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Development of set covering model for determining the open/closed facilities location and resizing capacity of facilities

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Abstract. Set Covering model determines the location of facilities that can be used that minimize the cost of assigning facilities to the point of request with the limitation that each facility was used for a number points of request. If there is an imbalance between the volume of demand points and the capacity of the facilities, it is necessary to open/closed facilities. In fact, facility location problem can extended for the decision not only open/closed but resizing area the existing facilities that can be adjusted considering the availability area of facilities location and demand points. This case has not been accommodated on the basic model of set covering. Not all the existing facilities can be resized. Resizing the area of facility location was assumed discrete. The aims of this study was optimized the algorithm of set covering model. The solution this study was divided into two stages. The first stage was screening facilities that can be resized with survey location. The second stage was set covering model which the facilities will be close/opened and resize the existing facilities.

1. Introduction

Theory and location modeling were first introduced by Weber [1] who revealed the problem of finding a single facility to minimize the total travel distance between the facility and a group of customers. Determination of the best location for one or more facilities so that customers or demand points can be served well [2]. According to Owen & Daskin [3] determining the location of facilities is very important for planning in various aspects for public and private facilities. This will affect the operational and logistical activities of a facility. Determination of the location of the facility can be determined from the size of the required costs [4] [5]. Besides based on the cost of determining the location of facilities can be determined through the distance from the demand point to the facility [6]. Hotelling [7] developed facility theory by studying the location of two facilities on one line. Customers choose the closest facility from two facilities and vendors to maximize their market share. Some real problems in determining the location of facilities both public and private include determining the location of the facility. In recent years, there have been many applications regarding the location of facilities such as public facilities, such as offices, post offices, fire engines, and hospitals) and private facilities (such as factories and other industrial facilities) [8] [9]. The mathematical model was developed by calculating the probability of a



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specific busy ambulance and validated by a simulation model carried out in determining the location of a facility [10].

In addition to the above facilities, one of the public facilities that requires optimal decision making in determining the location of facilities is a landfill. Where the model is, there is a temporary landfill located close to residents. Several studies regarding the choice of location of facilities related to the impossibility of these facilities close to residents or demand points because several factors related to health, odor, aesthetics, etc [11, 12, 13, 14]. This may be due to different models of waste management, especially household waste collection. In household waste collection, some countries use bin that was not permanent or easily moved to collect household waste and use compactors as a means of transported the garbage before being sent to landfills. Some countries use the permanent trash bin for collect household waste. Coffe & Coad [15] explain its in two categories, such as Haul Container System and Stationary Container System. In [11], the demand point was describe as people in campus building. Research on determining the location of waste disposal facilities that have been carried out using optimization techniques as a search for solutions.

The criteria used in determining the location of facilities using the set covering model include the location of the facility, the location of the demand point, the distance between the location of the facility and the location of the demand point, cost, capacity of the facility and others. This study assumes that the garbage disposal facility is a stationary container system in the form of a permanent building consisting of several types of facilities in accordance with the volume of capacity. Because they are stationary, each facility cannot be moved, and in one location the capacity of the facility can be adjusted with resized to determine the volume of new capacity for existing facilities. Adjustment of the area is certainly not possible for every location of the facility with the same size, because this depends on the availability of land that still exists in the facility area. Thus, determining the size of the resized area cannot be done simultaneously.

The demand point classification in this study assumes that waste can be collected through several types of sources not only from households but can also from other facilities such as offices, shopping centers, markets, education, recreation areas and others. Decision variables in this study not only determine which facilities will be opened or closed, but which old facilities can be expanded based on the type of facility (maximum capacity volume) and available area. In real conditions, it could be that with the request of the community or decision makers, some facilities do want to be closed, so that if an imbalance occurs between the availability of the capacity of the landfill and the amount of waste produced by the community.

So the purpose of this study is to show the concept of capacity expansion in the decision to open or close a facility based on the importance of decision making. Based on the conditions of developing criteria for the type of facility and facility decision variables that can be expanded, the solution to the location of the facility is discrete in two stages. Daskin [16] describes three conditions for the completion of a facility location namely planar, discrete and network. The first stage is direct screening to the location of the location of existing waste disposal facilities by determining the maximum area that can be expanded by measuring the length and width of the area, while the height is not expanded because it is related to the ability to move to transportation. This stage generates new volume capacity data for existing facilities. The second stage is developing a mathematical algorithm for the set covering model with the development of the criteria above. Completion of the set covering model is not simultaneous, using the LINGO 11.0 program.

