Analysis of Covering Problem Models for Setting the Location of a Ready-Mixed Concrete Plant: Case Study of the Rayong Province, Thailand

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Abstract. Decision makers must prepare good plans when developing large-scale projects. The Thai government has been increasing economic growth in three provinces under the Eastern Economic Corridor Development Program (EEC). The project includes reconstruction and new construction. This paper aims to find locations for several ready-mixed concrete plants to cover all ready-mixed concrete needs in the Rayong province. The plant location problem could be solved using optimization modelling for a set covering location problem (SCLP) and a maximal covering location problem (MCLP). The results show that two ready-mixed concrete plants location in the Mueang Rayong district and Klaeng district could meet the problem solution.

1. Introduction

Many construction projects have been initiated to support the Thai government’s Eastern Economic Corridor Development Project (EEC). New infrastructure and renovation of existing facilities including highways, high-speed trains, an industrial city and an airport have been planned on Chachoengsao, Chonburi, and Rayong, as shown in Figure 1.

The private sector will benefit from these projects by supporting the demand for construction materials. Ready-mixed concrete is an essential construction material. However, supplying ready-mixed concrete is challenging because it takes a significant investment, and other issues must be addressed [1],[2]. Furthermore, the life of ready-mixed concrete is short, and it must be delivered within approximately two hours once it is produced. Delivery time is dependent on distance, driving time and geography. The existing facility location is inappropriate for service due to potential problems in product distribution. As a result, concrete manufacturers cannot provide satisfactory services to all users. The target of this research is:

1. To find the optimum location for the problems in providing ready-mixed concrete service by analyzing the two methods.
2. To compare the result of methods between the set covering location problem (SCLP) and the maximal covering location problem (MCLP)
3. To compare the advantage and disadvantages of the two methods.

This paper is organized as follows: In Section 2, we review the literature addressing covering problem models for each field. In Section 3, the methodology of the two models is presented. Section 4 describes vital data and assumptions of the case study. In Section 5, the result is analyzed and discussed. Finally, the last section provides a conclusion.
Figure 1. An overview of the EEC. Source: The Eastern Economic Corridor Office of Thailand

2. Literature Review

The literature related to the covering problems in this paper can be divided into two main topics: SCLP and MCLP, which were formulated as the integer programming problem (IP) by [3], [4] and [5]. By now, the SCLP and MCLP are the most extensive and classical models of finding the optimal solution for a decision problem in which the decision variable is binary 1 or 0 (open or closed). Many researchers [6] studied and adopted the covering problem in various research areas. However, we found that there were few studies on the construction management field [7], especially for applying the covering problem models with real cases. We summarize the literature review in Table 1.

| Problems Type | Applications | References |
|---------------|--------------|------------|
| SCLP          | Ambulance location | [8]        |
| MCLP          | Emergency facility location | [9]        |
|               | Bus stops location | [10]       |
| SCLP          | Healthcare facility location | [11]       |
| MCLP          | Ambulance location | [12]       |
|               | The workload capacity for a facility | [13]       |
| SCLP          | Emergency Service Facilities | [14]       |
|               | Hub location | [15]       |

3. Methodology

The objective of this work is to find the optimal solution of setting up ready-mix concrete plant sites to serve the new construction projects in Rayong province. To clarify the research results, we experimented by applying both the SCLP model and the MCLP model to the problem and compared the results in
many dimensions. Because the target of the study aims to find the minimum number of plants required, the integer programming for both covering problem models could guarantee that every demand node is covered by at least one facility within the determined time (the maximum delivery time constraint). Therefore, the solution could be achieved. We could formulate the mathematical models for SCLP and MCLP as follows:

3.1. The set covering location problem (SCLP)
The SCLP was first proposed originally by [4], and the solution provided by this method includes an unlimited number of facilities unless specified otherwise. SCLP is an appropriate model that can cover all users and low construction costs due to the objective function to minimise.

\[
\text{Min } z = \sum_{j=1}^{n} c_j x_j
\]  

Subject to

\[
\sum_{j \in N_i} t_{ij} x_j \geq 1 \quad \forall i \in I
\]

\[
x_j \in \{0,1\} \quad \forall j \in J
\]

Objective functions and constraint functions:
Equation (1) the objective function \(z\) desires the minimum number of facility locations \(j\) (a ready-mixed concrete plant) that cover all demand nodes \(i\) under the maximum delivery time. Equation (2) defines the constraint that each demand node must be served by at least one facility. Equation (3) defines the decision variable \(x_j\) as binary variable 1 or 0.

