Siting Hospital and Health Center in Halmahera Islands Indonesia

○ Fauzy AMMARI Keiichi OGAWA Toshihiko MIYAGI
Graduate School of Engineering, Gifu University, Japan

1. INTRODUCTION

Halmahera Islands are a part of North Maluku province. 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. Based on census 1991, total population of North Maluku province is 568.780 inhabitants. The population are separated equally in 21 subdistrics and 320 islands. The Halmahera island, which is 80% of North Maluku regency area, only 40% from whole population in province. In spite of that the magnitude of population are spreading in many small islands around Halmahera island. Our network for studying was build for the south part of Halmahera island, Obi islands, Bacan islands, and Kayoa islands as shown in the original map in figure 1. This is one of motivations for us to apply the model to this area.

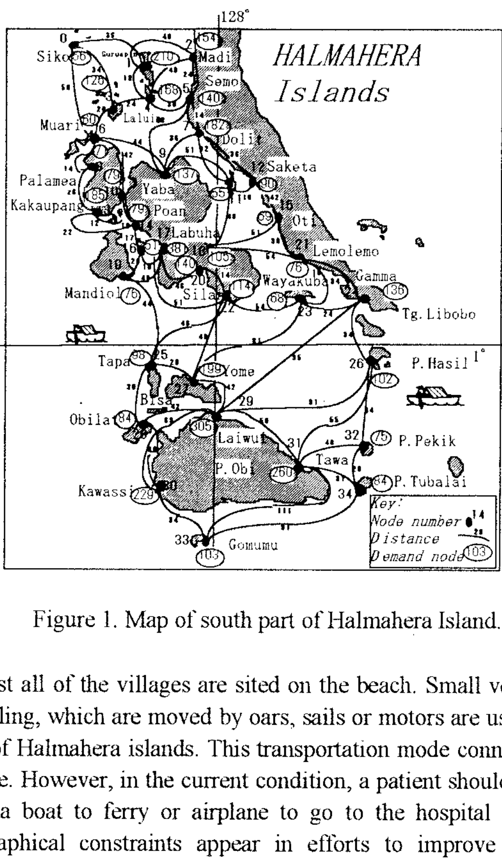


Figure 1. Map of south part of Halmahera Island.

Almost all of the villages are sited on the beach. Small vessels for travelling, which are moved by oars, sails or motors are used in the area of Halmahera islands. This transportation mode connects each village. However, in the current condition, a patient should transfer from a boat to ferry or airplane to go to the hospital site. The geographical constraints appear in efforts to improve physical infrastructure for health service in this area, because that area consists of hundred islands and mountains. Commonly, developing countries has limited funds allocated to the health sector.

The allocation of patients (nonemergency) is working based on user-attracting system. The user-attracting system denote the choice of facility is made by the user. Such systems should have a spatial interaction model to represent user choice behavior. In doing so, Leonardi (1981) describes two subsystems as follows. The first subsystem is the accessibility-sensitive demand mechanism. It depends on the location size, and proximity of the facilities. Usually, the demand will increase with the accessibility of the location. The second subsystem is the congestion-sensitive demand mechanism. Leonardi (1981) identifies that the congestion-sensitive demand mechanism receives as inputs the actual demand from each location, the location and size of facilities in each location, and the transport cost between demand and facility locations.

2. MODEL

The background of basic model is median model with an adjustment of the decision of allocation variable. 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 described in figure 2.

