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Assessing the Coverage of Health Care Facilities in Surakarta using the Hierarchical Maximal Covering Model: Case Study

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Abstract. The assessment of optimal health location becomes one of the main concerns of developing countries to avoid the occurrence of epidemic diseases that can reduce the quality of life of the community. The purpose of this study is to assess the ability of the existing health facility in Surakarta City, Indonesia to serve the available demand based on the hierarchy of National Health Insurance Program (NHIP). The assessment is modelled by using integer linear programming called model of capacitated hierarchical maximal covering. The results of this study found that not all of the existing demand has been able to be served by the existing health facilities. At the first level, it is found that not all communities in Banjarsari district could be served by Basic Healthcare Unit or Family Doctors because of their capacity are not sufficient to serve all demand. While at the fourth level, demand from Kasih Ibu Hospital could not served by dr. Moewardi Hospital because the distance between the two hospitals exceeds the allowed critical distances.

1. Introduction

Problems related to the health sector have long been the focus of much research. Problem factors of the health sector consist of service quality, accessibility of health facilities, the cost of medical personnel and medical equipment that continues to increase, and the number of the elderly population which continues to grow and thus require more health services. These factors have brought health topics on the agenda of political practitioners and non-medical practitioner research [1]. One study in the problems of the health sector is a much-discussed issues related to the location of health care facilities [2]. Optimal health care facility location is the most important decisions to guarantee the fulfillment of the population needs for health services. The unavailability of health care services and poor site accessibility will lead to increased mortality (death) and morbidity (illness) [3].

Optimal health care facility location can be measured by the criteria of efficiency and effectiveness of the facility. Effectiveness in terms of facilities, medical personnel, and equipment utility. Efficiency in term of the distance and travel time required for the patient to reach the facilities [4]. Site assessment of optimal health care facilities has to be one of the main concerns of developing countries to avoid the occurrence of epidemic diseases which can degrade the quality of life [5]. The importance of treatment and prevention can be seen in a disease such as diarrhea, dengue fever, and malaria in developing countries which require immediate treatment to prevent the severity of the disease that can lead to death. Thus, in a developing country, it must be assessed whether the location of available health facilities was optimal or not.

Indonesia is a developing country with the 4th most populous country in the world. The country has a National Health Insurance Program (NHIP) that managed by Health and Social Insurance Agency (BPJS). The program has a hierarchical structure in which a patient must first go to the basic health care unit or family doctor then referred for further service if needed to hospital type C/D, hospital type B, and hospital type A, respectively. BPJS is a legal entity established by the government to ensure that all Indonesian people can obtain health services replaces the role of the Ministry of Health and Military Health Insurance in implementing the health insurance in Indonesia with the exception of the poor who earn Indonesia Health Card (KIS). According to Law No. 24 of 2011 by 2019 all Indonesian citizens must register all members of their Family Card (KK) in BPJS.

Surakarta city is a city with the highest population density in Central Java, Indonesia with 12,831 inhabitants/km^2 [6], therefore the determination of the optimal location is important to maintain the health of Surakarta Citizen. Surakarta city has 10 public hospitals, three specialty hospitals and 17 Basic Healthcare Units (BHUs). The health care facilities that studied in this research are non-emergency health care facilities that have been registered in the National Health Insurance Program (NHIP). Those facilities are unevenly spread in 5 districts of the city. The only one hospital type A is located on the east side of town, and three hospitals type B is located close to the city center therefore it is assumed that the health care facilities in this city has not been able to serve all existing demand. It is important to evaluate the efficiency and effectiveness of the location of the existing facilities in terms of NHIP rule.

To evaluate the hierarchy of existing health care facilities in Surakarta, an optimization model using integer linear programming (ILP) was utilized in this study [7][8][9]. Ahmadi-Javid [10] explained the frequencies of the modeling approaches used to formulate the Health Care Facility (HCF) location problems. Over 50% of the papers used integer programming, including ILP, INLP, MILP and MINLP, with ILP and MILP as the most popular modeling approaches. It seems that many of the HCF literatures, the most widely used is the modeling approach that results a simple model, which can be optimally solved within a reasonable time.