3.2. The maximal covering location problem (MCLP)
The MCLP was first presented originally by [5], so to solve the problem with the smallest number of facilities. This problem agrees with real situations in the construction industry better than the SCLP when the manager must consider the construction cost in the planning phase.

\[
\text{Max } z = \sum_{i=1}^{n} w_i y_i
\]  

Subject to

\[
\sum_{j \in N_i} t_{ij} x_j \geq y_i \quad \forall i \in I
\]

\[
\sum_{j=1}^{n} x_j = P
\]

\[
x_j \in \{0,1\} \quad \forall j \in J
\]

\[
y_i \in \{0,1\} \quad \forall i \in I
\]

Objective functions and constraint functions:
In Equation (4) the objective function \(z\) is to maximize the demand nodes coverage, under the maximum delivery time that can be covered with the number of facilities. In Equation (5), the constraint defines that all demand nodes must be serviced from facility locations within the coverage travel time from at least one facility that was set. In Equation (6), the constraint defines that the least coverage (at least one a possible facility, it must previously set). Equation (7) and (8) are the constraint defines a
decision variable $x_j$ and $y_i$ as binary variable 1 or 0. All the sets and indices the parameters and the decision variables of the SCLP and MCLP are shown in Table 2.

We explain that the different points of mathematical equations between the two methods are:

1. The MCLP adds a binary decision variable for considering the facility that covers the demand nodes $y_i$, but the SCLP does not consider the amount of supply required by each demand node.

2. The MCLP can add the parameter $P$ for limiting the number of facilities, but the SCLP cannot limit the number of facilities.

### Table 2. The Description of an element of two methods for generating models

| Symbol | Description |
|--------|-------------|
| **Sets and Indices:** | |
| $i \in I$ | The set of demand nodes supersede with the districts into Rayong province. |
| $j \in J$ | The set of facility locations available to be selected for setting a ready-mixed concrete plant |
| **Parameters:** | |
| $c_j$ | The construction cost of a facility (ready-mixed concrete plant) at location $j$ |
| $t_{ij}$ | The traveling time between the demand nodes $i$ and possible facility locations $j$ |
| $N_i$ | $\{ j | t_{ij} \leq S \}$ The set of all possible facility locations $j$ that can cover the demand nodes $i$ within the maximum delivery time constraint. |
| $S$ | The maximum delivery time to ensure the service quality according to the pragmatic standard. |
| $P$ | The number of facilities which are previously assigned. |
| $w_i$ | The demand node at $i$ (The average amount of ready-mixed concrete (m$^3$/day)) |
| **Decision Variables:** | |
| $x_j$ | A binary variable for setting the location $j$ as a ready-mixed concrete plant site. |
| $y_i$ | $x_j = 1$, if the facility $j$ is chosen to be setting up a ready-mixed concrete plant, $x_j = 0$, otherwise |
| $y_i$ | A binary decision variable indicates that the facility can covered the demand nodes at $i$ |
| $y_i = 1$, if the demand nodes at $i$ covered, $y_i = 0$, otherwise |

### 4. Case study
Rayong province is in the eastern part of Thailand and borders the Gulf of Thailand at the north. There are many heavy industries and much tourism in this area. Rayong was selected for our study because it is one of the provinces in the EEC pilot project, a large-scale, Thai-government project. We conducted field surveys at Rayong, including road networks, shortcuts, and traffic junctions.

#### 4.1. The Road network and Data
All data collected for maps are publicly available and provided by The Ministry of Tourism and Sports Thailand [16]. The travelling time was taken from the geographic information system (GIS) [17]. via the web service provided by the publicly available, The Ministry of Transport, Thailand. These data are synthesised to give an important parameter before feeding the data to both the SCLP and MCLP models, as shown in Table 3: Travel time in the SCLP and MCLP.

#### 4.2. Comprehensive assumption of models
The SCLP model can solve the covering location problem and produces the ideal number of facilities without any limiting constraint. However, this solution may not be practical for real business where investment policies could be applied as constraints to the model. Thus, the MCLP [4] was created to support additional system parameters such as the maximum number of facilities and construction costs.
of individual facilities. Moreover, the MCLP is capable of searching for new facility locations while the existing facilities are considered. This additional functionality helps demand nodes proliferate to receive more comprehensive services. However, both SCLP and MCLP are deterministic versions, so all assumed parameters must be clearly stated and consistent with the real world. These techniques have been validated against various resource allocation problems, construction site problems, and other interesting issues [18]. The solution can be considered reliable and optimal because our study applied both techniques and found that the solutions produced by SCLP and MCLP aligned.

4.3. Result
Quality control of the concrete-supply service is the most important factor in our research. Therefore, this research applied recommendations of civil engineering experts and the Institute of Engineering of Thailand (EIT) standards [19] to control the quality of construction. We used the maximum delivery time of 60 minutes in the SCLP, and the MCLP models include the same parameters. The results of both SCLP and MCLP are shown in Table 4.

