A SIMULATION STUDY ON THE EFFECT OF PHYSICAL DISTRIBUTION FACILITIES IN THE TOKYO METROPOLITAN REGION

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ABSTRACT

This paper aims to formulate a freight transportation cost simulation model that explains the relationship between freight transportation costs and the number or the location of physical distribution facilities in urban areas. Then the study determines whether the location of existing regional physical distribution centres is appropriate, and clarifies the necessity of pickup and delivery depots for transshipment of inner-city freight in a CBD. Pickup and delivery depots could be essential facilities as well as regional physical distribution centres to reduce total freight transportation costs, and their cost saving would be almost one half of that of regional physical distribution centres.

1 INTRODUCTION

Traffic congestion and environmental problems in the Tokyo metropolitan region are becoming more serious as a result of the increase in freight vehicles that now account for almost one half of the total traffic in the urban area. Physical distribution facilities, regional physical distribution centres or the pickup and delivery depots, may be effective in decreasing freight traffic in urban areas, because they could raise the load factor of freight vehicles.

In the Tokyo metropolitan region, five regional physical distribution centres for transshipment and storage of inter-city freight transportation have been constructed by Tokyo-To and Saitama Prefecture according to the master plan decided by the Law concerning the Construction of Physical Distribution Business Centres. However, it is not clear whether the size and the location of these regional physical distribution centres are appropriate or not for decreasing the number of freight vehicles.

Having analysed data from a particular industry, Yoshimoto (1993) concluded that the distribution centre was effective in reducing the cost of freight transportation. Ieda, *et al* (1992) proposed a model which could evaluate the effect of the co-operative transportation system at the CBD in Hakata, Kyushu. Then, Nemoto (1992) showed how much could be saved from co-operative distribution systems in Hakata. These studies were based on the co-operative transportation project which was experimentally conducted in a restricted area in Hakata.

The relationship between distribution facilities and the characteristics of freight was studied using data of the Tokyo metropolitan region (Kuse, *et al*, 1994). Then, Takahashi, *et al* (1995) formulated a freight transportation cost simulation model that explained the relationship between freight transportation costs and the number or location of physical distribution facilities in urban areas. They clarified the effect how much freight transportation cost can be saved by the existing regional physical distribution centres. However, the total effect of reducing freight transportation costs has not been studied in the case where both several public regional distribution centres and pickup & delivery depots were established in the metropolitan area.

This study aims to evaluate which zones in the Tokyo metropolitan region are suitable for regional physical distribution centres for decreasing the transportation costs, and clarifies the necessity of pickup & delivery depots for transshipment of inner-city freight in the CBD. By focusing on freight that has an origin or destination located in the Tokyo 23 Wards area, we compare the effects of regional physical distribution centres and pickup & delivery depots.

2 A FREIGHT TRANSPORTATION COST SIMULATION MODEL

2.1 A simulation model

The freight transportation costs are composed of pickup and delivery costs from origin to destination and transshipment and storage costs at the physical distribution facilities. There are two types of freight transportation services in urban areas, the one is "the direct freight transportation service ⟨type A⟩ " and the other is "the indirect freight transportation service ⟨type B⟩ ". These two types of freight transportation services are described in Figure 1.

