ESTIMATING THE SUITABLE NUMBER, LOCATION AND SCALE OF URBAN PHYSICAL DISTRIBUTION FACILITIES

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abstract: This paper proposes a methodology which determines the reasonable number of distribution facilities, along with their locations and sizes by analyzing the total cost trade-off between the transportation cost and the facility cost of the distribution facilities. An interactive approach using the METRO (MEta Truck Routing Optimizer) system and manual inspection was adopted in investigating potential locations of distribution facilities to facilitate computation. The methodology was applied using actual data taken from the Goods Movement Survey of Tokyo Metropolitan Region focusing on 16 basic items suitable for distribution center handling.

1. INTRODUCTION

Goods movement contributes extreme amount to traffic congestion; infrastructure deterioration; safety reduction; and air, noise, and visual pollution, which are all issues of public concern. Although the goods movement system functions, it probably does not operate in the most efficient manner, particularly in regard to public concerns. The private and fractional nature of goods movement leads to business rather than industry-wide solutions, wherein system capacity, fuel, and manpower are used inefficiently. These inefficiencies are detrimental to the public sector in terms of higher transportation costs imposed on consumer products.

Recently, changes in the industrial structure, diversification of consumer preferences, and advancement in information technology have resulted to Just-in-Time (JIT) distribution causing reduced truck loading factors and more frequent delivery of trucks. In Tokyo, JIT has been actively performed as manifested by a substantial share of over 50% of the total freights delivered for express shipments with specified delivery time windows causing severe traffic congestion on the urban networks (TMATPG, 1994). Data from the Japanese Ministry of Construction shows that approximately half of the total number of vehicle-kilometers are traveled by trucks and that the average travel speed during peak hours in the metropolitan area continued to decrease from 30.7 kilometers per hour in 1983 to 23.2 kilometers per hour in 1994.

One of the solutions proposed by the Japanese Government to address these problems is the provision of public distribution facilities in order to reduce traffic congestion and improve the quality of the urban environment. The development of public distribution facilities is one of the attempts of the public sector to change the existing method of

delivery to consolidated delivery in order to increase the loading factors of trucks. Since distribution facilities are suitably located near sites with good access points at the outskirts of the urban area, it can function as a central facility for consolidating goods, thereby concentrating the usage of large heavy vehicles on expressways and preventing them from entering and circulating in the urban area. Thus, developing urban distribution facilities and adopting consolidated delivery can result to increased efficiency of road usage, and a reduction in the number of inner city truck movements. A study conducted in the Netherlands showed that in a pilot city with a population of 100,000 people, the number of vehicle-kilometers were reduced by almost 50 per cent after the introduction of urban distribution facilities (OECD, 1992).

Models on facility location have mostly focused on transportation distance or transportation cost. Among these are the well-known Weber problem and the classical *p*-median problem by Hakimi, wherein *p* facilities are located so as to minimize the sum of all the distances from each customer to its nearest facility. An extension of the problem considers not only the transportation cost but also the set-up cost of establishing the facilities, which may include land cost as well as construction cost. These problems can be adequately solved using operations research. Meanwhile, Daganzo *et al* (1985), Blumenfeld *et al* (1985), Campbell (1993) among others, have analyzed physical distribution from a terminal using approximate analytic models of the transportation, inventory and terminal costs. Lately, environmental aspects have also been integrated into facility location models. Weigel (1992) presented a simulation model incorporating the so-called "external" costs due to noise, air and water pollution. Also, Taniguchi *et al* (1998) proposed a mathematical model that optimized the size and location of logistics terminals considering the amount of air pollution emitted by trucks. As the model takes into account the road network and traffic conditions, optimal location of the logistics terminals can be determined from the candidate nodes within the given road network.

The main factors affecting the location of physical distribution facilities are proximity to arterial roads, proximity to customers and other facilities related to freight, and land and labor availability. Of these, proximity to arterial roads has the greatest impact. This result is important in a transportation planning context, because it implies that, by varying the transportation system, the urban planner is able to have some influence on the location of freight facilities in urban areas.

