NETWORK IMPROVEMENT AND GEOGRAPHICAL ADVANTAGE OF FREIGHT CENTER

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Abstract: Corresponding to the expressway network improvement, freight centers for inter-regional truck transportation have been spatially rearranged, to the vicinities of focal junctions of expressway network. Such change is very critical for rearranged planning of municipalities directly to strongly depending on freight delivery industries. However, freight center location does not change continuously even transportation improvement are gradual, or trucks do not always use expressway in order to cut transportation time as much as they can. Such phenomena might be caused by cycles of delivery per day, which alters the cost function of delivery from linear function for transportation time, to stepwise function jumping up around 2, 4 and 8 hours.

This paper aims to analyze the effect of inter-urban expressway network improvement on freight center location pattern from the regional planning. We formulate this problem as a two level optimal facility location model with stepwise cost function, and apply it to national-wide freight system. Furthermore, we check the stability of the freight center location against the change of the transportation time.

Key Words: Expressway, Freight center, Centrality, Delivery cycles

1. INTRODUCTION

1.1 Expressway and Freight Center Location

In Japan, road transportation time among major cities has been very much decreased due to improvements of inter-regional expressway network. For example in Chugoku area, two locations, Okayama and Hiroshima, had provided the function of freight center (Tsuchiyama *et al.*, 1990). Around 1990, two main corridors (Sanyo expressway and Chugoku expressway) from east to west and Seto-Chuou expressway which includes the SETO-OHASHI, series of large scale suspended bridges from north to south connecting between Honshu island and Shikoku island, were facilitated. In 1999, due to the completion of inner-Shikoku network, each prefectures in Chugoku and Shikoku area become directly connected by expressway network (Fig.1). These improvements contributed for decreasing transportation time among islands, and indirectly, affected the regional freight center location. Several firms shut Hiroshima center and integrated the function to the center around Okayama.

Concerning to the effect of road network improvement, Forkenbrock, D.J. *et al.* (1996) discussed the relation between expressway and business location decision. They conducted a questionnaire for manufactures and warehouses, in order to ask the ratings among factors of freight center location. The responses showed that transportation time to customer was the third important factor, following to quality and cost of labor. Moreover, accessibility to expressway network itself was listed following to the transportation time to customer, which was also reported by Kieschnick (1981). Even the firms locating on 10 to 20 miles apart from expressway, were satisfied with the accessibility to expressway. Based on these results, they concluded that if the region was already matured in the quality of labor, infrastructures other than roads, accessibility to customer would strongly determine the geographical advantage. According to the result, we can expect that transportation time to customer should be an important factor in

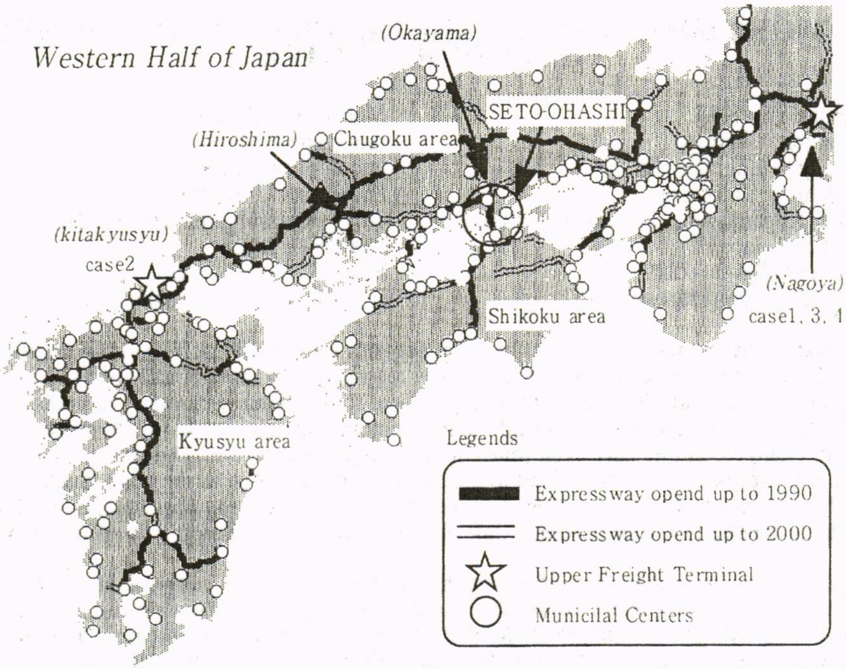

Figure 1. Study area (western half of Japan)

locating decision, since the freight center doesn't need too much qualified labor.

Kawabata (1986) classified wholesales into four types according to unit trading size of goods (i.e. lot size) in supply and demand. In his classification, the freight center in type B (large supply lot and small demand lot ; food, clothes, car, oil, medicine, etc..) is mainly expected to deliver the goods to customers in the territory. If the goods are highly standardized enough to cut the explanation about how to use it by face to face interaction, the freight center purely possesses a function of delivery. Such center prefers to locating in the center of gravity of the territory because they can reach anywhere in the territory with equally short transportation time. If unstandardized goods require a face to face explanation, the freight center needs business or service professionals in addition to freight truck drivers, then the center should be located with convenience both for frequent services and deliveries.

Ishiguro, K. *et al.* (1998) pointed out that the service function requiring face to face interaction tends to be separated from a freight center. They analyzed the difference of specialized indexes between monetary sales and shipments. According to the prefectural indexes, they presumed that the major trend in wholesales would be the separation of face to face merchandising and freight transport. Furthermore, from a longitudinal analysis, they found that the number of prefectures specialized in shipment was decreasing, and a lot size traded from the prefectures specialized in shipment was enlarged. They also pointed out that food wholesale firms become larger, or consolidating.