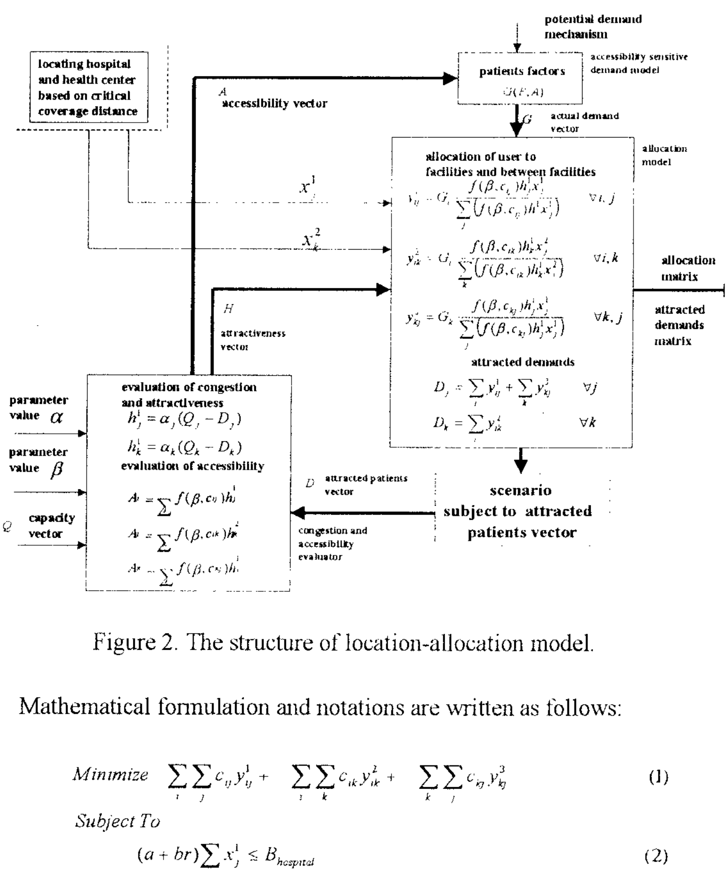


Figure 2. The structure of location-allocation model.

Mathematical formulation and notations are written as follows:

$$Minimize \quad \sum_i \sum_j c_{ij} y^1_{ij} + \sum_i \sum_k c_{ik} y^2_{ik} + \sum_k \sum_j c_{kj} y^3_{kj} \qquad (1)$$

Subject To

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

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

$$x^2_k \le \sum_j a_{kj} x^1_j \qquad \forall k \in K \qquad (4)$$

$$y^1_{ij} - x^1_j G_i \le 0 \qquad \forall i \in I, j \in J \qquad (5)$$

$$y^2_{ik} - x^2_k G_i \le 0 \qquad \forall i \in I, k \in K \qquad (6)$$

$$2y^3_{kj} - (x^2_k + x^1_j)G_k \le 0 \qquad \forall k \in K, j \in J \qquad (7)$$

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

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

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.

where

k, j = *subscripts labeling the candidate site of healthcenter and candidate site hospital;*
G_k = *total referral patients from health center site k;* D_j = *attracted demand in hospital site j;*
h_j = *a measure of attractiveness of hospital in site j;* c_{kj} = *the total cost associated with a displacement from healthcenter site k to hospital site j, measured in appropriate units,*
β = *a spatial discount parameter* (≥ 0) *to be valued empirically,* $f(\beta, c_{kj})$ = *a space discount function such as* $\exp(-\beta c_{kj})$*(as used here) or* $c_{kj}^{-\beta}$, *which is strictly monotonically declining;*
y_{kj} = *the number of referral patients in healthcenter site k allocate to hospital site j.*
Q_j = *the capacity of hospital site j;* D_j = *the total demand attracted in hospital site j;*
α_j = *given constants, typical of each location.;* $B_{hospital}, B_{h.center}$ = *budget for hospital and h.center,*
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.*

3. NUMERICAL EXAMPLE

To illustrate the model, we consider a network based on Halmahera network with total population 20.000 as shown in figure 3. Network with 9 nodes and each node has demand in 100 unit. The number of hospital and health center to be located equal 2, respectively. The facilities will be located at the demand nodes, where one candidate site for locating one facility. The critical coverage distance is 35. The rate of patients in average are equal 1.0%. The referral patients rate is approximately equal 10% of the patients coming from each demand node.

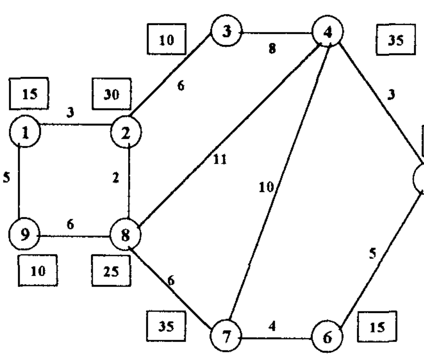


Figure 3. A given network.

We adopt Lagrangian Relaxation Method to handle this example with relaxing constraints (5), (6), and (7). Then, use some method to modify the Lagrange multiplier in such a way that the violated constraints are less likely to be violated on the subsequent iteration. The method outlined below is that of subgradient optimization. We start with deciding the initial value of Lagrange multiplier. After that, we can update the Lagrange multipliers by computing a step size. The formula outlined below is the summary of calculations.

