

Spatial Interaction Model in Health-Care Facility Location-Allocation *

医療施設配置に関する空間相互作用モデルの構築*

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1. Introduction

The costly and inefficient producing of complete services for health care in all demand nodes and its patient's flows motivate us to study the location-allocation problems of hierarchical facilities. Generally, health service facilities with the large coverage are the health centers or the village clinics and the hospitals. We concerned with hospital (or general hospital) as an upper level and health center as a lower level⁽⁴⁾. Planning of public health care facility location is done by regional planning agencies to prevent maldistribution of resources and services, which can seriously affect the availability, appropriateness, and cost of health services, and the health of the population. The amount of care that the system should be capable of providing must be specified by the planning agency.

Basically, the gravity model of spatial interaction is based on an analogy with Newtonian physics. In general terms, it postulates that the amount of interaction between an origin and a destination increases proportionally with the sizes of the origin and the destination but decreases with some function of the distance between them (Ritsema and de Jong, 1999)⁽⁶⁾. The gravity model, among other methods, is of a simple nature, with a high statistical explanatory power (Endoh, 2000)⁽⁵⁾. In the field of spatial interaction modeling the majority of applications have been set within a static or comparative static framework (Clarke et al., 1998)⁽³⁾. There are different types of gravity models, depending on the distance function that is used and on the constraints on the numbers of customers from each area and to each shop. Most commonly used in retail applications is the singly constrained gravity model (Ritsema and de Jong, 1999)⁽⁶⁾, make it possible to propose new application in facility location choices.

As the use of gravity models become more widespread, it is most adopted as a tool in the research topics of spatial interaction. Their popularity can be explained by the following fact: spatial interaction is an expression of consumer behaviour and important phenomenon in regional economy. Transportation planning and consumer behaviour, for example, are very common application areas for gravity models (Mikkonen, K. and Luoma, M., 1999)⁽¹³⁾.

In real conditions, Holmber (1999)⁽⁹⁾ notes that in public facility location problems the users are often free to make their own choice of facility. However, in the common modeling class, public sector facility location models have been defined as those that minimize user cost for a given level of service subject to a public budget constraint, whereas private sector models are those that minimize the total cost for meeting fixed user demands (Erlenkotter D., 1983)⁽⁶⁾. The most important part of location allocation model is the allocation rule, that is, the way users are assigned to facilities (Leonardi, 1983)⁽¹¹⁾. In the well-known models of the "plant-location" family, the embedded allocation rule is the assignment of the least-travel-cost facility (Leonardi, 1983)⁽¹¹⁾. Gore (1991)⁽⁸⁾ describes that it would involve specifying rules of access regarding eligibility, priority, and location of the service and relating those to the person's actual position in the system, including endowment, location, and a wide range of other phenomena relevant to access.

One interesting case in public facility location problem is health care facility location. Based on the reviews outlined above, This study mainly aims at developing a formulation and a simple solution procedure for location-allocation of hierarchical health care facilities. The purpose of this paper is to find answers to the following questions:

1. How to combine an allocation based on spatial interaction model and a simple mathematical model of hierarchical health care facility location? The key issues that we are considered with are: (1) where the facilities should be located, (2) how to allocate demand nodes with a set of facility type, and (3) how the patients behavior based on spatial interaction effect works.
2. How the calculation procedure could be established to handle the location-allocation of health care problem based on a simple real network of Halmahera Islands?

This paper is organized as follows. After the introduction, an information of social conditions of Halmahera Islands Indonesia will be presented, especially the geographical conditions. In the modeling sections we present the concept of the modeling facility location problems, patients allocation problems, formulating the patients allocation model, main formulation of the model, and an outlined flowchart of calculation procedure. We also consider some scenarios allocation and location for an extension in spatial interaction modeling. In the section 5, to see the model performance, we demonstrate the model in a simple real. Here, we begin the numerical example by definition of the objective network, then the assumption of the parameters, setting cost function in several types based on parameter value, and we summarize the performance of the model. In

* Keywords: Hierarchical Facility Location, Spatial Interaction, Regional Planning

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section 6, we explain some findings of this study as a conclusion.

2. Social Conditions of the Objective Area

To show the background of the formulation, we try to explain a realistic condition of the objective area of this study, that 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 kilometers¹⁵⁾ 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 is separated in 21 sub-districts and 320 islands. The Halmahera Islands have 80% of North Maluku regency area, and only 40% of whole population in province.

Almost all of the villages are sited on the beach. Small ships which are moved by oars, sails or motors are used for travelling in the area of Halmahera islands. These transportation modes connect between villages. 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 as 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.

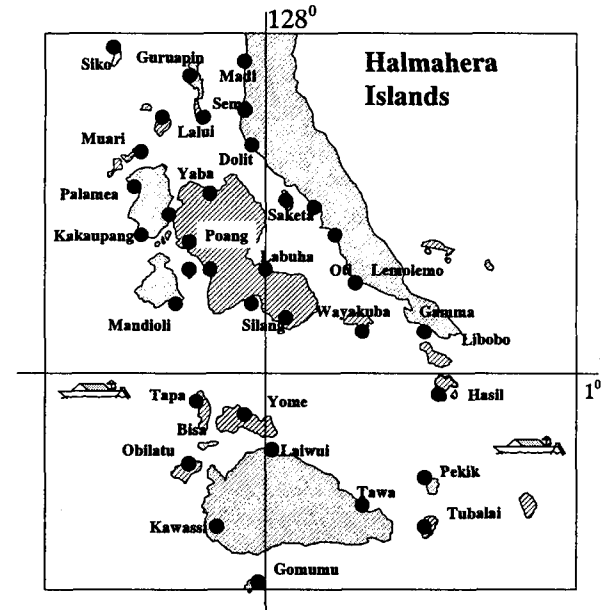


Figure 1. South part map of Halmahera Islands, Indonesia.