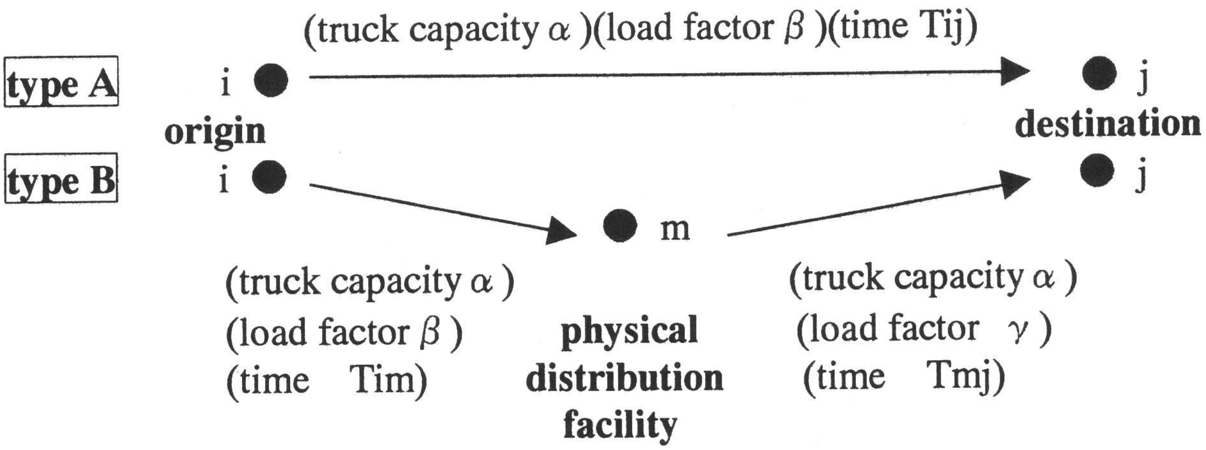

Figure 1 Freight transportation service

Here,

- α : loading capacity of a truck
- β : loading factor from origin i to destination j for type A, and from origin i to the physical distribution facility m for type B
- γ : loading factor after the physical distribution facility, from m to j, for type B
- δ : loading & unloading cost at physical distribution facility that is in proportion to the transportation cost in a narrow sense
- θ : transportation cost per a truck, per one hour
- μ : weight of one freight
- W_{ij} : the total weight of freight from i to j
- T_{ij} : transportation time from i to j
- F_{ij} : the number of freight from i to j
- i : origin of freight ($i = 1,2, \cdots, I$)
- j : destination of freight ($j = 1,2, \cdots, J$)

Freight transportation by "type A" takes T_{ij} as the necessary time from the origin i to the destination j, and β as the truck loading factor. So, the transportation vehicle-hour from i to j, G_{ij}, and the freight transportation cost from i to j, C_{ij}, are defined as follows.

$$G_{ij} = W_{ij} / \alpha / \beta \times T_{ij} = \mu \times F_{ij} / \alpha / \beta \times T_{ij}$$

$$C_{ij} = G_{ij} \times \theta$$

The total transportation cost without physical distribution facilities in the metropolitan area is described as follows.

$$CT = \Sigma i \Sigma j\ Cij = \Sigma i \Sigma j\ (\theta \times \mu \times F_{ij} / \alpha / \beta \times T_{ij}) \qquad (1)$$

Freight transportation by type B, however, takes ($T_{im} + T_{mj}$) as the necessary time, and the loading factor is β between the origin i and the centre m, and γ between the centre m and the destination j. Thus, transportation vehicle-hour between i and j via the physical distribution facility m, C'_{ij}, is described as follows.

$$C'_{ij} = \theta \times G'_{ij}$$

$$= \theta \ (\mu \times F_{ij} / \alpha / \beta \times T_{im} + \mu \times F_{ij} / \alpha / \gamma \times T_{mj}) \times \delta$$

Normally, $\beta < \gamma$ and $T_{ij} < (T_{im} + T_{mj})$. Then, the individual freight OD selects the type where transportation cost is less expensive as compared with the other. So the total freight transportation cost from i to j is expressed as follows.

$$CT''_{ij} = \min \{ C_{ij}, C'_{ij} \}$$

Therefore, the freight transportation cost if we have physical distribution facilities, CT', in the metropolitan region is represented in equation (2).

$$CT' = \Sigma i \Sigma j\ C''_{ij}$$

$$= \theta \times \mu / \alpha \times \Sigma i \Sigma j \min \{ F_{ij} / \beta \times T_{ij} , (F_{ij} / \beta \times T_{im} + F_{ij} / \gamma \times T_{mj}) \times \delta \} \qquad (2)$$