The ILP model used in this research is maximal covering model that aims to maximize the demand covered by the facilities for each level using the distance of healthcare facility and demand point also the capacity of each facility as the constrains. This study differs from previous studies. Cocking, et al. modeled the health facilities in Nouna district, Burkina Faso as a facility location network design problem and make conclusions about how best to improve the physical access of the health facilities [11]. Fo and Mota addresses the question of locating healthcare facilities in Brazil by considering the most important location models: P-median model, set and maximal covering models and P-center model [4]. But both studies have not considered hierarchical location problems.

The results of this research may be used to indicate the percentage of total demand covered by the healthcare facilities and the utility of health care facilities' capacity in Surakarta. The covering of existing health care facilities in Surakarta can be explained based on the distance between the point of demand with the existing health facilities (efficiency) and the of the service capacity of health facilities to all of the demand points (effectiveness) [12].

2.   Method

The basic model is the maximal covering model by Ahmadi-Javid [10] with the objective function to maximize the demand covered by the facilities. The covering is constrained by the distance between demand point and facilities compared to allowed critical distance. The model is further developed by including hierarchical structure based on Toreyen [13] so the model can accommodate the hierarchy in NHIP Indonesia. This model maximizes the demand for each hierarchy level. As the facilities have limited capacity so a capacity constrain need to be considered. This makes the model further developed based on Hua [14] model on capacitated maximal covering models so that the model now has the objective function of maximizing demand for each level (function 1 to 4) with distance between demand point and facilities compared to allowed critical distance (function 5 to 8), facility capacity (function 13 to 16), demand served by only 1 facility (function 9 to 12), and single streamed

demand (function 17 to 19) as the constrains. The model does not consider partial coverage and split demand. The final model can be found as follows:

Objective Function:

Maximize Z1 + Z2 + Z3 + Z4

$$Z1 = \sum_{i \in I} \sum_{j \in J} A_{ji} F_i \qquad (1)$$

$$Z2 = \sum_{j \in I} \sum_{h \in H} A_{hj} F_j \qquad (2)$$

$$Z3 = \sum_{h \in H} \sum_{g \in G} A_{gh} F_h \qquad (3)$$

$$Z4 = \sum_{g \in G} \sum_{l \in L} A_{lg} F_g \qquad (4)$$

Constraints:

$$A_{ji} d_{ij} \leq S \quad \forall i \in I, j \in J \qquad (5)$$

$$A_{hj} d_{jh} \leq S \quad \forall i \in I, h \in H \qquad (6)$$

$$A_{gh} d_{hg} \leq S \quad \forall i \in I, g \in G \qquad (7)$$

$$A_{lg} d_{gl} \leq S \quad \forall g \in G, l \in L \qquad (8)$$

$$\sum_{i \in I} A_{ji} \leq 1 \quad \forall j \in J \qquad (9)$$

$$\sum_{j \in J} A_{hj} \leq 1 \quad \forall h \in H \qquad (10)$$

$$\sum_{h \in H} A_{gh} \leq 1 \quad \forall g \in G \qquad (11)$$

$$\sum_{g \in G} A_{lg} \leq 1 \quad \forall l \in L \qquad (12)$$

$$\sum_{j \in J} A_{ji} F_i \leq C_j X_j \quad \forall i \in I \qquad (13)$$

$$\sum_{h \in H} A_{hj} F_j \leq C_h X_h \quad \forall j \in J \qquad (14)$$

$$\sum_{g \in G} A_{gh} F_h \leq C_g X_g \quad \forall h \in H \qquad (15)$$

$$\sum_{l \in L} A_{lg} F_g \leq C_l X_{lg} \quad \forall g \in G \qquad (16)$$

$$F_j = \Theta \sum F_i \quad \forall j \in J \qquad (17)$$

$$F_h = \Theta \sum F_j \quad \forall h \in H \qquad (18)$$

$$F_g = \Theta \sum F_h \quad \forall g \in G \qquad (19)$$

Sets:

$i \, \epsilon \, I$: sets of sub-district demand point

$j \, \epsilon \, J$: sets of family doctor and basic health care unit

$h \, \epsilon \, H$: sets of hospital type C/D

$g \, \epsilon \, G$: sets of hospital type B

$l \, \epsilon \, L$: sets of hospital type A

Input Parameters:

S : Allowed critical distance

P : Number of family doctor & basic health care unit

Q : Number of hospital type C/D

R : Number of hospital type B

T : Number of hospital type A

F_i : Demand at sub-district i

F_j : Flow demand at BHU/ family doctor j

F_h : Flow demand at hospital type C/D h

F_g : Flow demand at hospital type B g

d_{ij} : distance between demand point i to facility j

d_{jh} : distance between demand point j to facilty h

d_{hg} : distance between demand point h to facilty g

d_{gl} : distance between demand point g to facilty l
C_j : capacity of BHU/ family doctor j
C_h : capacity of hospital type C/D h
C_g : capacity of hospital type B g
C_l : capacity of hospital type A l
Θ : Propotion of patient needed to be referred further

Decision Variables:
A_{ji} : 1 if demand point i served by facility j, 0 otherwise
A_{hj} : 1 if demand point j served by facility h, 0 otherwise
A_{gh} : 1 if demand point h served by facility g, 0 otherwise
A_{lg} : 1 if demand point g served by facility l, 0 otherwise
X_j : 1 if facility j active, 0 otherwise
X_h : 1 if facility h active, 0 otherwise
X_g : 1 if facility g active, 0 otherwise
X_l : 1 if facility l active, 0 otherwise

In Surakarta City there are 51 Sub-districts, 17 Basic Health Care Units, 30 Family Doctors, 6 hospitals type C/D, 3 hospitals type B, and 1 hospital type A. The demand points are measured in each sub-district center of population density as seen in Figure 1. The distance used in this model is determined using Google Maps real path distance between demand point and facilities Indonesian Ministry of Health standard of reference proportion of 15% is used as the value of referral proportion (Θ) for all levels except level I that used historical data of 5% reference from BHU ad family doctor to hospital type C/D. Then the model is solved using IBM ILOG CPLEX Optimization Studio version 12.7.1.
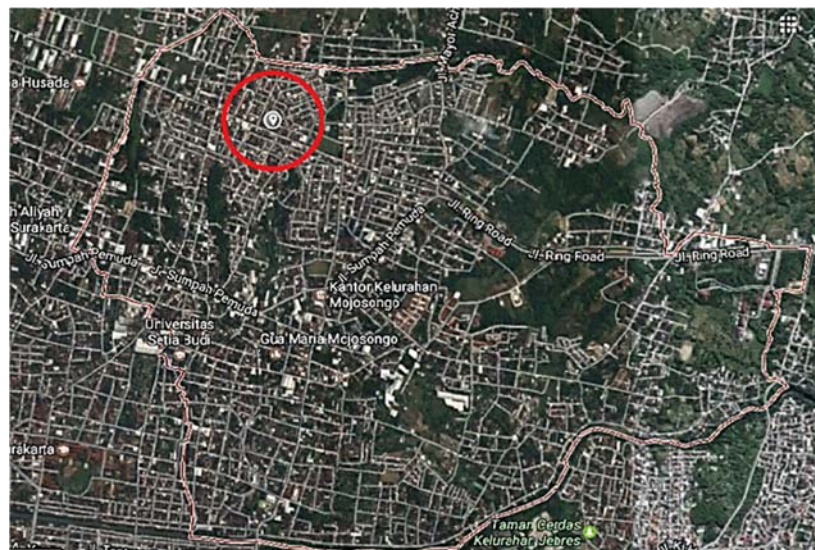

Figure 1. Example of Mojosongo sub-district center of population density.