Table 3. Supersedes the travel time of a concrete mixing truck between a pair of a demand node.

| No. | District          | Mueang Rayong | Ban Chang | Klaeng | Wang Chan | Ban Khai | Pluak Daeng | Khao Chamao | Nikhom Phattana |
|-----|------------------|---------------|-----------|--------|-----------|----------|-------------|-------------|----------------|
| 1   | Mueang Rayong    | 0             | 20        | 34     | 44        | 11       | 38          | 55          | 21             |
| 2   | Ban Chang        | 20            | 0         | 50     | 57        | 25       | 36          | 71          | 19             |
| 3   | Klaeng           | 34            | 50        | 0      | 17        | 40       | 57          | 28          | 48             |
| 4   | Wang Chan        | 44            | 57        | 17     | 0         | 33       | 41          | 22          | 46             |
| 5   | Ban Khai         | 11            | 25        | 40     | 33        | 0        | 31          | 55          | 14             |
| 6   | Pluak Daeng      | 38            | 36        | 57     | 41        | 31       | 0           | 62          | 18             |
| 7   | Khao Chamao      | 55            | 71        | 28     | 22        | 55       | 62          | 0           | 68             |
| 8   | Nikhom Phattana  | 21            | 19        | 48     | 46        | 14       | 18          | 68          | 0              |

4.4. Analysis Result
The methods of the SCLP and the MCLP was modelled using software General Algebraic Modeling System (GAMS) and chose XPRESSMP (Trial Version Free Download) The results are analyzed and explained as follows:

1. The SCLP and MCLP provide the same results when the delivery time is 60 minutes. Both methods showed an ideal result of two facilities to supply sufficient ready-mixed concrete for each demand node.

2. We decided to locate the ready-mixed concrete plants at Mueang Rayong and Klaeng district to cover the desired nodes throughout the province with minimum construction cost. These results will be valuable for decision-makers and project managers in planning and construction management.

Table 4. The result of the SCLP and MCLP models.

| No. | District          | The demand nodes | SCLP | MCLP |
|-----|------------------|------------------|------|------|
|     |                  |                  | S ≤ 60 | P = 0 | P = 1 | S ≤ 60 | P = 2 | P = 3 |
|     |                  |                  | w_i   | x_j   | y_j   | z     | x_j   | y_j   | z     |
| 1   | Mueang Rayong    | 185              | 1     | 1     | 975   | 1     | 1     | 1,100 | 1     | 1     | 1,100 |
| 2   | Ban Chang        | 155              | 0     | 1     |       |       | 1     |       |       |       |       |
| 3   | Klaeng           | 175              | 1     | 1     | 1     | 1     |       |       |       |       |       |
| 4   | Wang Chan        | 125              | 0     | 1     |       |       | 1     |       |       |       |       |
| 5   | Ban Khai         | 130              | 0     | 1     |       |       | 1     |       |       |       |       |
The demand nodes

| No. | District           | The demand nodes | SCLP \( S \leq 60 \) | MCLP \( S \leq 60 \) |
|-----|-------------------|------------------|------------------------|-----------------------|
|     |                   |                  | \( P = 0 \) \( P = 1 \)\( P = 2 \)\( P = 3 \) | \( P = 0 \) \( P = 1 \)\( P = 2 \)\( P = 3 \) |
| 6   | Pluak Daeng       | 145              | 0 \( x_{j} \) \( y_{j} \) \( z \) | 1 \( x_{j} \) \( y_{j} \) \( z \) |
| 7   | Khao Chamao       | 85               | 0 \( x_{j} \) \( y_{j} \) \( z \) | 1 \( x_{j} \) \( y_{j} \) \( z \) |
| 8   | Nikhom Phattana   | 100              | 0 \( x_{j} \) \( y_{j} \) \( z \) | 1 \( x_{j} \) \( y_{j} \) \( z \) |
|     | Min \( z \)       | 2                |                        |                       |
|     | Max \( z \)       | 975              | 1,100                  | 1,100                 |

5. Conclusion
An optimization technique is applied for finding the optimal solution to a problem of locating production facilities in the optimal location, and then the results are adrenalized.

The main conclusions of this research are as follows:
1. The SCLP and MCLP models can be applied to this situation, following the Engineering Institute of Thailand standards [19] and civil engineering recommendations. These standards and guidelines are designed to uphold the strength and quality control of ready-mixed concrete used for structural purposes.
2. Two facilities are required to cover all the demand nodes of the province. Furthermore, if cheaper costs are desired for constructing a new facility, two facilities are sufficient.
3. The SCLP and MCLP methods were compared, using similar objectives and different constraints. The two methods provided similar results, as shown in Table 4. As a result, the new positions of the ready-mixed concrete plant should be set at the Mueang Rayong and Klaeng districts. See Figure 2 to clarify conclusions 1, 2 and 3
4. The SCLP and MCLP methods had individual advantages and disadvantages.
a. The MCLP limits the number of facilities, but the SCLP does not. The MCLP can be used to forecast the need for material such as cement sand and rock at each demand node. On the other side, these data can be used to prepare for designing the concrete mixture of the plant (in the overview).

b. The SCLP focuses on finding the minimum number of facilities that can cover the region within the maximum delivery time only. However, the real situation must consider many other dimensions of the problem.

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