As far as the cost saving ratio, R, is concerned, equation (3) is derived from equations (1) and (2).

$$R = (CT - CT') / CT \qquad (3)$$

Finally, the cost saving ratio R is described as the reduction ratio of "the freight-time,($F_{ij} \times T_{ij}$), divided by the loading factor".

$$R = (\Sigma i \Sigma j C_{ij} - \Sigma i \Sigma j C''_{ij}) / \Sigma i \Sigma j C_{ij}$$

$$= \{ \Sigma i \Sigma j Cij - \Sigma i \Sigma j \min (C_{ij}, C'_{ij}) \} / \Sigma i \Sigma j C_{ij}$$

$$= \{ \theta \Sigma i \Sigma j G_{ij} - \theta \Sigma i \Sigma j \min (G_{ij}, G'_{ij}) \} / \theta \Sigma i \Sigma j G_{ij}$$

$$= [\Sigma i \Sigma j (\mu F_{ij} \times T_{ij} / \alpha / \beta) - \Sigma i \Sigma j \min \{ \mu F_{ij} \times T_{ij} / \alpha / \beta ,$$

$$(\mu F_{ij} \times Tim / \alpha / \beta + \mu F_{ij} \times T_{mj} / \alpha / \gamma) \times \delta \}]$$

$$/ \Sigma i \Sigma j (\mu F_{ij} \times T_{ij} / \alpha / \beta)$$

$$= \{ \Sigma i \Sigma j (F_{ij} \times T_{ij} / \beta) - \Sigma i \Sigma j \min (F_{ij} \times T_{ij} / \beta ,$$

$$(F_{ij} \times T_{im} / \beta + F_{ij} \times T_{mj} / \gamma) \times \delta \}$$

$$/ \Sigma i \Sigma j (F_{ij} \times T_{ij} / \beta) \quad (4)$$

Although the loading factor β and γ might be different from industry to industry, we do not have enough empirical data except for a study by Yoshimoto (1993) where β was set at 0.58 and γ at 0.95. The authors define the index of the improving ratio of loading factors in the form of $\{ (\gamma - \beta) / \gamma \}$ which varies between 0 and 1. Yoshimoto clarified that the index of the improving ratio of loading factors is 0.39 in a particular industry. Moreover, Kitada (1992) obtained a result that the loading & unloading cost at the physical distribution facility, δ , is 1.2. In this paper, we apply these values for the simulation.

In this simulation, it is assumed that β , γ and μ are fixed regardless of industry or item of freight. As these data have been obtained from a few previous studies, it is not appropriate to apply them in general. Thus, a sensitivity analysis has been carried out in the simulation.

2.2 The system of physical distribution facilities in the metropolitan region

As the Tokyo metropolitan region has more than 30 million people and its radius is 50 km, the average freight transportation time in the region is extremely longer than in other cities in Japan. Even though regional physical

Consignors (other cities or overseas)

↑ ↓ (highway or road)

Regional Physical Distribution Centres(in the metropolitan region)

↑ ↓ (highway or urban arterial road)

Pickup & Delivery Depots

↑ ↓ (urban arterial road or distributor)

Consignees (commercial, business, residential area in the city)

Figure 2 Freight transportation and physical distribution facilities

distribution centres were established to promote efficiency of inter-city freight transportation, freight vehicles usually have low turnaround times per day because of long trip times and traffic congestion in the CBD, no matter how they utilise the regional physical distribution centres. Therefore, pickup and delivery depots to relay freight between centres and consignees could be as important as regional physical distribution centres in the metropolitan region (Figure 2).

Thus, it is advisable to introduce not only regional physical distribution centres but also pickup and delivery depots in the Tokyo Metropolitan Region. The freight transportation cost simulation model we can evaluate the effect of these pickup & delivery depots as well.

