $P^* - P_p$.

Study in this field probably started in the 17th century with the so-called Fermat Problem. Fermat (as cited in Vygen, 2004) first proposed a model with $n = 2$, $p = 3$, and $\omega_p = 1$ for all p, which was later solved to determine point P^* by many recognized mathematicians, Torricelli, Cavalieri, Simpson, and Heinen (see Vygen, 2004, p. 3). Weber (1909) extended the Fermat Problem by further considering imbalance of ω_p. The Weber Problem is famous in location theory and involves finding a point in a plane and minimizing the total transportation costs from this point to many destination points with different costs per unit distance. Weiszfeld (1937) proposed an iterative algorithm (Weiszfeld's Algorithm) for the Weber Problem. A more complex problem with $p > 3$ was later studied by Kulin and Kuenne (1962). They outlined an iterative numerical method for the general Weber Problem in spatial economics. Tellier (1972) also presented a direct numerical