Siting Hospital and Health Center in Halmahera Island Indonesia with Spatial Interaction Model

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1. Introduction

This study aims at developing a formulation and a developing Genetic Algorithm for location-allocation of hierarchical health care facilities. To show the background of the formulation, we try to explain a realistic condition of the objective area of this study is Halmahera Islands, North Maluku, Indonesia. North Maluku is an archipelago province in Indonesia, which consists of 320 small islands. The total area is 103.789 square kilometers with 22.698 (22%) square kilometers land territory and 81.091 square kilometers (78%) sea territory. The geographical constraints appear in efforts to improve physical infrastructure for health service in this area, because that area consists of hundred islands and mountainsas shown in the original map in figure 1. In the current condition, a patient should transfer from a boat to ferry or airplane to go to the hospital site. It is interesting to identify the location-allocation problems of this area because the condition of Halmahera Islands has some particular characteristics as follows: (1) decision associated with displacement cost, (2) mode of transportation, (3) allocations are influenced by regional season or climate, (4) problem of construction network, (5) problem of connection between facility, (6) problem of congestion happened in a site of facility, (7) construction fund is limited, and so on. This problem is particularly complicated in a demand network which contains the spreading of villages on small islands and big islands (figure 1).

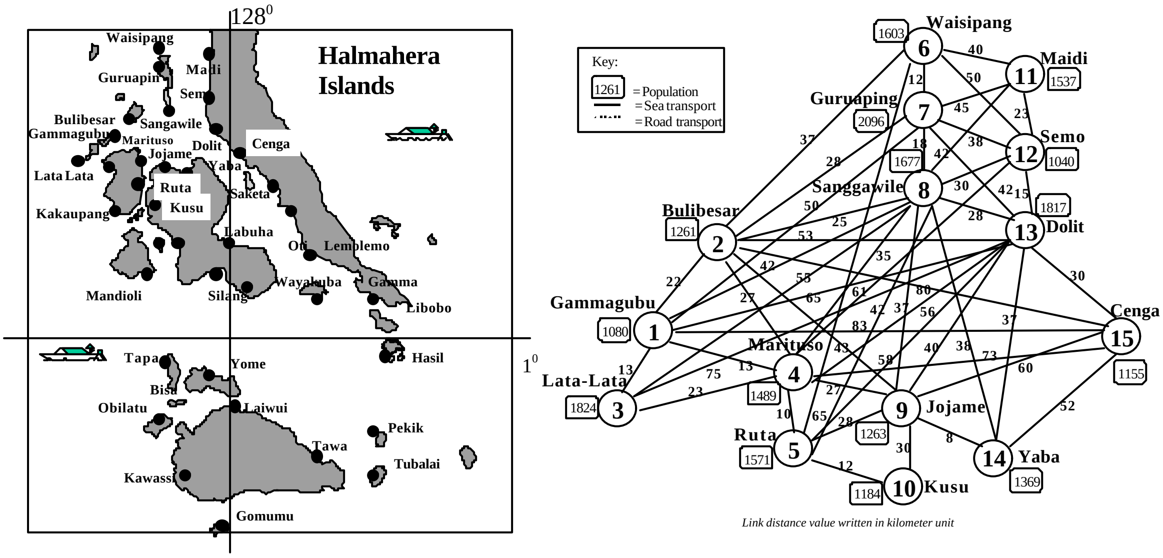


Figure 1. A Part of Halmahera Islands, Indonesia and a Network Model

2. Modeling of Location-Allocation Problem

The basic model is median model with an adjustment of the decision of allocation variable. We are concerned with three kinds of patients flow, that is, the allocation to hospital or health center and the referral allocation from health center to hospital. This is done by changing the nature of allocation variable from a 0-1 to a stochastic variable, that is, the probability that the patients at node i attracts to a facility at j. The form for user-attracting model is as follows:

$$y_{kj}^{1} = G_k \frac{f(\boldsymbol{b}, c_{kj}) h_j^1 x_j^1}{\sum_j f(\boldsymbol{b}, c_{kj}) h_j^1 x_j^1} \qquad \forall k, j \tag{1}$$