The firm consolidation of wholesales simultaneously causes integration and relocation of freight centers. Kawabata (1995) investigated some case studies in the location of branch office and freight centers of wholesales, in order to clarify the influence of telecommunication networking. As driving forces of integration and relocation of centers, he pointed out two kinds of forces: scale merit and globalization of territory. Scale merit has the affinity with separation of face to face merchandising and freight transport. Once the separation is started, positive feedback between integration of freight centers and functional separation begins to work, because the functional specialization as a freight center (i.e. separation) intensifies the scale merit. Globalization of territory is a direct consequence of consolidation. Consolidation usually causes abolition of some centers, then reassigns the freight from territory of the abolished centers to the other remaining centers . Due to inconvenient location of the remaining centers for the enlarged territory, these centers are pulled to the central spot of time-distance circle on the new territory. Improvement of telecommunication networking is classified as a cause of globalization, too.

According to these researches and reports, the relation between expressway and freight center location can be summarized as follows. Functions expected to the freight center (merchandising or transport) is the most important factor to determine the location. Conventionally, the function of freight center was combined face to face merchandising service with freight delivery. Because the combined freight center can't utilize the scale merit achieved by functional specialization, functional separation strategy becomes more efficient and common. As another way to reinforce the scale merit, consolidation is also effective. As a consequence of consolidation, conventional freight centers are relocated to the central spots of time-distance circle on the new territory. Improvement of expressway network strongly affects the time-distance circle around the freight center, also. Even if there is no intentional consolidation or integration of freight center, the geographical advantage as freight center is strongly affected by a network improvement, especially in case of drastic transportation time shrinking.

1.2 Purpose of This Study

The summary above is enough to understand the large scale changes in freight center location. If expressway improvement is done, which changes the geographical advantage of each area as freight center, therefore some areas are enhanced, or the others loose their conventional position. Such change in the geographical advantage will accelerate a firm to relocate their freight centers, which may result in deterioration of regional economy. From a regional planning viewpoint, understanding the mechanism of change in geographical advantage is very important to make a regional policy.

Considering the real situation, however, a question still remains why freight center locations do not continuously change by network improvement, or why trucks do not always use expressway in order to cut transportation time as much as they can. Conventional explanations are because of fixed location cost, or because toll of expressway is expensive comparing with the merit of transportation time saving.

In addition to above discussion, we can answer to this question more reasonably by considering delivery cycle per day. Because of working time regulation of truck drivers, round driving time determines the possible number of delivery cycles per day, then the amount of fixed cost per delivery cycle. Consequently, the delivering cost is not linear function of round transportation time, but the cost jumps up around 2, 4 and 8 hours. Therefore, if transportation time after network improvement still sits in the same category as before(e.g. 4.2 hr improves from 6.5hr), that change gives little significance in freight cost. In that case, the truck drivers keep to use conventional untolled road in order to cut the toll of expressway. As an another feasible reason, accessibility to the upper freight terminal locating close to the factory or warehouses at major port, is also an important factor to determine the location of regional freight center.

In order to analyze the change in geographical advantage as a freight center location corresponding to expressway network improvement, we modify facility location model which includes not only transportation cost between customers and regional freight center, but the cost between regional freight center and upper freight terminal, with stepwise cost function which jumps up around 2, 4 and 8 hours. Relocation of freight center usually corresponds to the relocation of regional division to minimize the total cost of nationwide delivery system. If accessibility of a certain location is improved, it makes a possibility that the previous covering area is cut and shared by the neighboring centers, or the firm decides to shut down a less functioned freight center. In order to cover such possibilities, wider area analysis is required even though a interest of study is focused on the specific region. In this study, we set the target region for Chugoku and Shikoku area. Therefore, we apply the model for the real network of western half of Japan, which includes Chugoku and Shikoku area in the middle.

2. OPTIMAL FACILITY LOCATION MODEL

2.1 Facility Location Problem

Facility location problem was originally developed in operations research, one of a class known as location / allocation problems (Hansen, P. *et al.*, 1987). Whether the location spots are continuous or discrete in objective field, the objective function is differently formulated. Usually, candidates for facility location spot can be limited in discrete spots, because population is sparsely dotted in the field, affected by geographic obstacles. Facility location problem in discrete field is often applied in freight planning (i.e. Love, R. F. *et al.*, 1988), or transit facility planning (i.e. Willoughby, K. A. *et al.*, 2001). Kashiwadani, M. *et al.* (2000) evaluated the effect of regional expressway network in Chugoku and Shikoku area. Applying p-median problem including the external fixed facility to actual road network, they calculated the average covering time and used the time as a index of regional accessibility in order to clarify the effect of SETO-OHASHI.

Facility locations are usually determined by cost minimization of private companies, but from public standpoint discussed by Taniguchi, E. *et al.*(1999), it should fulfill multiple objectives such as environmental load (co_2 emission) minimization, as well as economical efficiency. They applied multi-objective programming to get a optimal size and location set of public logistics terminals. Since this paper describes the behavior of private firms in regional level, however, we use single objective programming based on cost minimization criterion.