3 THE EFFECT OF PHYSICAL DISTRIBUTION CENTRES

The authors analysed which zones in the Tokyo metropolitan region are the regional physical distribution centres suitable for decreasing the transportation costs. In order to save time for the simulation model, we focussed on freight to the Tokyo 23 Ward Area. The volume of freight in the Tokyo 23 Ward area accounts for about 20% in terms of weight, and 40% in terms of the amount of freight in the Tokyo metropolitan region.

As a result of the simulation, four regional physical distribution centres were selected which can save freight transportation costs (Table 1). The location of physical distribution centres resulting from the simulation is a little different from the location of existing public regional physical distribution centres,

Table 1 The relationship between the improving ratio of loading factors and the effect of physical distribution centres

The improving ratio of loading factors		Type A	Type B	Total	Effect
0	Freight-time ×1000	83,712 (100 %)	—	83,712 (100 %)	(0.0 %)
	Freight ×1000	1,241 (100 %)	—	1,241 100 %	
0.20	Freight-time ×1000	83,673 (99.0 %)	36 (0.1 %)	83,712 (100 %)	(0.0 %)
	Freight ×1000	1,240 (99.9 %)	1 (0.1 %)	1,241 (100 %)	
0.39	Freight-time ×1000	67,821 (83.2 %)	14,565 (16.8 %)	82,386 (100 %)	(1.6 %)
	Freight ×1000	1,017 (81.9 %)	224 (18.1 %)	1,241 (100 %)	
0.60	Freight-time ×1000	52,117 (67.1 %)	23,963 (32.9 %)	76,080 (100 %)	(7.3 %)
	Freight ×1000	788 (63.5%)	453 (36.5%)	1,241 (100 %)	

Keihin, Kasai, Itabashi and Adachi (Figure 3).

As far as the sensitivity analysis is concerned, the share of type B rises as the number of centres and the improving ratio of loading factors $\{(\gamma - \beta)/\gamma\}$ increases. The share of type B in terms of freight volume is only 0.1% when the improving ratio of loading factors is 0.20, 18.1% for 0.39 and 36.5% for 0.60, respectively. On the other hand, the effect of these centres in terms of cost is 0%, 1.6% and 7.3%, respectively.

Items of goods which are transported via each regional physical distribution centre is different from one centre to another centre. Clothes, furniture, foods, stationary, precision machines, electrical machines could be transported via physical distribution centres and most of them are freight from wholesaler to retailer, and from manufacturer to manufacturer. Moreover, the origins of this freight is mostly warehouses and factories, and the destinations are housing, factories and commercial establishments.