Accessibility is a measure of user's benefit consistent with a spatial interaction behavior. Leonardi (1981) describes that users seem to apply a definite distance-decreasing discount factor on facilities. The most natural measure of accessibility seems to be a sum of the capacities (or attractiveness) of all service facilities. Each capacity is discounted with space-discount factor. The simplest congestion-sensitive demand model is a linear feedback signal that is proportional to the difference between total capacity and attracted demand, which changes the value of the attractiveness weights for each facility. The evaluation results of congestion and attractiveness provide new attractiveness vector to the main model (location-allocation model) and for the evaluation of accessibility. The new accessibility vector will be employed as a variable for the accessibility sensitive demand model. The objective function (1) minimize the total patient (demand) weighted travel cost from a demand node to the health center or hospital and referral patients from health center to hospital. Constraint (2) stipulates that the hospital must be located is limited based on hospital budget. Constraint (3) states the number of health centers are to be located is depend on budget. Constraints (4) state that at candidate health center k can be covered by more than one selected hospital based on critical coverage distance. Constraints (5) state demand at node i can only be assigned to a hospital at candidate site j if we locate a hospital at candidate site j. Constraints (6) similar to constraints (5) state demand at node i can only be assigned to a health center at candidate site k if we locate a health center at candidate site k. Constraint (5) and (6) link the location variables and the allocation variables. Constraints (7) state the link of referral patients from a health center at candidate site k to a hospital at candidate site j. Constraints (8) and (9) are the integrality constraints, respectively. Mathematical formulation are written as follows:

Minimize

$$\sum_i \sum_j c_{ij} y_{ij}^1 + \sum_i \sum_k c_{ik} y_{ik}^2 + \sum_k \sum_j c_{kj} y_{kj}^3 \qquad (1)$$

Subject To

$$(a+br)\sum_j x_j^1 \le B_{hospital} \qquad (2)$$

$$(a'+b'r')\sum_k x_k^2 \le B_{h.center} \qquad (3)$$

$$x_k^2 \le \sum_j a_{kj} x_j^1 \qquad \forall k \in K \qquad (4)$$

$$y_{ij}^1 - x_j^1 G_i \le 0 \qquad \forall i \in I, j \in J \qquad (5)$$

$$y_{ik}^2 - x_k^2 G_i \le 0 \qquad \forall i \in I, k \in K \qquad (6)$$

$$2y_{kj}^3 - (x_k^2 + x_j^1) G_k \le 0 \qquad \forall k \in K, j \in J \qquad (7)$$

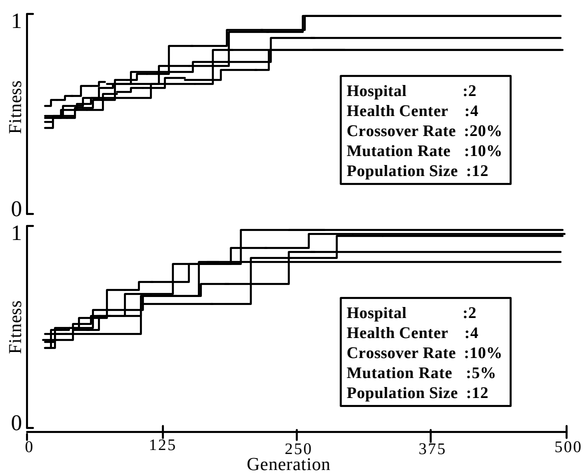
$$x_j^1 = \{0,1\}, \quad x_k^2 = \{0,1\} \qquad \forall k \in K, j \in J \qquad (8)$$

$$y_{ij}^1 \ge 0, y_{ik}^2 \ge 0, y_{kj}^3 \ge 0 \quad \forall i \in I, k \in K, j \in J \qquad (9)$$