This paper suggests a procedure that determines the suitable location of public distribution facilities in the Tokyo Metropolitan Region. An interactive approach was adopted to facilitate computation by using the MEta Truck Routing Optimizer (METRO) system and through manual inspection. The methodology was applied using actual data taken from the Tokyo Goods Movement Survey focusing on sixteen basic items commonly handled at distribution facilities.

2. METHODOLOGY

2.1 Assumptions

The methodology was based on the following assumptions:

1. Demand Regions (or customers) were represented as points and assumed located at the

centroids of each zone. The amounts of each commodity type for each demand area were also given. Each customer was to be served by its closest distribution facility.

2. Distribution Facilities were to be located in demand areas. Goods were also handled simultaneously at distribution facilities and each distribution facility had sufficient capacity to serve all customers. Existing distribution facilities were also assumed not utilized.

3. Transport Cost was based on Euclidean distances and by direct transport. Also, inbound costs were excluded from the cost trade-off analysis since their sensitivity to the number of distribution centers is very limited.

4. Facility Cost was composed of land and construction costs and depends on facility size. Average unit commodity handling capacity of existing public distribution facilities was also used.

5. Delivery fleet was comprised of standard four-ton (4T) trucks and existing average loading factor for all delivery trucks was used.

In assumption 3, it is common in existing facility location models to ignore inbound cost and to consider distribution facilities as supply points. This assumption can be justified by the minimal relative increases in the total inbound transport cost when plotted against the number of distribution facilities (Mc Kinnon, 1989).

2.2 MEta Truck Routing Optimizer (METRO)

The MEta Truck Routing Optimizer (METRO) is a delivery planning optimization system mainly used as a decision support for operational levels of planning. METRO incorporates the Weiszfeld algorithm (Brimberg and Love, 1993) to locate distribution facilities and determine the allocation of demand points to each facility. The location-allocation procedure is given below:

Let p : number of facilities
i : customer index
j : facility index
(X_i, Y_i) : demand point (customer) coordinates
D_i : customer demand

1. select the number of facilities p
2. **while** stopping criterion $\neq$ True **do** (the stopping criterion is satisfied when the coordinates of the facility j, $(x(j), y(j))$, undergo negligible changes)
3. assign each customer to its nearest facility
4. determine centroid of the assigned customers at each facility j by *mean_x(j), mean_y(j)*
5. *// Extended Weiszfeld Algorithm*
6. *x(j):=mean_x(j), y(j):=mean_y(j),* $\forall$ $j=1,\ldots,p$
7. **while** stopping criterion $\neq$ True **do**
8. **for** each facility j **do**
9. *sum_x:=sum_y:=sum:=0*
10. **for** each assigned customer i at facility j **do**

```
        r:=Euclidean distance between points i and j
        if r > 0 then
            sum_x:=sum_x + D_i X_i / r
            sum_y:=sum_y + D_i Y_i / r
            sum:=sum + D_i / r
    x(j):=sum_x/sum
    y(j):=sum_y/sum
```

In the first stage of the METRO, an initial solution was set-up for the inputted number of facilities. Each customer was then allocated to its nearest distribution facility. The centroid of each customer cluster was then calculated and assigned as the new location of the distribution facility. In the second stage, the customers were allocated all over again to its nearest distribution facility. Through gradual improvements of the resulting facility plan, near optimal location of the facilities was determined.

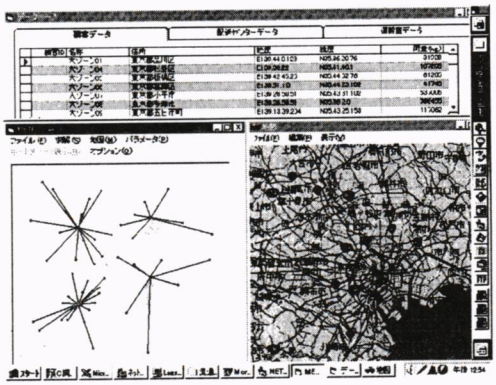


Figure1. Sample output of the METRO

2.3 Cost Functions

Transport cost was expressed as the product of the total travel distance between the distribution facility and the customer, and the unit transport cost per kilometer.