Step Size:

$$t^n = \frac{\alpha^n (UB - \ell^n)}{\sum_i \sum_j \left\{ y_{ij}^{1\,n} - x_j^{1\,n} G_i \right\}^2 + \sum_i \sum_k \left\{ y_{ik}^{2\,n} - x_k^{2\,n} G_i \right\}^2 + \sum_k \sum_j \left\{ 2 y_{kj}^{3\,n} - (x_k^{2\,n} + x_j^{1\,n}) G_k \right\}^2}$$

$$t^n \geq 0 \qquad n = 1, 2, \ldots..$$

The Lagrange Multipliers

$$\lambda_{ij}^{n+1} = \max\left\{0, \lambda_{ij}^n + t^n (y_{ij}^1 - x_j^1 G_i)\right\} \qquad \forall i, j$$

$$\lambda_{ik}^{n+1} = \max\left\{0, \lambda_{ik}^n + t^n (y_{ik}^2 - x_k^2 G_i)\right\} \qquad \forall i, k$$

$$\lambda_{ij}^{n+1} = \max\left\{0, \lambda_{kj}^n + t^n (2 y_{kj}^3 - (x_k^2 + x_j^1) G_k)\right\} \qquad \forall k, j$$

Initial Value of $\lambda_{ij}, \lambda_{ik}, \lambda_{kj}$,

$$\lambda_{ij} = \tau(\overline{G} + 0.5(G_i - \overline{G})) \qquad \forall i, j$$

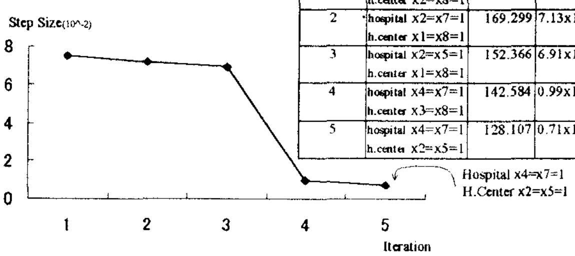
$$\lambda_{ik} = \tau(\overline{G} + 0.5(G_i - \overline{G})) \qquad \forall i, k$$

$$\lambda_{kj} = \tau(\overline{G} + 0.5(G_k - \overline{G})) \qquad \forall k, j$$

Where

t^n = *the step size at the nth iteration of the Lagragian procedure;*
α^n = *a constant on the nth iteration;* UB = *the best (smallest) upper bound on the main model;* ℓ^n = *the objective function of the Lagrangian function on the nth iteration;* y_{ij}^{1n} = *the value of the allocation variable,* y_{ij}^1, *on the nth iteration;* x_{ij}^{1n} = *the optimal value of the location variable,* x_{ij}^1, *on the nth iteration;* $\overline{G}$ = *average demand value;* G_i = *demand at i;*
τ = *initialization parameter;* λ_{ij}^n = *the Lagragian multiplier.*

Figure 4 shows a result of five iterations for the value of parameters deciding adequately to show the working of adopting procedure. Hospitals are located at node 4 and node 7 and health centers are located at node 2 and node 5.



Iteration	Configuration	Obj. Value	Step size
1	hospital x4=x7=1 h.center x2=x8=1	178.236	7.49x10^-2
2	hospital x2=x7=1 h.center x1=x8=1	169.299	7.13x10^-2
3	hospital x2=x5=1 h.center x1=x8=1	152.366	6.91x10^-2
4	hospital x4=x7=1 h.center x3=x8=1	142.584	0.99x10^-2
5	hospital x4=x7=1 h.center x2=x5=1	128.107	0.71x10^-2

Figure 4. The result of calculation.

4. CONCLUSION

A spatial interaction model in choosing a site of hospital or health center has been combined with a simple hierarchical location model. Our model could be showing the performance of users-attracting based on the congestion and accessibility criterion of spatial interaction effect to minimize the total patients weighted travel cost. We find some effects in a simple numerical illustration with a Lagrangian Relaxation method. It is this observation that motivates the searching optimal solution that represent compromises between the location decision maker and the behavior of users and their willingness to choose access. 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. For the whole network of Halmahera Islnads, it is efficient in computer time to use Genetic Algorithm.

References

1. Ammari, F. and Miyagi, T.(1999) Health Care Facilities Location Model with Genetic Algorithm. *Journal of the EASTS,* , Vol.3, No.4, 55-69.
2. Leonardi, G. (1981) A Unifying Framework for Public Facility Location Problems-Part 1: A Critical Overview and Some Unsolved Problems, *Environment and Planning A, Vol.13,* 1001-1028.