This is also one of motivations for us to model in type of median problem. The median model has a power in linking

the location variables and the allocation variables. We use a part of the area in our numerical calculation.

3. Modeling of Location-Allocation Problem

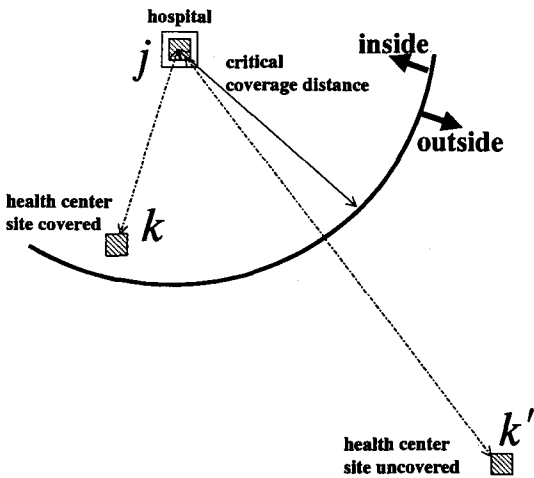
(1) Concept of the Modeling

In the starting of this study, a model of location-allocation of hierarchical health care facility are developed based on the system-attraction facilities^{1),4)}. In the system-attraction facilities, the public authority decides both of locations of facilities and the rule of allocation of patient to facilities. In ordinary application, the system attraction implicitly deals with cases in which there are emergency types of demands. It generates the facility to be as near as possible to the demand.

The extension of this system is doing as follows. The problem is formulated as a minimization of total patient's-weighted travel distance. Basically, this model is based on the hypothesis that the location and allocation are controlled by different decision-makers. The following assumptions have been made in order to achieve a tractable problem structure. (1) Health care facility system consists of hierarchically coordinated two level facilities. (2) Each health center must be located within a critical coverage distance of the hospital. (3) The facilities can be located anywhere on the network. (4) Users' behavior is based on spatial interaction (gravity) model.

(a) Facilities Location Problems

The physical location configuration of hospitals and health centers is determined in relation to the hierarchy. The important factor is the ability of hospitals site to cover health centers site. Since the most important thing is to save patients as quickly as possible. Critical coverage distance has sense of critical travel time for referral movements to the next treatment in a higher facility. Thus, we are concerned not with facility placement disperse, but with the resulting coverage patterns of those placements. The relation of hospitals and health centers based on the critical coverage distance is illustrated in figure 2.