2.2 Model Formulation and Algorithm

We consider a representative freight transport firm who delivers freight from given upper freight terminal to the customers national-widely distributed using expressway network. We assume the firm only imports goods and distributes them to the customers. Therefore the freight is generated from the upper freight terminal at a port. Transportation cost reflects the required binding time of the trucks and drivers, then jumps up around 2, 4, and 8 hours. From upper terminal to regional freight center, transportation cost is r times cheaper because of larger lot size of transport. We call r as concentration ratio between regional center to upper terminal by customer to regional center ($0 < r < 1$, given in calculation). In order to count the accessibility to the upper terminal, we propose two level location model as following (1) to (5), modified conventional facility location model.

$$\min_{\mathbf{x},\mathbf{y}} Z^p(\mathbf{x},\mathbf{y}) = \sum_{i\in I}\sum_{j\in J} w_i x_{ij}(C_{ij} + rC_{jK}) + \sum_{j\in J} f_j y_j \tag{1}$$

subject to

$$\textstyle\sum_{i\in I} x_{ij} = 1 \quad \forall i \in I \tag{2}$$

$$x_{ij} \leq y_i \quad \forall i \in I, \forall j \in J \tag{3}$$

$$y_j \in \{0,1\} \quad \forall j \in J \tag{4}$$

$$x_{ij} \in \{0,1\} \quad \forall i \in I, \forall j \in J \tag{5}$$

where, $I = \{1, ..., n\}$: index set for customers, $J = \{1, ..., m\}$: index set for candidate of freight center location, K : location of upper freight terminal (given in calculation), $y_j = 1$

: locating a freight center in candidate j (otherwise, $y_j = 0$), $x_{ij} = 1$: customers in spot i assigned to a freight center in j (otherwise, $x_{ij} = 0$), w_i : number of customers in i, C_{ij} : transportation time between i and j, r : freight concentration ratio f_j : location cost in j.
By these modification, the objective function (1) is still linear in y_j and x_{ij}, consisting of interaction cost and location cost, because K and r are given in the calculation. y_j and x_{ij} are binary numbers as (4) and (5), this problem is binary integer programming problem (IP). (2) is a condition to cover all $i \in I$. (3) is a consistency between y_j and x_{ij}, if customer in i can not be assigned to j without facility (eliminating $x_{ij} = 1$ when $y_j = 0$).

If binary conditions (4) and (5) are relieved to positive real, we get a linear programming (LP) and simplex method is applicable to get the optimal solution Z^p_{LP} (Campbell, 1990). Due to a strength of constraint for solution space, Z^p_{IP} is not less than Z^p_{LP}, and equal sign only appears when optimal LP solution is integer. However, simplex method needs a long calculation time for the problem with many constraints. Actually our model includes m (number of freight center candidates) × n (number of demand locations) constraints, and the constraints matrix is sparse. Such problem can not be effectively solved even by modern LP and interior point method. Another popular algorithm for IP is branch and bound method, which is an enumeration method using lower bound information of objective function. This procedure makes sub-problems by setting restrictions on some locating candidates j (i.e. $y_j = 1$ or $y_j = 0$ for some j), which is called 'branch', and estimate the lower bound of the branch j. If the lower bound of the branch j is inferior to another branch that is already estimated, we can terminate the branch j and move to further branch, which is called 'bound'. Therefore, the efficiency of branch and bound critically depends on the accuracy of lower bound and calculation time for sub-problems. The algorithm for sub-problem is required accuracy and quickness.

Erlenkotter (1978) proposed an efficient procedure based on branch and bound method. According to duality theorem in LP, the value of dual objective function under a set of feasible dual solution gives a lower bound value of the primal objective function ($Z^d \leq Z^p$). If Z^d is equal to Z^p, the feasible dual solution is optimal. The dual objective function for (1) is formulated as following (6).

$$\max_{\nu} Z^d(\nu) = \sum_{i \in I} \nu_i \tag{6}$$

The objective function will be maximized subject to

$$\textstyle\sum_{i \in I} max\{\nu_i - C_{ij}, 0\} \leq f_j \quad \forall j \in J \tag{7}$$

where, ν_i : dual variables.
As relationships between optimal primal solutions (y^*_j, x^*_{ij}) and optimal dual solutions (ν^*_i) under LP solution space, complementary slackness conditions are required as following (8) and (9).

$$y^*_j(f_j - \textstyle\sum_{i \in I} max\{\nu^*_i - C_{ij}, 0\}) = 0 \quad \forall j \in J \tag{8}$$

$$(y^*_j - x^*_{ij})(max\{\nu^*_i - C_{ij}, 0\}) = 0 \quad \forall i \in I, \forall j \in J \tag{9}$$

When a primal objective function is to be minimized, the corresponding dual objective function is to be maximized. By introducing slack variables (s_j), we can rewrite (8) into (10)

$$\begin{aligned} &\textstyle\sum_{i \in I} max\{\nu_i - C_{ij}, 0\} + s_j = f_j \qquad \forall j \in J \\ &if\ s_j = 0 \Rightarrow y_j = 1, otherwise, y_j = 0 \end{aligned} \tag{10}$$

Eq.(10) means that ν_i can be increased until blocked by one of f_j. Therefore, if we increase ν_i with filling the constraint in *eq.*(10), we can maximize the dual objective function (6) and obtain y_j by checking s_j. x_{ij} is obtained by checking the minimum C_{ij} among j with $y_j = 1$, then $x_{ij} = 1$ for such j.