2. Literatur Review

Facility location models are investigated in discrete space, planar continuous space, and particular in a network environment [17][6]. It can be seen that the planar form will provide a large area without restrictions, while the discrete form of the facility has a location point. It is also different from the form of a network model that will provide a network from either the route or anything else in the facility.

According to Daskin [16] location theory can be used for discrete problems where there are only demand points and facility points without special requirements. One method is set covering. The set covering problem was firstly introduced by Toregas in 1970, but it was published by Toregas & ReVelle [18]. The problem of determining this location used to find the minimum number of facilities (from their location) so each request can be fulfilled optimally with distance and time. Set covering is a method that can be used to minimize the number of facilities that will cover demand. The covering set still only determines which facilities will be maintained. In addition, the facility point has been determined in advance based on the area covered [16]. Based on this, a model was developed to find out the allocation of demand to facilities and to limit the maximum distance between the demand points and facilities without firstly determining the facilities included in the coverage area.

The covering set in Daskin [16] also has the characteristic of using binary numbers (1,0) which can only determine whether demand can be allocated or not. In other function the binary will show which facilities will be maintained because they can cover demand and are closed when not covering demand. The impact of using binary numbers also makes each source point only able to allocate to one facility point. So, demand can be allocated when volume is less than capacity. In reality there are problems where the amount of capacity is greater indeed than demand but the size of the capacity of each facility is smaller than demand. Based on these problems, this journal develops a set covering model that requires additional research steps to be carried out before the set covering method is implemented when there is a problem that the volume to be allocated is greater than the capacity. If volume demand more than capacity of facility we can take a new facility or resize the facility [19]. Set covering model has not grouped the types of each demand and facility. So in this model development also develops the type of facilities and demand with the additional indexes. Based on figure 1 this model can be applied to discrete locations where facilities and demand points have points both latitude and longitude.

2. Numerical Model

2.1. Set Covering Model

Set covering model is one of the oldest from optimization problems in the literature of mathematical programming [20]. Set Covering is a model to determine the lowest cost of the placement of several facilities where each point of demand can be achieved by a minimum of one facility [16]. Set covering problem (SCP) is a mathematical model that is important for some problem solving applications [21]. Set covering problem classified as NP-Complete [22][23][24]. So, set covering is an optimization method that has a function to enable the number of needed facilities to uncover other facilities. Selected facilities will be able to cover requests for other facilities, so it will minimize the number of facilities that can reduce costs because the facility can cover all requests. According to Daskin [16].

2.2. Mathematical Model Development

The set covering model as one of the discrete location theory models has always been developed that determined facilities will be retained to be open/closed. The following mathematical model of set covering in this study from the set covering model of Daskin [16]. This study assumed that the facility has several types and the demand point has several categories. Its were not accommodated before in set covering model. There were three types of facilities and two categories of demand points. Its such as

type K , type L and type M for types of facility and demand points I and demand points J for classifications of demand point.

The mathematical model in this study uses notations as follows:

- I = Set of demand point type I with the index i
- J = Set of demand point type J with the index j
- K = Set of alternative point of facility type K with index k
- L = Set of alternative point of facility type L with index l
- M = Set of alternative point of facility type M with index m
- C_k = capacity of facilities type K with index k (m^3/day)
- C_l = capacity of facilities type L with index l (m^3/day)
- C_m = capacity of facilities type M with index m (m^3/day)
- V_i = volume of demand points type I with the index i (m^3/day)
- V_j = volume of demand point type J with index j (m^3/day)
- D_{max} = maximum distance between demand point with facility by seeing the ability of people walking by carrying load
- D_{ik} = the distance between the demand points type I with index i and alternative facility locations type K with index k
- D_{il} = the distance between the demand points type I with index i and alternative facility locations type L with index l
- D_{im} = the distance between the demand points type I with index i and alternative facility locations type M with index m
- D_{jk} = the distance between the demand points type J with index j and alternative facility locations type K with index k
- D_{jl} = the distance between the demand points type J with index j and alternative facility locations type L with index l
- D_{jm} = the distance between demand points type J with index j and alternative facility locations type M with index m
- T_d = total mileage as distance of fulfillment
 $= \{k,l,m\}d_{ik} + d_{il} + d_{im} + d_{jk} + d_{jl} + d_{jm} \leq T_d \}$
 all alternatives to facility locations includes the point of the demand points with index i (N_i) and j (N_j)