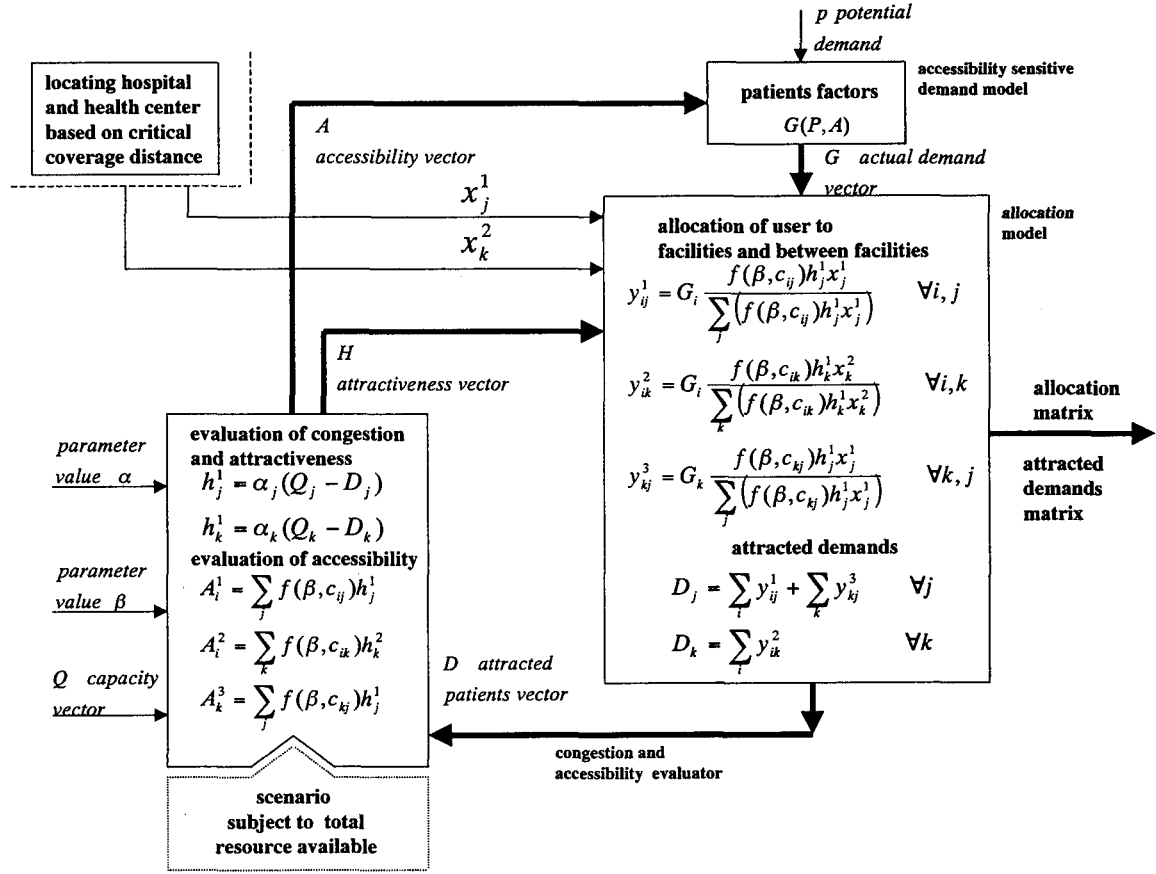


Figure 3. Structure of allocation model.

(b) Patients Allocation Problems

The allocation of patients (non-emergency) is based on user-attracting system. The user-attracting system denotes the user choice of facility. Such systems are formulated by a spatial interaction model to represent user choice behavior. Leonardi (1981)¹⁰ describes two subsystems as follows. The first subsystem is the accessibility-sensitive demand mechanism. Usually, the demand will increase with the increasing of accessibility to the location. The second subsystem is the congestion-sensitive demand mechanism. Leonardi (1981)¹⁰ identifies that the congestion-sensitive demand mechanism is expressed based on the inputs of the actual demand and accessibility value.

The part of allocation is based on the patient's decisions. The patient's decisions theoretically based on spatial criterion as well as congestion and accessibility. It is called user-attracting facilities. User-attracting facilities denote those, such as retail/service or health-care facilities, where the user makes the choice of facility. Such system should have a spatial interaction model to represent user choice behavior. For facilities in excess demand, almost the rule in developing countries, destination-constrained gravity-type models are defined, where the actual demand satisfied at each origin region is endogenous. This gravity model was 'embedded' in a least square optimization criterion for locating health-care services in the United Kingdom, as explore in the paper of Mayhew and Leonardi (1982)¹². The overall problem was concave, with a unique optimum. The main distinction point with system attracting facilities is that

users may not choose their nearest facility because (a) it may have very long queues for admission and (b) the referring doctor may prefer a specialist in another facility. Also it is important to allow satisfied and thus unsatisfied demand at each facility to be endogenous, this information is important for policy purposes, especially for areas with high levels of unsatisfied demand.

(2) Formulating of the Patients Allocation

The basic model is median model with an adjustment of the decision of allocation variable. We are concerned with three kinds of patient's 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 (notation is written in the last page):

$$y_{kj}^1 = G_k \frac{f(\beta, c_{kj}) h_j^1 x_j^1}{\sum_j f(\beta, c_{kj}) h_j^1 x_j^1} \quad \forall k, j \quad (1)$$

Accessibility is a measure of user's benefit consistent with a spatial interaction behavior. Leonardi (1981)¹⁰ 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. Accessibility is represented as:

$$A_i = \sum_j f(\beta, c_{ij}) h_j \quad (2)$$

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. Its weight are evaluated according to the formula,

$$h_j = \alpha_j (Q_j - D_j) \quad (3)$$

Based on the definition of subsystems above, the overall location-allocation system can be assembled. It is an adjustment of Leonardi (1981)¹⁰ framework shown in figure 3.

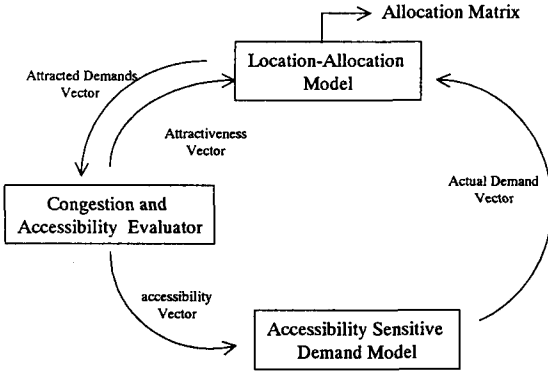


Figure 4. The diagram of evaluating vectors.

In the allocation model, we implicitly deal with case in which the congestion and the accessibility are always evaluated based on attracted patient's vector. 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. Based on the input vectors and parameters, the main model is working as a cycle until the optimal value is estimated (figure 4).

(3) Mathematical Formulation of the Model

Based on the above assumptions, mathematical formulation is written as follows:

$$\text{Minimize} \quad \sum_i \sum_j c_{ij} y_{ij}^1 + \sum_i \sum_k c_{ik} y_{ik}^2 + \sum_k \sum_j c_{kj} y_{kj}^3 \quad (4)$$

$$\text{Subject To} \quad (a + br) \sum_j x_j^1 \leq B_{\text{hospital}} \quad (5)$$

$$(a' + b'r') \sum_k x_k^2 \leq B_{\text{h.center}} \quad (6)$$

$$x_k^2 \leq \sum_j a_{kj} x_j^1 \quad \forall k \in K \quad (7)$$

$$y_{ij}^1 - x_j^1 G_i \leq 0 \quad \forall i \in I, j \in J \quad (8)$$

$$y_{ik}^2 - x_k^2 G_i \leq 0 \quad \forall i \in I, k \in K \quad (9)$$

$$2y_{kj}^3 - (x_k^2 + x_j^1) G_k \leq 0 \quad \forall k \in K, j \in J \quad (10)$$

$$x_j^1 = \{0,1\}, \quad x_k^2 = \{0,1\} \quad \forall k \in K, j \in J \quad (11)$$

$$y_{ij}^1 \geq 0, y_{ik}^2 \geq 0, y_{kj}^3 \geq 0 \quad \forall i \in I, k \in K, j \in J \quad (12)$$