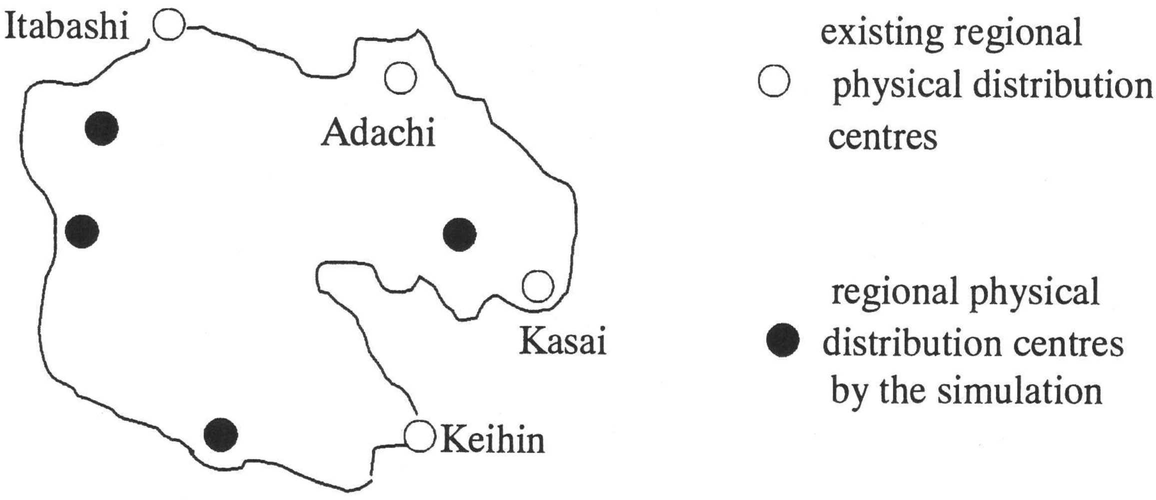

Figure 3 The location of regional distribution centres

4 THE EFFECT OF PICKUP & DELIVERY DEPOTS

The simulation study was conducted in order to decide the location of pickup and delivery depots and their effects on the total freight transportation cost even though pickup and delivery depots have not been established yet by the public sector. Ginza, the biggest commercial district in the Tokyo metropolitan region, was taken as the study area for this simulation. We utilised the same model that was used for the regional physical distribution centres. Finally, four pickup and delivery depots for the Ginza area were chosen by the simulation as shown on Figure 4.

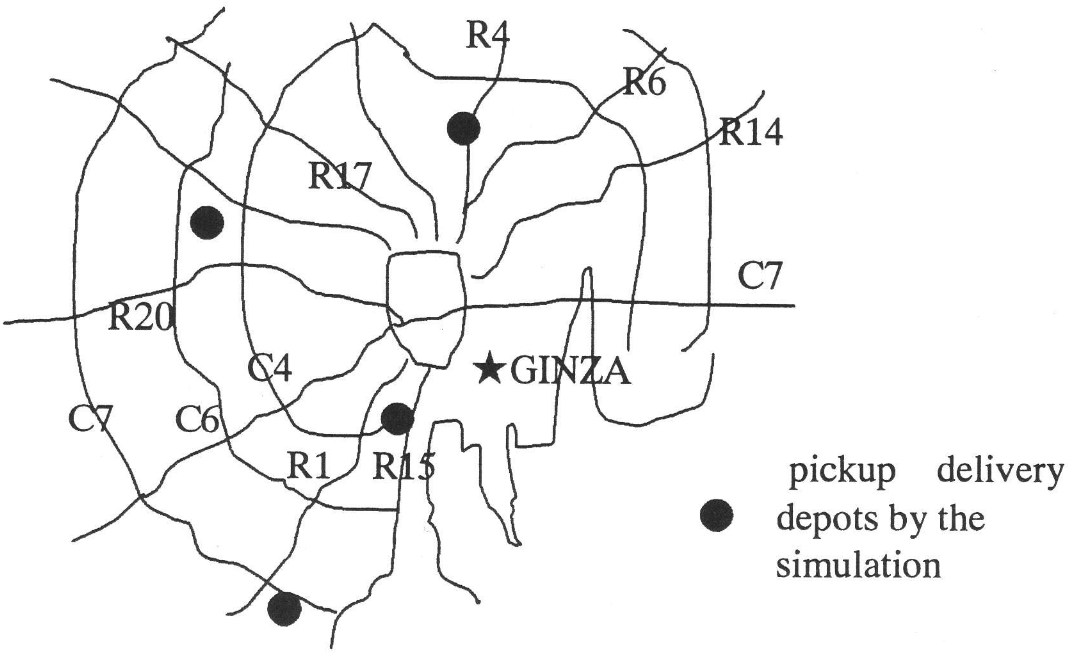

Figure 4 The location of pickup & delivery depots

Table 2 The relationship between the improving ratio of loading factors and the effects of pickup & delivery depots