Erlenkotter's procedure consists of three stages. First stage is called *dual ascent procedure*, we increase ν_i in stepwise from the lowest C_{ij} among j for each i until all ν_i blocked by f_j through *eq.*(10). However, *dual ascent procedure* can not always give a set of optimal solution, because the solution of this procedure depends on the ascending order in ν_i. Then secondly, if $Z^p \neq Z^d$, we can check violations in *eq.*(9). Decreasing ν_i which violates *eq.*(9), then again ν_i are increased with different ascending order, in order to get better solution. That is called *dual adjustment procedure*. Thirdly, in case of $Z^p \neq Z^d$ after *dual adjustment procedure* finished, final stage (*branch and bound*) is required. In this stage, by checking violations in *eq.*(9) again, we can branch for violating j and evaluate the lower bound of the branch, then bound to another violations. In the third stage, *dual ascent / adjustment procedure* are repeatedly called as subroutines in order to estimate a lower bound of the branch. Through the application test, Erlenkotter reported that even if *dual ascent / adjustment procedure* can not give a optimal solution, these procedure yields the good approximation to optimal (i.e. $\delta = Z^p - Z^d$ is small enough), this procedure can terminate a branch efficiently in most case. We apply this algorithm for our problem.

3. APPLICATION

3.1 Data and Case Setting

We set western half of Japan as study area, in order to include Chugoku and Shikoku area in the middle. The locating candidates and customer spots are municipal centers that totally count to 268 ($n = m = 268$, all of them are shown in Fig.1).

As a number of customers (w_i) that are served with imported goods, we calculated the aggregated population of towns or villages to the closest municipal center. Because of difficulty to get the data, we use density of each municipal centers as a proxy of location cost (f_j). Inter-city transportation time (C_{ij}) is the shortest time path based on expressway, national road and prefectural road network. Since the target network is inter regional, we can neglect the congestion (transportation time is flow independent). We calculate it by using GIS function (ARC/INFO), for three different time points in 1990, 1995, 2000, corresponding to the historical improvement of expressway network. In order to consider freight delivery cycle, we modify transportation time matrix (C_{ij}) as following. For example, when $C_{ij} \geq t_l$; l th threshold, it is revised to $C_{ij} + t_l$. We make three thresholds as $t_1, t_2, t_3 = 2, 4, 8$ (hours). In this model, relative weight of transportation cost to location cost determines the result number of centers and mean coverage time. We adjust the weight in the basic case, in order to cover whole area with a maximum in round 8 hours. Freight concentration ratio (r) is a ratio of the lot size of upper freight to that of lower freight traffic. The ratio reflects characteristic of goods which determines the delivery frequency, freight lot size and inventory cost. However, we can not directly determine the ratio based on actual data, but the range is expected in $0 < r < 1$. In this study, we set three value ($r = 0.2, 0.5, 0.8$) in order to clarify the effect of the difference.

As an upper freight terminal (K), we set two alternative ports based on the amount of imported cargo in 1998. Nagoya ($K = 6$) port is the third major locating on the most eastern side in our study area, then it can represent the transport flow from the top three ports in 1998, which are Yokohama and Chiba locating more east than study area. In reality, Hanshin port ($K = 72$) is the other major port in the study area. We tested to calculate the case with upper freight terminal in Hanshin, but the freight center locations in Chugoku and Shikoku area were not substantially different from the case with Nagoya terminal. That result was because both of Nagoya and Hanshin port locate in eastern side of the target area. In our study, This case (upper terminal : Nagoya, expressway network : 2000) is referred as a base case in this study.

At first, we show the three cases of the different freight concentration ratio r(the other parameters are same as the base case). Secondary, we compare the base case with the freight center

Table 1. Simulation results

upper terminal	expressway network	cost function	f.c. ratio	primal objective	dual objective	no. of centers	covering time -2	2 to 4	4 to 8	over 8	
Nagoya	2000	stepwise	0.5	5410.3	5356.8	11	175	71	22	0	(Fig.2)
Nagoya	2000	stepwise	0.2	3633.3	3622.8	16	180	67	21	0	(Fig.3)
Nagoya	2000	stepwise	0.8	7041.6	7029.8	12	150	80	37	1	(Fig.4)
Nagoya	1990	stepwise	0.5	5725.8	5691.8	12	116	80	40	2	(Fig.5)
Nagoya	2000	linear	0.5	1027.5	4027.1	14	155	88	25	0	(Fig.8)
Kiyakyusyu	2000	stepwise	0.5	5860	5856.5	11	163	80	24	1	(Fig.9)

location under 1990's transport conditions. In order to check the effect of stepwise formulation of the cost function, comparing with the case using linear cost function, we calculate the results in each year's highway network condition from1990 to 2000. Since we only have three expressway network data (C_{ij}^t), 1990, 1995 and 2000, the internal mediate year's data are approximated by linear interpolation. For example, C_{ij}^{1992} is calculated as following.

$$C_{ij}^{1992} = (1 - 0.4) \times C_{ij}^{1990} + 0.4 \times C_{ij}^{1995} \tag{11}$$

Furthermore, we check the influence of upper terminal by the case with Kitakyusyu ($K = 188$) terminal, the 6th major port in 1998, locating on the western side of study area. Kitakyusyu has a geographic advantage in trading with Asia, therefore, this case is corresponding to Asia-oriented freight service (upper terminal : Kitakyusyu, expressway network : 2000).

3.2 Simulations

By applying Erlenkotter's procedure to solve the problem in the cases above, obtained solutions are quite good approximation to the optimal ($e = \delta/Z^p \approx 0.01$ to 1.0% in Table 1). The freight center location for $r = 0.5, 0.2$, and 0.8 are shown in Fig.2 , Fig.3 and Fig.4, respectively. In these figures, solid lines are expressways opened up to 2000, small circles are freight centers that have each territories painted differently. In these figures, we can see the integration of territories and decrease in number of centers, with increase in r. If r is close to 0, which corresponds large lot size between upper freight terminal to freight center, the freight frequency in upper interaction is relatively low. In that case, many freight centers are located in order to cut the lower interaction cost between a freight center and customers. On the contrary, in case of high r, a small lot size in upper interaction, higher frequency tends to locate fewer freight centers because they can not expect much concentration function, for a freight center. Hence the merit of freight center locating is small. As a result, number of freight center decreases, as r increases.