The objective function (4) 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 (5) stipulates that the hospital must be located is limited based on hospital budget. Constraint (6) states the number of health centers is to be located is depend on budget. Constraints (7) state that at candidate health center k can be covered by more than one selected hospital based on critical coverage distance. Constraints (8) 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 (9) similar to constraints (8) 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 (8) and (9) link the location variables and the allocation variables. Constraints (10) state the link of referral patients from a health center at candidate site k to a hospital at candidate site j. Constraints (11) and (12) are the integrality constraints, respectively.

The results of the model is expected to show the performance of users' behavior based on the congestion and accessibility criterion of spatial interaction (gravity) effect in choosing a site of hospital or health center to minimize the total patients weighted distance in a network. It will affect the precision of locating the state of these facilities in node. In application to a network, with discrete candidate site and continuous candidate site, it needs a conditioned conventional heuristic algorithm because of two the types of facility.

(4) Procedure of Estimation of the Optimal Location

The procedure to calculate the optimal location and allocation can be described as follows. At the first step, the problem of locating hospitals and health centers are concerned based on critical coverage distance.

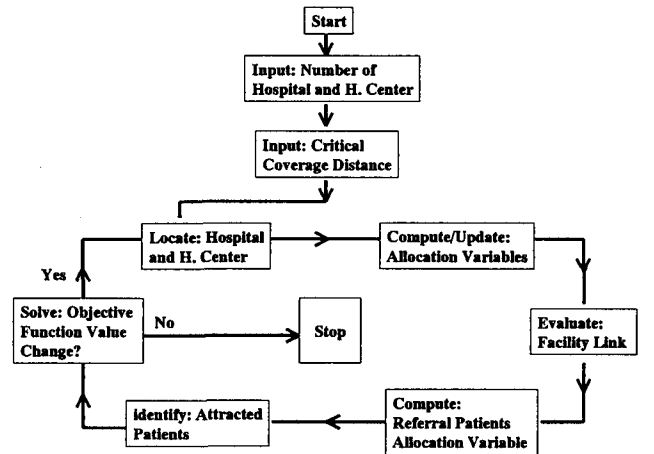


Figure 5. The outline of calculation procedure.

The second step deals with calculation of allocation variables. The decision of patients is based on the evaluation of congestion and accessibility, this procedure depend on all parameters of the spatial system. Because this procedure work in the NP-Complete (Non-Polynomial) problem, the iteration works until find a criterion. Figure 5 shows the procedure.

4. An Extension: Some Scenarios of Spatial Interaction

The allocation system contains endogenous variables and exogenous variables. The transportation cost function is considered as an endogenous in the framework because it is affected by distance, while potential demand mechanism is not endogenous. The input potential demands are totally exogenous, possibly given by the population-forecast model shown in figure 6. In the related model, only rough potential demands have been used as ground estimation of the number of patients in each node.

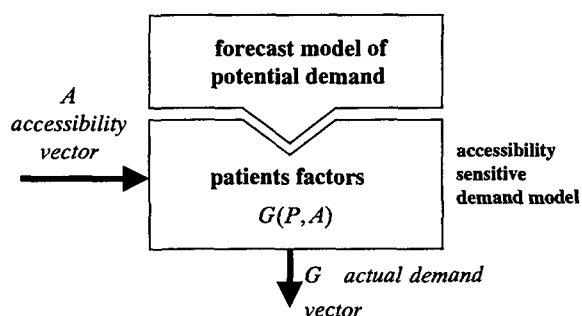


Figure 6. The accessibility demand model.

(1) Scenarios of Allocations Problem

The capacity input data also depend on exogenous feature, these are, resources for treating patients in-groups of specialties. The analysis of capacity vector brings us to the criteria of how the resource has been distributed to consumer. Mayhew and Leonard (1982)¹² formulate some different scenarios of health-care resource allocation, that is, equity, efficiency, and two types of accessibility. The criteria are linked by a common spatial interaction model. It is defined as follows:

1. The equity criterion: choosing a resource configuration such that the demands in each part of region are satisfied.
2. The efficiency criterion: choosing a resource configuration that maximizes the total benefit of consumers by satisfying their preferences for treatment in different locations.
3. Particular Accessibility-1: the first way is to choose a resource configuration that equalizes the average costs of travel from places of residence to places of treatment.
4. Particular Accessibility-2: equalizing the average accessibility costs will be inefficient if the variance in the observed costs between different of residence is large. Thus a second criterion is defined: it is to choose a resource configuration that maximizes the variance in the accessibility cost from places of residence to places of treatment.