Variable decision:

- X_k = (1, if the facilities type K with index k becomes the location of the can covered demand and 0, if the opposited)
- X_l = (1, if the facilities type L with index l becomes the location of the can covered demand and 0, if the opposited)
- X_m = (1, if the facilities type M with index m becomes the location of the can covered demand and 0, if the opposited)
- Y_{ik} = (1, if the demand points type I with index i can be met by alternative location k and 0, if the opposited)
- Y_{il} = (1, if the demand points type I with index i can be met by alternative location l and 0, if the opposited)
- Y_{im} = (1, if the demand points type I with index i can be met by alternative location m and 0, if the opposited)
- Y_{jk} = (1, if the demand points type J with index j can be met by alternative location k and 0, if the opposited)

Y_{jl} = (1, if the demand points type J with index j can be met by alternative location l and 0, if the opposited)

Y_{jm} = (1, if the demand points type J with index j can be met by alternative location m and 0, if the opposited)

The mathematical model set covering problem:

$$\text{Minimize: } \sum_{k \in K} C_k \cdot X_k + \sum_{l \in L} C_l \cdot X_l + \sum_{m \in M} C_m \cdot X_m \quad (1)$$

$$\text{Subject to } \sum_{k,l,m \in N_i} Y_{ik} + Y_{il} + Y_{im} \geq 1 \quad \forall i \in I \quad (2)$$

$$\sum_{k,l,m \in N_j} Y_{jk} + Y_{jl} + Y_{jm} \geq 1 \quad \forall j \in J \quad (3)$$

$$\sum_{i \in I} V_i \cdot Y_{ik} + \sum_{j \in J} V_j \cdot Y_{jk} \leq C_k \cdot X_k \quad \forall k \in K \quad (4)$$

$$\sum_{i \in I} V_i \cdot Y_{il} + \sum_{j \in J} V_j \cdot Y_{jl} \leq C_l \cdot X_l \quad \forall l \in L \quad (5)$$

$$\sum_{i \in I} V_i \cdot Y_{im} + \sum_{j \in J} V_j \cdot Y_{jm} \leq C_m \cdot X_m \quad \forall m \in M \quad (6)$$

$$d_{\max} \cdot X_k \geq \max \{d_k^i\} \cdot Y_{ik} \quad \forall k \in K \quad (7)$$

$$d_{\max} \cdot X_l \geq \max \{d_l^i\} \cdot Y_{il} \quad \forall l \in L \quad (8)$$

$$d_{\max} \cdot X_m \geq \max \{d_m^i\} \cdot Y_{im} \quad \forall m \in M \quad (9)$$

$$d_{\max} \cdot X_k \geq \max \{d_k^j\} \cdot Y_{jk} \quad \forall k \in K \quad (10)$$

$$d_{\max} \cdot X_l \geq \max \{d_l^j\} \cdot Y_{jl} \quad \forall l \in L \quad (11)$$

$$d_{\max} \cdot X_m \geq \max \{d_m^j\} \cdot Y_{jm} \quad \forall m \in M \quad (12)$$