3. Result

The result from the model for level I can be seen in the Table 1. Almost every sub-district in Surakarta City is covered by the existing primary health care facilities (Basic Health Care Unit and Family Doctor) except for 1 sub-district which is Kadipiro, Banjarsari because of the capacity of existing available health care near this sub-district is not sufficient to accommodate the demand.

Table 1. Level I Model Result.

District	Number of				Population
	Sub-district	BHU and Family Doctor	Covered sub-district	BHU and Family Doctor Used	
Banjarsari	13	15	12	4	181,106
Laweyan	11	10	11	5	102,333
Serengan	7	4	7	3	54,649
Pasar Kliwon	9	4	9	4	86,679
Jebres	11	10	11	5	14,209

The result for level II as seen in Tabel 2**.** Shows that the covering of BHU and family doctor is not tied within the sub-district but spread across the city, like in Serengan there are 4 BHU and family doctor and 0 hospital type C/D but the BHU and family doctor could be covered by hospital type C/D in other district. The number of covered BHU and family doctor differ from the available facilities because this model adopt single-stream demand in which because some BHU and Family Doctor does not cover any demand from previous level, they will not be covered in this level.

Table 2. Level II Model Result.

District	Number of			
	Sub-district	BHU and Family Doctor	Covered BHU & Family Doctor	Hospital Type C or D
Banjarsari	13	15	5	2
Laweyan	11	10	5	2
Serengan	7	4	3	0
Pasar kliwon	9	4	3	1
Jebres	11	10	5	1

The results for level III and IV can be seen in Table 3**.** The table shows that the existing hospital type A is unable the cover the demand from all hospital type B, this is caused by the distance between Kasih Ibu Hospital (type B) exceeded the allowed critical distance to dr. Moewardi Hospital (type A).

Table 3. Level III and IV Model Result.

District	Number of				
	Hospital Type C or D	Covered Hospital Type C or D	Hospital Type B	Covered Hospital Type B	Hospital Type A
Banjarsari	2	0	1	1	0
Laweyan	2	1	1	0	0
Serengan	0	0	0	0	0
Pasar kliwon	1	0	0	0	0
Jebres	1	1	1	0	1

A sensitivity analysis was also conducted in this research to identify the change in the percentage of demand covered by changing the value of allowed critical distance. The existing condition is condition B in which 2.5 kilometers is used for allowed critical distance between the sub-

district and primary health care facilities and 5 kilometers for allowed critical distance between primary health care facilities and hospital. From Table 4**,** it shows that the decrease of allowed critical distance will also decrease the percentage of covered demand, which indicated that the facilities is not well spread in Surakarta City because it's need of bigger allowed critical distance to stay covered. The best condition is condition C when the allowed critical distance between level III and IV is increased by 0.5 kilometers and make Kasih Ibu Hospital covered by hospital type A.

Table 4. Sensitivity Analysis.

Allowed Critical Distance (km)	Percentage of covered demand			
	Level I	Level II	Level III	Level IV
2.0 and 4.5	84%	93%	97%	0%
2.5 and 5.0	90%	98%	98%	20%
2.5 and 5.5	90%	98%	98%	80%

4. Conclusion

The demand for health care service in Surakarta City is mostly covered by the existing health care facilities except in level IV because of the allowed critical distance between level III to level IV is not far enough to make a hospital type A able to cover every available hospital type B. To increase the percentage of covered demand to 100%, the capacity of the BHU or Family Doctor in Kadipiro, Banjarsari district needs to be improved. Capacity can be increased by increasing operating hours and increasing the number of services at BHU or Family Doctor. This result can be used by the Public Health Office of Surakarta to plan the number and capacity of health care facilities needed to provide health services to the community. The critical distance of health services for hospital type A should be extended so that it could be cover more patients referred from hospital type B or C. It is recommended to carry out further research to improve the model with split demand so that the output of improved model can better represent the actual scenario.

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