(2) Scenarios of Location Problem

Another fundamental spatial concept is *Connectivity*. Connectivity refers to a linkage pattern among discrete locations. On the other hands, another spatial concept related to separation is that of *contiguity*. This is an expression of closeness, and together with its antithesis, dispersion, gives meaning to the concept 'degree' of separation. In macro level, Golledge (1990)⁷ describes the compartmentalizing of space by boundaries and the identification of specific districts and routes can be seen to have considerable relevance for macrospatial judgements, whether they are of the point-to-point variety or the area to area (urban A versus urban B).

In order to work with a choosing scenario, the exogenous capacity input in the structure of location-allocation model (figure 7) need to evaluate in the related scenario. The scenario has a task of control the value of capacity. In other words, the scenario subject to input capacity vector. The equity subsystem and efficiency subsystem is always against each other. But in view of the different resource configurations produced by the equity and efficiency criteria, it seems reasonable to create mixture submodel for certain types of health-care services to design a model that permits the user to trade-off one goal against the other. The condition that bring us to choose the equity and efficiency in a same time with controlling a trade-off parameter.

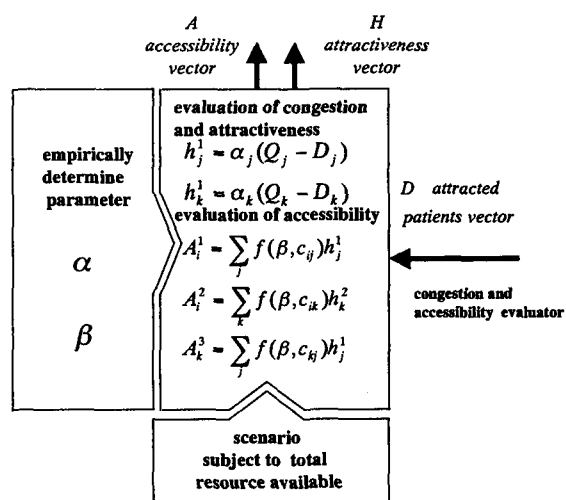


Figure 7. The evaluation diagram with inserting scenario.

5. Numerical Example

(1) Definition of the Objective Network

To apply the model, we consider a simple network with total population 20,000 as shown in figure 8. This network is based on Halmahera Islands network. Network consists of 9 nodes and each node has demand in 100 unit. The numbers of hospitals and health centers to be located are 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 number of patients for allocating to hospital in average is equal 1.0% of the populations per day. The number of patients for allocating to

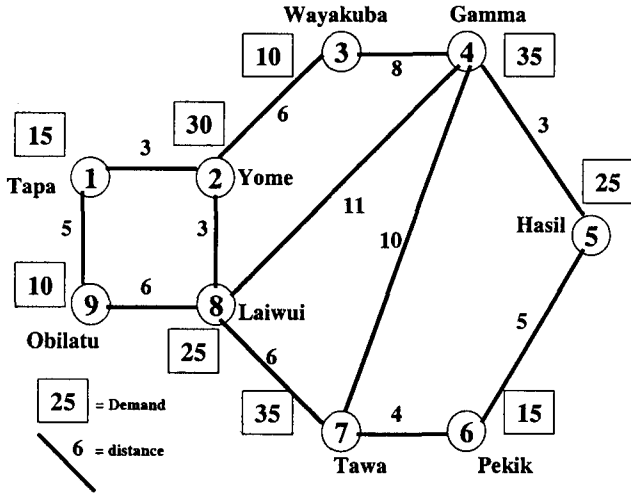


Figure 8. A part of Halmahera network.

health center in average is equal 0.5% of the population per day. And the referral patient rate is approximately equal 10% of the patients allocated to the health center.

(2) Assumption of the Parameters

Concerned with the calculation of allocation variables, the space discount function is assumed as exponential as follows:

$$f(\beta, c_{ij}) = \exp(-\beta c_{ij}) \quad (13)$$

Same function is assumed for the trips from demand node to hospital. Trips from demand node to health center and trips from health center to hospital. The parameter β , a spatial discount parameter, is assumed in variation values. The evaluation of congestion and attractiveness values is calculated based on equation (3). The capacity of hospital and health center in each site is 240 patients per day and 110 patients per day, respectively. The parameter α is an expression value of typical location. We assume parameter α are 0.25 for one site of hospital and 0.60 for another site of hospital. Similar, we assume parameter α are 1.0 for one site of health center and 0.50 for another site of health center. Here, we assume a different value of α , it offers a means of showing each location has different typical site. It is influenced to the facility congestion-sensitive attractiveness weights for the hospitals and the health centers. The measure of accessibility based on the space discount function and the value of attractiveness are calculated by equation (2). Relevant data for establishing travel cost function is distance data. The travel cost function is monotonic increasing function with parameter b for curve's shape and parameter e for multiple units, see equation (14), and figure 9. In the sub model of accessibility sensitive demand model, based on accessibility-increasing demand curve, we create an exponential increasing function for calculate actual demand vector. The function work based on the values of potential demand vector p and accessibility vector with parameter k for multiple units, see equation (15), and figure 10.

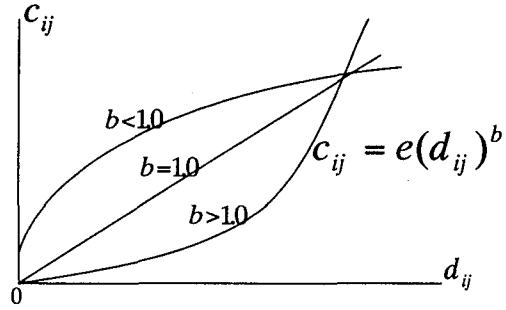


Figure 9. An increasing travel cost function.