k, j = *subscripts labeling the candidate site of health center and candidate site hospital*; G_k = *total referral patients from health center site k*;
c_{kj} = *the total cost associated with a displacement from health center site k to hospital site j*;
$\boldsymbol{b}$ = *a spatial discount parameter* (≥ 0) *to be valued empirically*; $f(\boldsymbol{b}, c_{kj})$ = *a space discount function such as* $\exp(-\boldsymbol{b}c_{kj})$
(*as used here*) *or* ${c_{kj}}^{-b}$; k = *parameter for actual demand function*; y_{kj} = *the number of referral patients in health center site k allocate to hospital site j*; d_{ij} = *distance*; $B_{hospital}$, $B_{h.center}$ = *budget for hospital and h.center*;
a, a' = *basic construction cost*; b, b' = *cost coeficient*; r, r' = *size of facility*; p_i = *potential demand*;
c_{ij} = *total cost between node i and candidate site of hospital j*; $a_{kj} = 1$ *if candidate h.center k is within* D_{hc} *travel time unit of candidate site hospital j*, 0 *otherwise*; $x_j^1 = 1$ *if candidate site of hospital is selected* ,0 *if not*;
$x_k^2 = 1$ *if candidate site of h.center is selected* ,0 *if not*; y_{ij}^1 = *allocation of patients at node i to hospital site j*;
y_{ik}^2 = *allocation of patients at node i to health center site k*; y_{kj}^3 = *allocation of referral patients from health center site k to hospital site j*;

3. Calculation Result

To apply the model, we consider a simple network with total population about 22.000 as shown in figure 1. The numbers of hospitals and health centers to be located are 2 and 4, respectively. The facilities will be located at the demand nodes, where one candidate site for locating one facility. The critical coverage distance is 100 km. The number of patients for allocating to hospital in average are equal 1.5% of the populations. The number of patients for allocating to health center in average are equal 1.0% of the populations. The referral patients rate is approximately equal 10% of the patients.



Combination Site of Facility	Objective Value		
	β=0.10	β=0.05	β=0.01
hospital at 4 and 8 h.center at 1,9,12, and 13	16635.921	19058.163	25077.119
hospital at 2 and 8 h.center at 3,7,9, and 13	18258.526	20951.892	26362.966
hospital at 3 and 10 h.center at 2,7,9, and 13	26137.749	28893.606	33054.159
hospital at 6 and 13 h.center at 2,7,9, and 15	21506.244	23787.987	29348.156
hospital at 6 and 13 h.center at 3,7,9, and 15	21288.872	23568.002	30554.448
hospital at 8 and 13 h.center at 3,7,9, and 15	19536.076	21939.761	27681.483
hospital at 8 and 9 h.center at 3,7,9, and 15	17869.058	20296.926	26966.855
hospital at 8 and 9 h.center at 2,3,9, and 15	19531.171	21884.383	26972.565
hospital at 8 and 9 h.center at 2,3,9, and 11	18744.003	21289.648	26801.266
hospital at 2 and 7 h.center at 5,6,9, and 12	19330.564	22073.413	27596.455
hospital at 4 and 13 h.center at 5,6,9, and 12	16503.883	19054.651	26500.852
hospital at 4 and 13 h.center at 5,7,9, and 12	16075.834	18670.939	25826.389
hospital at 2 and 13 h.center at 5,7,9, and 12	17528.876	20249.783	26596.092
hospital at 2 and 13 h.center at 3,4,5, and 11	28345.184	22875.001	28345.184
hospital at 4 and 8 h.center at 1,7,9, and 13	**15016.124**	**18123.709**	**24681.73**

Figure 2. Calculation Results

This observation motivates the searching optimal solution that compromises between the decision maker of location and the behavior of users, the calculation results shows in figure 2. In order to improve the current situation of Halmahera Islands with regards a coverage distance, it can be said that the provision of transport facility is urgent government policy.

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