The improving ratio of loading factors		Type A	Type B	Total	Effect
0	Freight-time ×1000	48,687 (100 %)	—	48,687 (100 %)	(0.0 %)
	Freight ×1000	178,398 (100 %)	—	178,398 (100 %)	
0.20	Freight-time ×1000	24,343 (51.1 %)	23,354 (48.9 %)	47,697 (100 %)	(2.0 %)
	Freight ×1000	95,861 (53.7 %)	82,537 (46.3 %)	178,398 (100 %)	
0.39	Freight-time ×1000	24,025 (57.0 %)	18,131 (43.0 %)	42,156 (100 %)	(13.4 %)
	Freight ×1000	95,267 (53.4 %)	83,131 (46.6 %)	178,398 (100 %)	
0.60	Freight-time ×1000	14,573 (42.5 %)	19,746 (57.5 %)	34,319 (100 %)	(29.5 %)
	Freight ×1000	71,544 (40.0%)	106,854 (60.0%)	178,398 (100 %)	

Sensitivity analysis was also performed under different improving ratio's of loading factors to understand the nature of these fluctuations on the effect of pickup and delivery depots (Table 2). The share of freight via these depots are 2.0%, 13.4% and 29.5% for the improvement ratio of loading factor 0.20, 0.39 and 0.60, respectively.

5 COMPARISON OF THE EFFECTS BETWEEN REGIONAL PHYSICAL DISTRIBUTION CENTRES AND PICKUP &DELIVERY DEPOTS

The effects of both regional physical distribution centres and pickup and delivery depots were clarified by simulation under the condition that the improving ratio of loading factors is 0.39, the observed value. As far as pickup & delivery depots are concerned, the simulation was conducted only for the Ginza zone which is one of the 115 zones in the Tokyo 23 Wards Area. If the effects of other zones in the Tokyo 23 Ward Area are similar to that of Ginza, the total reduction of freight-time resulting from pickup & delivery depots

Table 3 The comparison of the effects between regional physical distribution centres and pickup & delivery depots

	Physical distribution facilities	Effect
Reduction of freight-time	Regional physical distribution centres	1,326,176
	Pickup & delivery depots	6,531
Freights volume via physical distribution facilities	Regional physical distribution centres	224,254
	Pickup & delivery depots	83, 022
Reduction ratio of the transportation cost	Regional physical distribution centres	1.6 %
	Pickup & delivery depots	13.4 %

might be about 750 thousand. This is a little less than half of the reduction of freight-time of 1,326,176 in Table 3, resulting from regional physical distribution centres.

Although the cost saving ratio of regional physical distribution centres is only 1.6%, the effect of regional distribution centres is more than twice that of the pickup and delivery depots because of the difference in freight trip length.

The freight transportation cost is composed of the transportation cost in a narrow sense as well as the loading and unloading cost at the physical distribution facility. In this study, loading and unloading cost at the physical distribution facility were based on the actual observed value by Kitada (1992), that is 20% of the transportation costs in a narrow sense from the origin to the destination of all freight movements. Thus, the transportation cost in a narrow sense, exclusive of the loading and unloading cost saved by both regional distribution centres and pickup & delivery depots are larger than 1.6%, and 13.4%, respectively.

Since the volumes of exhaust gases and energy consumption are in proportion to freight-time, it is possible to reduce them by means of the introduction of regional physical distribution centres and pickup and delivery depots in the Tokyo metropolitan region.

5 CONCLUSIONS

a) Although existing regional physical distribution centres are generally effective in decreasing freight transportation costs, it is desirable to establish another centre in the western part of Tokyo.
b) It was clarified that pickup and delivery depots are effective in reducing freight transportation costs.
c) Freight transported via physical distribution centres or pickup and delivery depots would be mainly clothes, furniture, foods and stationery.
d) The share of goods transported via the centres or depots rises as the improvement ratio of the loading factor increases.
e) Origins of freight which utilise regional physical distribution centres or pickup and delivery depots would usually be warehouses and factories. The floor uses of the origin or the destination of freight via these centres or depots would be warehouses, factories and retail shops.
f) Pickup and delivery depots could be essential facilities to reduce total freight transportation costs, and their cost savings would be almost one half that of the regional physical distribution centres.

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