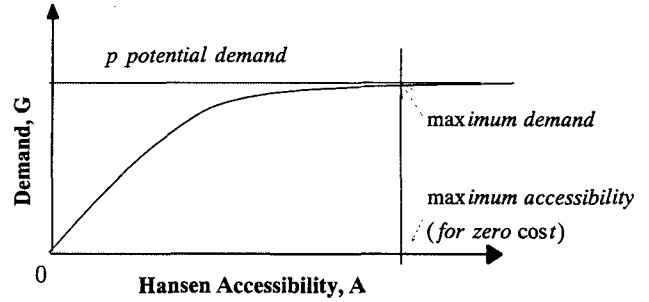


Figure 10. An accessibility-increasing demand curve.

$$c_{ij} = e (d_{ij})^b \quad (14)$$

$$G_i = p_i [1 - \exp(-\hat{k} A_i)] \quad (15)$$

(3) Difference of the Travel Costs by the Cost Functions

Table 1 shows travel costs for hospitals located at node 2 and node 5 and health centers located at node 1 and 8. It follows from (14) by putting $e=1.0$ and $b=1.0$. The values in the column indicate the patient weighted travel cost for allocating to hospitals and health centers. The actual demand is calculated based equation (15).

Table 1. Travel cost by the linear travel cost function.

e=1 and b=1							
node no.	patients weighted travel cost						objective value
	to hospital (j=2)	to hospital (j=5)	to h.center (k=1)	to h.center (k=8)	referral patients	referral patients	
	(ci2 x yi2)	(ci5 x yi5)	(ci1 x yi1)	(ci8 x yi8)	(ck2 x yk2)	(ck5 x yk5)	
1	44.998	0.011	13.618	3.454	10.696	0.006	1572.899
2	59.992	0.065	21.244	15.837			
3	8.302	25.849	21.244	21.116			
4	0.647	104.861	12.681	184.295			
5	0.051	49.994	18.760	173.430			
6	2.585	73.923	8.442	69.372			
7	178.924	113.711	8.951	100.524			
8	74.942	0.288	13.262	19.695	10.686	0.086	
9	79.939	0.154	18.701	7.558			
sub total	819.236		732.186		21.477		

Table 2 shows travel cost for hospitals located at node 2 and node 5 and health centers located at node 1 and 8. It follows from non-linear cost function (14) by putting $e=0.8$ and $b=0.9$. The values in the column indicate the patient weighted travel cost for allocating to hospitals and health centers. The actual demand is calculated based on equation (15). We record another case calculated by nonlinear travel cost function in table 3, by putting $e=0.7$, $b=0.8$. The performance of the three calculation results is concerned with choice of the hospital sites or health center sites.

Table 2. The results for a nonlinear travel cost function.
 $e=0.8$ and $b=0.9$

node no.	patients weighted travel cost						objective value
	to hospital (j=2)	to hospital (j=5)	to h.center (k=1)	to h.center (k=8)	referral patients	referral patients	
	(ci2 x yi2)	(ci5 x yi5)	(ci1 x yi1)	(ci8 x yi8)	(ck2 x yk2)	(ck5 x yk5)	
1	32.157	0.540	9.027	4.948	10.656	0.246	1095.690
2	44.545	1.651	15.192	11.845			
3	9.668	16.322	13.941	13.453			
4	5.966	73.769	27.365	102.672			
5	1.296	37.132	30.647	90.759			
6	8.682	47.132	13.572	38.237			
7	105.346	85.164	18.481	60.317			
8	52.941	3.477	12.576	13.148	10.573	0.950	
9	51.017	2.206	11.159	6.914			
sub total	579.012		494.253		22.425		

Table 3. Travel cost by the nonlinear travel cost function.

node no.	patients weighted travel cost						objective value
	to hospital (j=2)	to hospital (j=5)	to h.center (k=1)	to h.center (k=8)	referral patients	referral patients	
	(ci2 x yi2)	(ci5 x yi5)	(ci1 x yi1)	(ci8 x yi8)	(ck2 x yk2)	(ck5 x yk5)	
1	24.593	3.165	6.521	5.453	12.226	4.475	859.320
2	35.245	7.305	11.639	9.866			
3	9.200	11.573	9.653	9.689			
4	15.469	54.491	30.172	62.117			
5	5.696	29.441	29.239	53.135			
6	13.108	31.544	13.297	23.512			
7	70.607	64.505	20.956	39.328			
8	39.283	10.369	10.736	10.077	11.978	5.772	
9	33.767	6.618	7.471	6.031			
sub total	465.979		358.891		34.450		

Table 4 summaries some results in variation value of parameter b and e for different configurations of location site. Here, the best configuration is also depending on the value of b and e . The alternative configurations are indicated by the low value of objective function.

Table 4. Summary of some configurations of location.