Fig.5 shows the case with C_{ij} based on 1990's expressway network. The differences in expressway network between 1990 and 2000 are seen in Chugoku area which had only one corridor from east to west, in Shikoku area which had only one bridge to Chugoku area (south to north) and lacked most of inner-island network, and in Kyusyu area which had some missing links. In Fig.5, two freight centers located in Chugoku area alongside of the expressway corridor, compared with 4 centers in 2000 (Fig.2). The territories are different. Fig.6 and Fig.7 show the covering time of each municipal areas the nearest freight centers in 1990 (Fig.5) and in 2000 (Fig.2), respectively. Clearly, expressway improvement causes the decrease in covering time in Chugoku and Shikoku area. To providing of the second corridor to Shikoku area would contribute a lot for such decrease.

The freight center location under linear cost function is shown in Fig.8. The change in cost function alters relative weight of transportation cost to location cost, then number of centers.

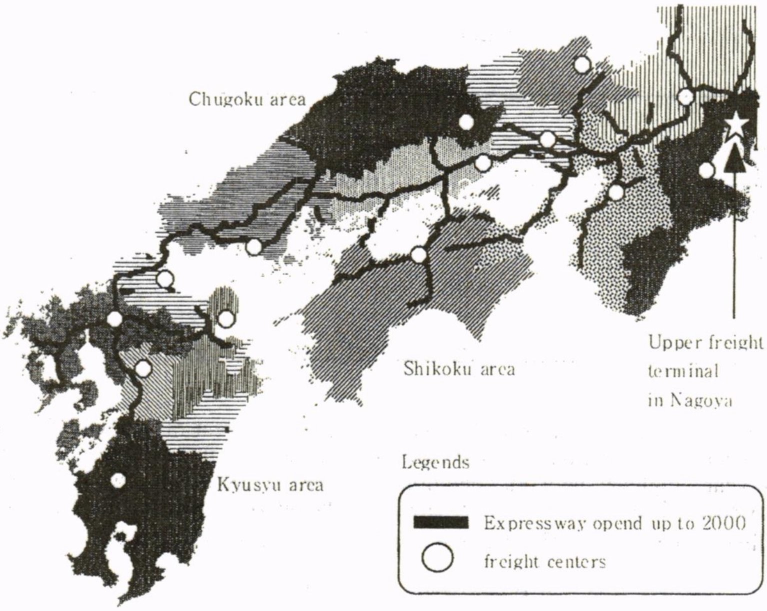

Figure 2. Location of freight centers in base (Nagoya, $r = 0.5$, 2000)

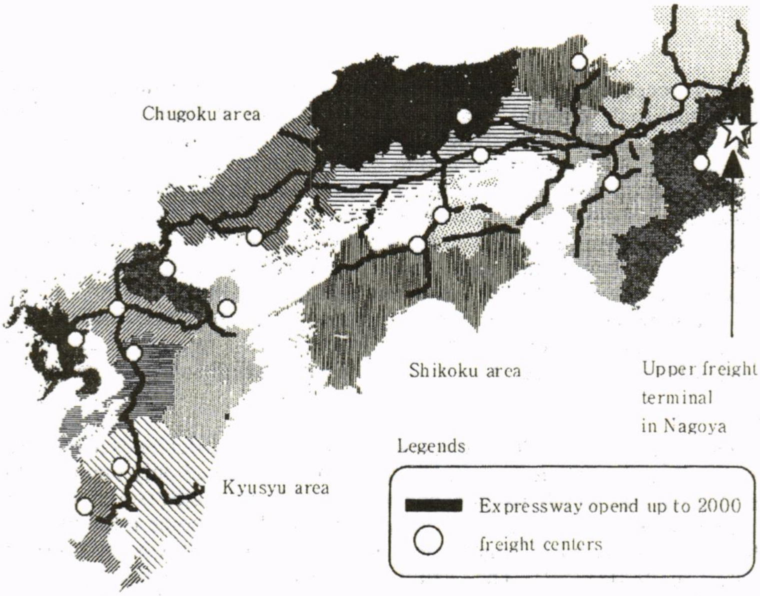

Figure 3. Location of freight centers in lower r (Nagoya, $r = 0.2$, 2000)

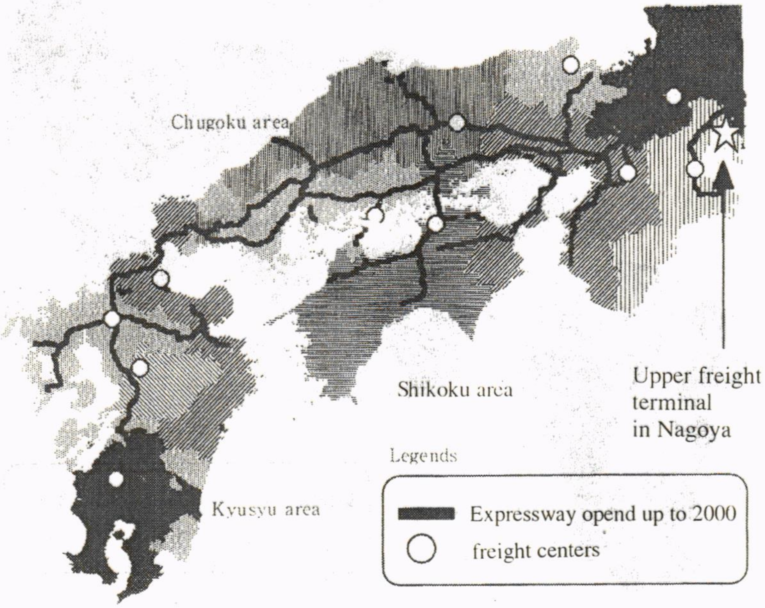

Figure 4. Location of freight centers in higher r (Nagoya, $r = 0.8$, 2000)