$$X_k \in \{0,1\} \quad \forall k \in K \quad (13)$$

$$X_l \in \{0,1\} \quad \forall l \in L \quad (14)$$

$$X_m \in \{0,1\} \quad \forall m \in M \quad (15)$$

$$Y_{ik} \in \{0,1\} \quad \forall k \in K \quad (16)$$

$$X_{il} \in \{0,1\} \quad \forall l \in L \quad (17)$$

$$X_{im} \in \{0,1\} \quad \forall m \in M \quad (18)$$

$$X_{jk} \in \{0,1\} \quad \forall k \in K \quad (19)$$

$$X_{jl} \in \{0,1\} \quad \forall l \in L \quad (20)$$

$$X_{jm} \in \{0,1\} \quad \forall m \in M \quad (21)$$

Equation (1) represents minimize the number of facilities consisting of three different types with the capacity of the facilities. Constraint (2) express that demand point type I and (3) express that demand point type J can at least be served by one facility such as sets of facilities type K, L and M . Constraint (4), (5) and (6) ensure that the sets of facilities type K, L and M have the capacity to accommodate both types of sets of demand points classification I and J . So, facility can't cover demand when the demand is more than its capacity. Constraint (7), (8), (9), (10), (11) and (12) restrict the maximum distance allocation from maximum mileage so the distance between the demand points and facilities is no more than the maximum distance for each sets of facilities type K, L and M and demand points classification I and J . Constraint (13), (14) and (15) are binary constraint for decision variabel open/closed facility existing and facility that will be resized for facilities type K, L , and M . Then constraint (16), (17), (18) were binary constraint that defines determination sets of demand point type I that will be covered by certain facilities and constraint (19), (20) and (21) were binary constraint that defines determination sets of demand point type J that will be covered by certain facilities.

3. Application on Hypotetical Data and Discussion

3.1. Hypotetical Data

The set covering model is tested through the application of hypothesis data. The process of changing the size of the facility area in this model that uses a discrete model which is done separately selected directly by researchers in the form of a point grid as in Figure 1. In real conditions, the grid points can be represented through the points of longitude and latitude. Figure 1 shows that there was three regions (A, B, and C) where each region has a location where demand points are from households (I) and one public facilities (J). There was I_1, I_2, I_3 for household and J_1, J_2, J_3 for other public facility. The demand points from household was assumed as a weight point as area, because of the difficulty of data retrieval if the location of the demand point was done for each house point for each household.

There are three types of facilities assumed in this study, namely facilities type K, L and M with differences in facility capacity. These three facilities are spread over three regions A, B and C. Region A has one type K (K_1) facility and one facility type L (L_1). Region B has one facility K (K_2) and one facility M (M_2). While region C has one facility K (K_3) and one facility L (L_2). In actual conditions, the number of facilities in one area can be more than one type of facility with more than one facility per facility. In real case the data application for this study can be describe fully for facility location decision for waste management in Yogyakarta [24]

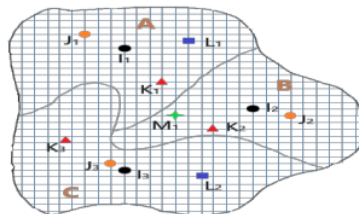


Figure 1. Discrete location in this model

Hypotetical data was carried out with distribution real case data with validation process firts, as follows:

3.1.1. Capacity of Facility

Facility capacity is the ability to accommodate a facility for the demand given to it. Hypothetical data on facility capacity in Table 1.

Table 1. Capacity of facilities

Facility	Volume (m ³)
K_1	5
K_2	7
K_3	1
L_1	1
L_2	2
M_1	2

3.1.2. Volume of Demand

Volume of demand points is the amount that will be allocated from the demand point to the facility. There are two classifications of demand points, namely households and other public facilities. Hypothetical data on demand volume for each demand points in Table 2 and Table 3.

Table 2. Volume of demand types I_i

Demand	Volume (m ³)
I_1	3
I_2	8
I_3	1

Demand	Volume (m ³)
J_1	1
J_2	3
J_3	1

Table 3. Volume of demand types J_j

3.1.3. Distance Facility Location and Demand Point

Distance is an important constraint in an allocation of demand to a facility in the set covering method [26]. So, distance is one of the needed data in solving problems with set covering. Distance measurement can use the distance and latitude distance approach in real conditions. Table 4 until Table 9 shown the distance data of facility locations each type and demand points each classification.

Table 4. Distance between K_k and I_i

	I_1	I_2	I_3
K_1	2	6	1
K_2	2	4	7
K_3	7	5	1

Table 7. Distance between K_k and J_j

	J_1	J_2	J_3
K_1	2	6	2
K_2	2	6	7
K_3	7	5	1

Table 5. Distance between L_l and I_i

	I_1	I_2	I_3
L_1	1	3	7
L_2	9	1	4

Table 8. Distance between L_l and J_j

	J_1	J_2	J_3
L_1	3	2	8
L_2	8	4	2

Table 6. Distance between M_m and I_i

	I_1	I_2	I_3
M_1	2	5	7

Table 9. Distance between M_m and J_j

	J_1	J_2	J_3
M_1	2	5	4

3.1.4. Maximum Distance

Set Covering Model solves the problem in minimizing the number of facilities needed to cover demand for all request node with the maximum service distance desired [17]. Maximum distance was the maximum distance allowed for demand to allocate to facilities. The maximum distance is assumed 5 m from the demand point to the facility location.