Combination Site of Facility	Objective Value		
	$e=1.0, b=1.0$	$e=0.8, b=0.9$	$e=0.7, b=0.8$
hospital at 4 and 7 h.center at 2 and 8	2038.958	1410.579	1039.575
hospital at 3 and 6 h.center at 4 and 5	2182.305	1493.686	1099.377
hospital at 5 and 8 h.center at 3 and 6	1509.896	1161.039	938.949
hospital at 2 and 7 h.center at 1 and 8	2048.467	1430.215	1053.327
hospital at 3 and 8 h.center at 4 and 9	1941.162	1384.604	1048.729
hospital at 1 and 8 h.center at 2 and 5	1938.475	1307.271	969.011
hospital at 2 and 5 h.center at 1 and 8	1572.899	1095.69	859.32

(4) Performance of Allocation Model

Figure 11 shows the performance of allocation model. There are two main feedback loops in the calculation of the allocation model. After decided a combination of facilities locations, we establish initialization in the step of accessibility sensitive demand model. The values of potential demand as an actual demand vector are used in this step. Attractiveness vectors are also constant. Based on initialization value, allocation of user to facilities are calculated by the all allocation patients, total demand in each hospital or health center are calculated in each iteration. These total demand values (attracted patients vector) work as a variable in congestion and accessibility evaluator. This 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 moving wave is appeared because the resulting weights renew a value for accessibilities. It is generate new value for total demand, over and over again, until the equilibrium is reached.

In calculation process, the models need some parameters for its measure. Here, the variation of the spatial discount parameter are used to show the distribution of patients in each iteration, the space discount function play an important role of the choice of allocation patients. Figure 11 and 12 show the geometric interpretation of the system. All of the figures indicate the same characteristic in the beginning of iterations, strictly waves are appeared at the beginning and then reduce until equilibrium tending of the system. Each spatial discount parameter gives different performance and equilibrium allocation concerned with the changing allocation behavior in space discount function.

Figure 12 shows the performance of allocation referral patients. These show two cases based on the different spatial discount parameters. The performance of referral patients shows, the referral patients tend to choose the both hospitals in same probability that in small value of parameter. Small parameter also describes that the equilibrium points are to be reached in long iteration.

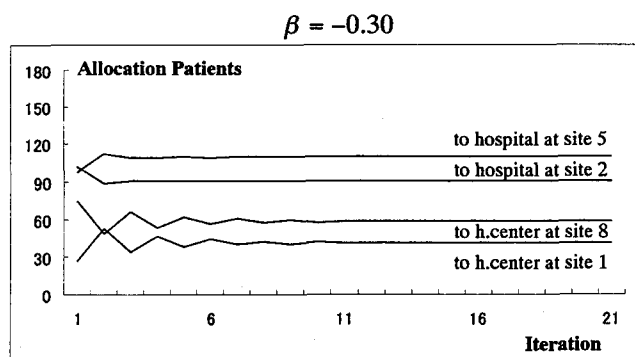
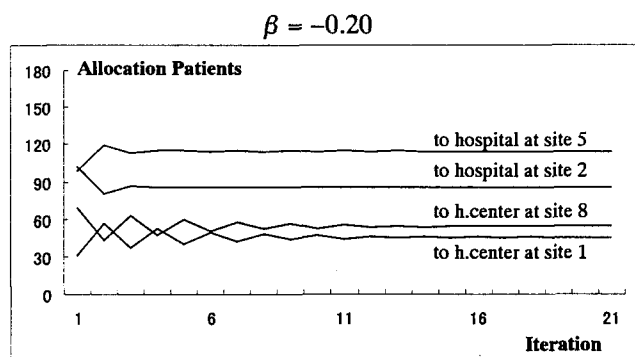
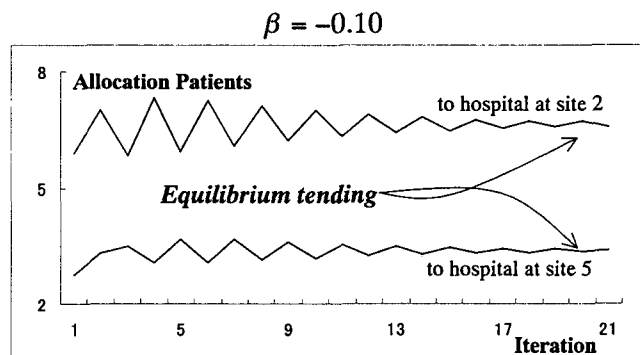
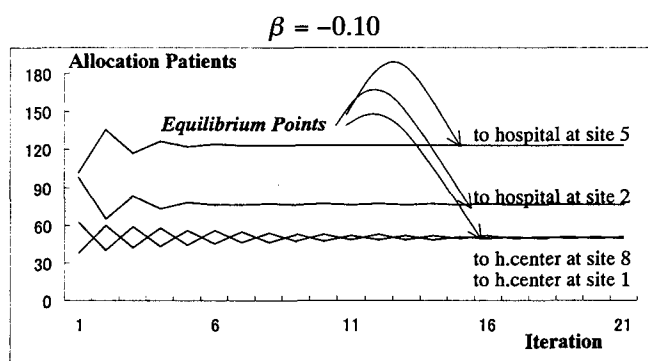
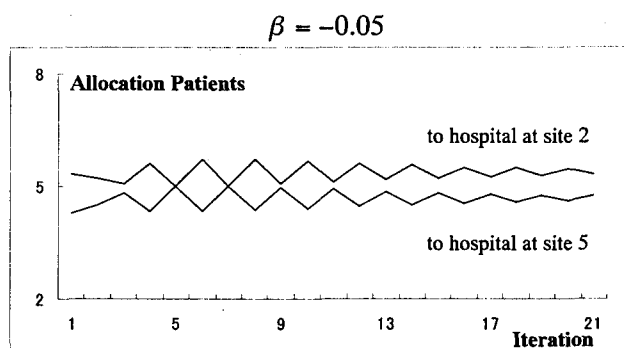
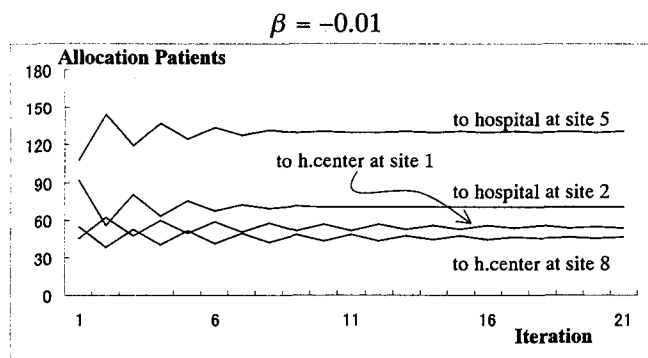