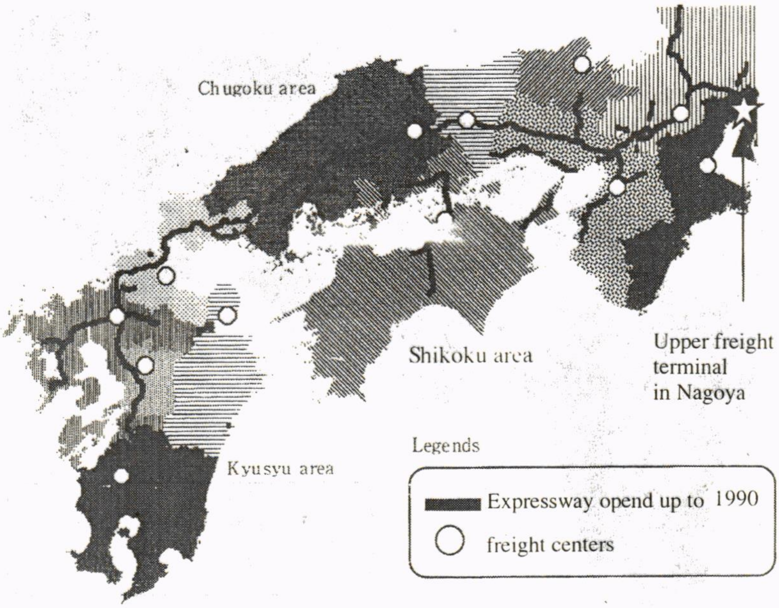

Figure 5. Location of freight centers in base (Nagoya, $r = 0.5$, 1990)

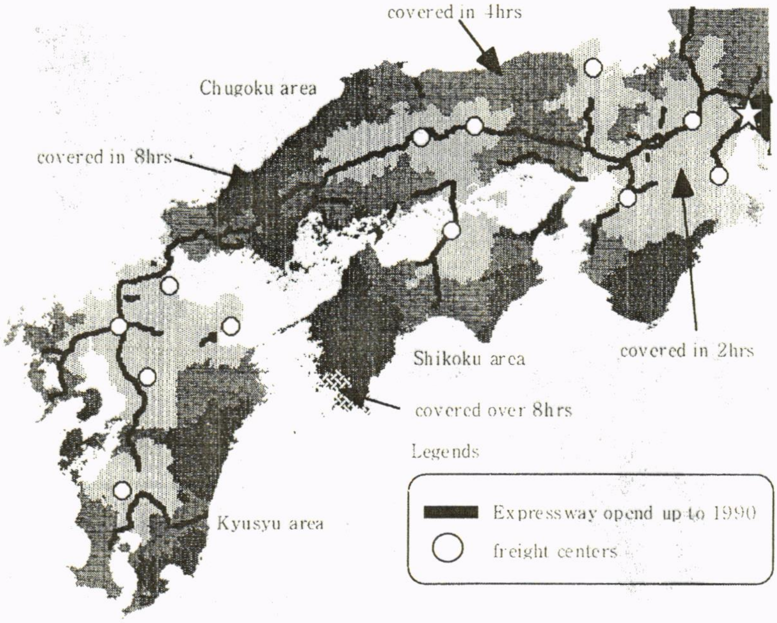

Figure 6. Covering time in base (Nagoya, $r = 0.5$, 1990)

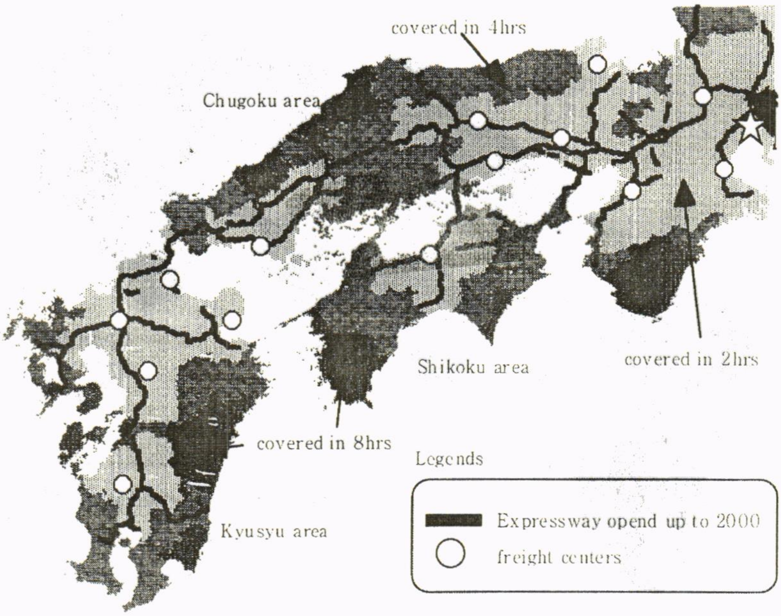

Figure 7. Covering time in base (Nagoya, $r = 0.5$, 2000)