3.2. Discussion

According to Hernandez [19], the resizing process in achieving goals in minimizing costs and the number of facilities to be allocated is important. The resizing process can be done based on consideration of extending costs and facility capabilities. The first stage for solution this problem was the screening location processes. The screening process for selecting these facilities can be done using the researchers consideration factors such as the distance from the demand point to facility and availability of land. After Screening and resizing the selected facilities, it can proceed the second stage to optimization solution of the set covering model was developed. So the objectives of the method will be achieved in minimizing the number of facilities.

The set covering model that used to the basic model in the development of this model has the purpose of choosing the facilities to be opened or closed, as well as the model to be developed has the same purpose. This developed model can be used in non-commercial facilities that have rules for range such as the maximum distance that can be reached. Research on the determination of facilities that will remain open at an objective to minimize facilities has often been done as in the research of Hernandez [19] and Wang et al [5]. The development of the model was different from others, this model was developed discretely so that it requires the initial stages before processing was importance for the data using a mathematical model. Model suitability testing is done using hypothetical data.

The set covering model that has been developed in terms of demand points classification and facility type that was originally single into several types consisting of demand volume, facility capacity, distance between demand and facilities, and maximum distance will be processed using the LINGO 11.0 software. According to the results, infeasible results were obtained for determining the facilities to be opened to accommodate demand allocations from 6 facilities consisting of 3 type of facilities K , 2 type of facilities L and 1 type of facility M . If there was infeasible solution shows that there was no solution space for this problem or there was no area that meets all the constraints. This was because demand with a volume exceeding facility capacity will not be able to send or allocate to facilities, such as garbage from I_2 sources cannot allocate to any facility.

According to Table 10, Facility K_2 will be resized to 9 m³ and L_2 to 3 m³ and will be analyzed with the same software. The results of the analysis show that facilities K_1 , K_2 , L_1 , and L_2 will still be opened. The K_1 facility will accommodate demand from J_1 and J_2 . Demand from I_2 and J_3 will be allocated to K_2 . Whereas for L_2 facilities will receive an allocation from I_1 . The demand of I_3 will be allocated to L_1 . The resizing process can be used for the set covering that has demand problems more than capacity. It also has the main purpose like the set covering purpose to minimize facilities that will still be placed. Allocation of demand from the point of demand to the facility can be seen in Table 10.

Table 10. Allocation of demand

No	Facility	Demand	Open/Closed Facility	Capacity (m ³)
1.	K_1	J_1, J_2	O	5
2.	K_2	I_2, J_3	O	7
3.	K_3	-	C	1

4.	L_1	I_1	O	1
5.	L_2	I_3	O	2
6.	M_1	-	C	2
				18

Based on the results of the analysis above, it can be seen that one of the weaknesses of the set covering method and discrete location, when the total volume of demand and total capacity has the same value or below, but the capacity of each facility is smaller than the volume of demand will infeasible solution. This is because the use of binary numbers (1.0) in the set covering method which can only give a decision when the demand will allocate to the facility. There are only two choices, namely allocated or not seeing capacity. This problem can be dealt by adding new facility with capacities that are in accordance with the volume of demand that cannot be allocated yet or other than that, it can process with resizing possible facilities. The hypothetical data processing with this model were done by changing the size of the selected facility. This model can uses for the real situation problem if the volume of facility capacity not balanced with the volume of demand point in set covering model. The decision of facility location for the set covering model is not only open / closed facility with the addition of new facilities but still maintaining the existing facilities by conducting resized capacity.

4. Conclusion

Problems will arise when the demand point volume is greater than the capacity of existing facilities. The set covering model developed can represent a real problem where there are several classifications of demand points and several types of facilities that have different capacities and can adjust the size of existing facilities, not only the decision of open / closed facilities, but also can be changed the size of the area of the facility that has been exist so that a new volume is obtained. Model solutions will be obtained in two simultaneous steps. Stage one, namely resizing existing facilities can be requested to be done separately and selected directly by carrying out the screening process and stage 2 is optimizing the model of covering covering. Further research can be developed by searching for solutions simultaneously with the help of Geographic Information System (GIS) so that the location of demand points can be determined through each point of the household's household. In addition, GIS can also help determine the area of a facility that may be directly expanded in size and also measure distances with another approach, namely nekwork. So the set covering model is no longer discrete but network.

5. Reference

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