Figure 11. The performance of allocation model.

Figure 13 shows the patient flows based on spatial interaction effects. The number of patients allocated to each type of facility is strongly depend on the total cost associated with a displacement from each type of facilities. Since, in this numerical example, we adopt a space discount function working based on travel cost function (eq. (14)) and a spatial discount parameter β in eq.(13). Basically, the space discount function contains a meaning of facility choice. Patient choices are implicitly started to work depend on the travel cost value. Consequently, the travel cost value work

Figure 12. The performance of allocation referral patients.

together with the attractiveness of the facility to find the accessibility value for all routes. The results of the calculation brings the patients allocation diagram as shown in figure 13, that is, almost the patients are allocated to the facilities site with high values of accessibility. Because, the coverage distance parameter is high, the referral patients in these two health centers are allocated to the hospital site with high accessibility.

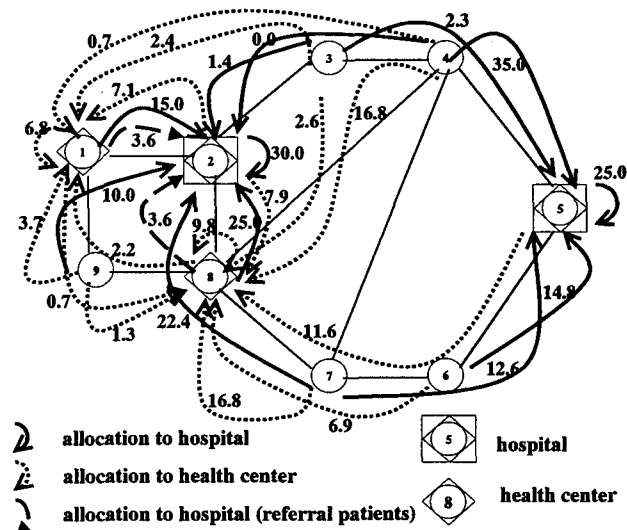


Figure 13. Patient flows based on spatial interaction model.

6. Conclusion

A spatial interaction model in choosing a hospital or health center has been combined with a simple hierarchical location model. This model can deal with the performance of users-attracting based on the congestion and accessibility. The

spatial interaction model is based on the minimization of the total patients weighted distance (or travel cost). Some effects are found in a simple numerical example with a simple algorithm. This observation motivates the searching optimal solution that compromises between the decision-maker of location and the behavior of users.

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Notation:

k, j = subscripts labeling the candidate site of health center 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 health center site k to hospital site j ;
 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 $c_{kj}^{-\beta}$; \hat{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;
 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.;

α_j = given constants, typical of each location.;

$B_{\text{hospital}}, B_{\text{h.center}}$ = budget for hospital and h.center;

a, a' = basic construction cost; b, b' = cost coefficient;

r, r' = size of facility; p_i = potential demand;

e, b = related parameter for travel cost function;

c_{ij} = total cost between node i and candidate site of hospital j ;

$a_{ij} = 1$ if candidate h.center k is within $D_{h.c}$ 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 ;

医療施設配置に関する空間相互作用モデルの構築

Fauzy Ammari, 小川 圭一, 宮城 俊彦

本研究では、2段階の医療施設配置問題のモデル化と、その解法の提案を行う。ここでは、上位の医療施設として大規模病院、下位の医療施設として医療センターを想定している。提案したモデルでは、施設配置問題と利用者の配分問題はそれぞれ異なる意思決定者の行動により定められる。施設配置問題については利用者の総移動距離の最小化に、利用者の配分問題については移動距離と施設容量に基づく個々の利用者の選択行動に基づくものとする。このモデルを、インドネシア・ハルマヘラ地区の交通ネットワークに適用し、施設配置問題における空間相互作用について論じる。

Spatial Interaction Model in Health-Care Facility Location-Allocation

Fauzy AMMARI, Keiichi OGAWA, and Toshihiko MIYAGI

This study aims at developing a formulation and a simple solution procedure for location-allocation of hierarchical health care facilities. We deal with hospital as an upper level and health center as a lower level. The model is based on the hypothesis that the location and allocation are controlled by different decision-makers. The results that we expected in our model show the performance of users' behavior based on spatial interaction effect in choosing a site of hospital or health center to minimize the total patients weighted distance in a simple real network.