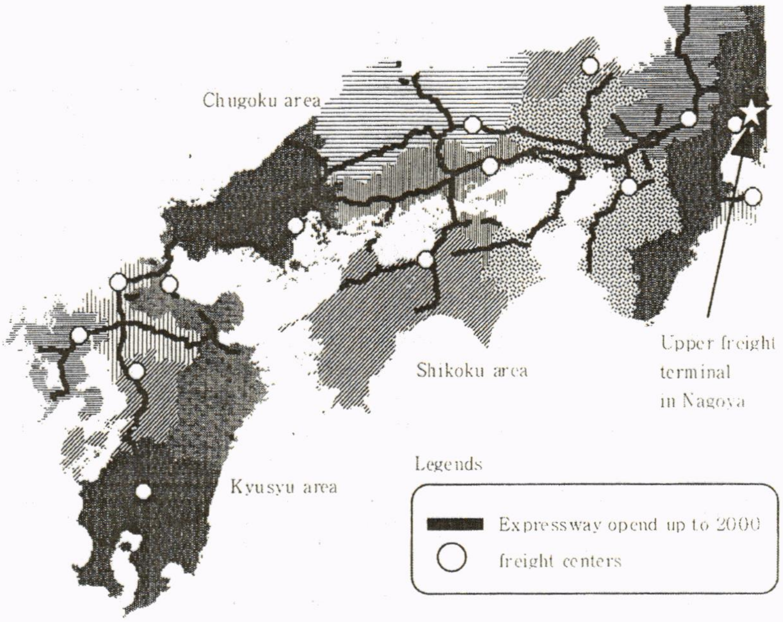

Figure 8. Location of freight centers with linear cost function (Nagoya, $r = 0.5$, 2000)

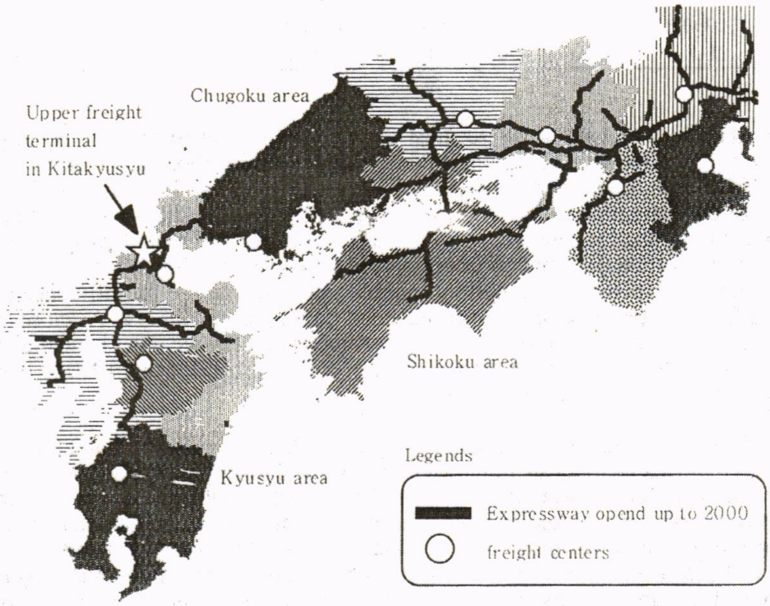

Figure 9. Location of freight centers in Kitakyusyu terminal (Kitakyusyu, $r = 0.5$, 2000)

Table 2. Longitudinal Change

upper terminal	expressway network	cost function	f.c. ratio	primal objective	dual objective	no. of centers	covering time -2	2 to 4	4 to 8	over 8	
Nagoya	1990	stepwise	0.5	5725.8	5694.8	12	146	80	10	2	(Fig.5)
Nagoya	(1991)	stepwise	0.5	5681.1	5651.1	11	146	83	38	1	
Nagoya	(1992)	stepwise	0.5	5635.5	5609.5	11	147	89	31	1	
Nagoya	(1993)	stepwise	0.5	5618.1	5568.5	12	153	83	31	1	
Nagoya	(1994)	stepwise	0.5	5522.9	5520.4	11	153	90	24	1	
Nagoya	1995	stepwise	0.5	5460.9	5460.3	11	154	88	25	1	
Nagoya	(1996)	stepwise	0.5	5451.8	5451.1	11	154	88	25	1	
Nagoya	(1997)	stepwise	0.5	5394.5	5393.9	11	156	86	25	1	
Nagoya	(1998)	stepwise	0.5	5391.2	5385.8	11	157	88	22	1	
Nagoya	(1999)	stepwise	0.5	5387.7	5374.8	12	164	80	23	1	
Nagoya	2000	stepwise	0.5	5410.3	5356.8	14	175	71	22	0	(Fig.2)
Nagoya	1990	linear	0.5	4278.5	4272.9	19	167	87	14	0	
Nagoya	(1991)	linear	0.5	4248.7	4244.1	20	172	79	17	0	
Nagoya	(1992)	linear	0.5	4211.8	4213.6	18	167	83	18	0	
Nagoya	(1993)	linear	0.5	4181.7	4180.4	17	166	84	18	0	
Nagoya	(1994)	linear	0.5	4145.9	4144.8	16	160	87	21	0	
Nagoya	1995	linear	0.5	4107.6	4106.6	15	157	87	24	0	
Nagoya	(1996)	linear	0.5	4097.6	4095.0	16	159	85	24	0	
Nagoya	(1997)	linear	0.5	4086.8	4086.2	15	158	87	23	0	
Nagoya	(1998)	linear	0.5	4069.1	4068.7	14	154	89	25	0	
Nagoya	(1999)	linear	0.5	4048.3	4047.9	14	154	89	25	0	
Nagoya	2000	linear	0.5	4027.5	4027.1	14	155	88	25	0	(Fig.8)

For ease to compare with case 1, we readjust the weight in order to give the equal number of centers with case 1 (=14). Concerning to the geographical location of centers, we can not observe drastic difference between stepwise and linear cost function. However, on Table 1, the distributions of covering time from freight centers to customers are different, then the freight centers in linear cost function case are located in more remote spots from the customers than in stepwise function, in spite that number of centers are same. Concerning to location robustness of freight centers in response to expressway improvement, we can see the difference between stepwise cost function and linear cost function, along time series on Table 2. As close to 2000, the number of freight centers of linear cost function decreases. On the other hand, the number of freight centers of stepwise cost·function constantly keeps 11 to 12 around 1990 to 1995, then it rapidly increases to 14, up to 2000.

Fig.9 shows the case with upper terminal in Kitakyusyu. Comparing to Fig.2 and Fig.9, freight centers in both figures tend to locate to the vicinities of focal junctions or alongside of expressway. Freight centers usually locate in the center of its territory, but some centers are drawn to the upper freight terminal location. In spite of globally similar freight centers locations, there are some local differences, comparing to the base case. In Chugoku area, number of freight centers is 4 in Kitakyusyu case, 1 more center than base case because if the rearrangement of territory. In Shikoku area, the location of center moves to north eastern entrance in order to cover the eastern part of the island. In Kyusyu area, one center of the five is abolished and reassigned the former territory to the surrounding survival centers.

3.3 Discussion

Through the calculations, location of many freight centers and territories were quite robust for the different cases, even if the upper freight terminal location was changed (Fig.9). Those stable centers located in western or eastern edge of study area, where the improvement of expressway had almost finished in 1990. Another explanation for this global stability can result in geographical features. The population does not evenly scatter, but concentrates on a few cities because of only a few planes in these area, major cities locate along coastal lines shown in Fig.1. Therefore, the tensions to pull the freight center are also spatially biased. Since the model including transportation cost to the upper freight terminal, freight center locate on the spot where the tensions between customer and upper terminal are balancing. The ratio between upper (to freight terminal) and lower (to customers) transportation cost (r) were unity, upper lot size and lower lot size are equal, then there were no scale merit to make a delivery center in each regions. Therefore r is always less than 1, the freight center is always pulled to customers stronger than to the upper terminal. The spots which have geographically advantage in covering surrounding areas are stable and robust for the change of conditions, if the network improvement keeps insignificant.

The effect of stepwise cost function was clarified by comparing with linear cost function cases. The spatial arrangement of freight centers did not show the significant difference due to the cost function shape, but the spatial distribution of covering time was different. Longitudinal comparing showed the robustness of freight center locations under stepwise cost function. If a freight center covers demand (customer) points exceeding a threshold in stepwise cost function, such points bring larger loss for total cost than in linear cost function. In other words, stepwise cost function brings stronger tension to customer side for freight center, and the case of stepwise cost function tends to locate the spots convenient for covering customers within a short time as shown in Table 1. Which setting can describe the practical situation ? If the freight center covers a lot of demand points within the thresholds as 2,4, and 8 hours, the transport firm can easily utilize the freight driver more than twice a day. Therefore, the accessibility to customers is more important than the accessibility to upper freight terminal or expressway network, and if the expressway contributes to cut the transportation time enough to jump the threshold of delivery cycle, the merit of expressway can receive in wider area, which correspond to other research (i.e. Forkenbrock, D.J. *et al.*1996, or, Kieschnick, 1981).

In the middle area in the case study area (Chugoku and Shikoku area), relocation of freight center often happened than in the edged areas. Owing to the significant improvement of expressway network in these area between 1990 and 2000, accessibility to other cities was improved, then relocation occurred. Besides above, the possible reason is following. Since the spatial distribution of population is not intense in these areas, the tensions to pull the freight center are not strongly biased, then the locations of freight center easily move. Comparing the number of centers among these cases, more centers locate in 2000. This result shows the possibility that the network improvement does not always cause the integration of freight centers. The less number of freight centers in 1990 might be interpreted that additional freight center building can not decrease the total cost if the network improvement is not significant. But once the improvement of transportation time exceeds the threshold, the incentive to add the freight center by utilizing freight trucks more than twice a day, is born.

4. SUMMARY AND CONCLUSIONS

In this study, we proposed a two level facility location model in order to count the location effect of upper freight terminal on regional freight centers. In the model, we set the stepwise transportation cost function reflecting the freight truck delivery cycles per day, which practically determine the cost of transport firms. The problem could be efficiently solved by Erlenkotter's procedure, sets of solutions were quite good approximation to the optimal. Through the simulations, we could confirm the geographical advantage of the vicinities of focal junctions of expressway network, and such advantage was usually stable for the network improvement. The location feature of our model conditioned to the stepwise cost function well explained the robustness of the actual freight center location. From longitudinal comparison, it was clarified that improvement of expressway network do not always cause the integration of freight centers.

Remaining issues are following. At first, in our model, location cost of regional center includes only fixed cost, but it is practically affected by the number of customers in its territory. Together with using more practical location cost data and explicitly including inventory cost, the model should be expanded to variable location cost problem. Secondary, we should compare the freight center location of our model with real case in order to enhance the validity of using stepwise cost function. Finally, we gave only one location of upper freight center exogenously , but the number and the location should be endogenized to multiple upper freight terminal problem. Furthermore, in the real world, consumer goods become more diversified and specialized. Such trend makes lot size smaller and delivery more frequent in freight transport, then alter the required function of regional freight centers. It's also important to analyze the relation between above trend and regional freight center location.

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