$$Tc = (d \times f \times u) \tag{1}$$

where

d : round trip distance from the distribution facility to customer and vice versa
f : delivery frequency
u : transport cost per unit distance

Facility cost for each distribution center was given by:

$$Fc = [\{(C_l \times a_l)/(y_l \times d)\} + \{(C_b \times a_b) / (y_b \times d)\}] \times p^{\alpha} \tag{2}$$

where

C_l, C_b : land and construction prices, respectively
a_l, a_b : land and building areas, respectively
y_l, y_b : period of operation of land and building life, respectively
d : days in operation per year
p : number of distribution facilities
α : facility expansion factor

The facility expansion factor α is a correction factor which considers increases in land area as the number of distribution facility increases. The additional increase in land area corresponds to spaces not directly related to material handling or other logistic functions but extra spaces provided for manpower and miscellaneous needs such as toilets, places for rest, and parking (Kuse *et al*, 1996).

The total cost was expressed as:

$$Total\ Cost = \sum_{j=1}^{p} \sum_{i=1}^{m} Tc_{ji} + \sum_{j=1}^{p} Fc_j \tag{3}$$

where

Tc_{ji} : transport cost from the distribution center j to the customer i
Fc_j : facility cost of the distribution center located at j

2.4 Location Procedure

The following procedure was used to identify reasonable facility locations.

1. Customer data requirements input (coordinates, demand, etc.).
2. Determine customer allocation. Customers are allocated to the facilities based on geographical characteristics to eliminate absurd groupings.
3. For every value of p (number of distribution centers), calculate transport and facility costs based on the location plan generated.
4. Calculate total cost.
5. Plot transport, facility and total costs versus the number of distribution centers p.
6. Perform sensitivity analyses.
7. Select the number of distribution facilities which is the best and select most reasonable facility plan.

3. CASE STUDY

3.1 Data

A case study using data taken from the Goods Movement Survey of the 1994 Integrated Urban Transport Plan for Tokyo Metropolitan Region was performed to locate public distribution centers in the region.

The Tokyo Metropolitan Region consists of the Tokyo Metropolis and the surrounding prefectures of Kanagawa, Saitama, and Chiba. It is perhaps the most crowded area in the world with a population of about 30 million in 1994 occupying only an approximate total land area of 15,000 square kilometers. An enormous concentration of economic activity is focused within this relatively small area as reflected in the transportation of passengers and freight in Table 1. This area accounts for about 38 percent of the total number of passengers and 27 percent of the total tonnage of freight in Japan. It is noteworthy that road, particularly truck transport, accounts for a majority of freight with 86.7 percent. Water transport accounts for 11.8 percent while rail accounts for only 1.5 percent.

Table 1. Transportation in Tokyo Metropolitan Region

Mode	Passengers (million)		Freight (million tons)	
	1989	Share	1989	Share
Rail	12,959.4	44.4	26.7	1.5
Road	16,204.6	55.5	1,505.6	86.7
Water	12.5	-	205.0	11.8
Air	35.8	0.1	0.45	-
TMA Total	29,212.3		1,737.7	
Japan Total	77,217.5		6,549.2	
Percentage	37.8		26.5	

Source: Shiomi *et al* (1993)

The Goods Movement Survey report included an independent locational study plan for the additional regional distribution facilities designed to serve the metropolitan region. Twelve additional regional distribution facilities were recommended to supplement the five existing public distribution facilities located in Adachi, Itabashi, Keihin, Kasai and Koshigaya (Table 2). Therefore, in total, seventeen public distribution facilities were planned for the Tokyo Metropolitan Region. The proposed facilities were judiciously located on sites with good access points (Fig. 2).

As an ultimate improvement plan in the future, the distribution facilities were envisioned to form a logistics network in which the existing four distribution facilities located in Tokyo will serve as hubs servicing the central portion of Tokyo. These will be referred to as urban distribution facilities. On the other hand, the remaining facilities located outside Tokyo will be referred to as regional distribution facilities. These facilities will serve as transshipment points of inbound trucks coming from far away places throughout Japan, and consequently serve as feeders to the four urban distribution facilities.

Table 2. Existing public distribution facilities in Tokyo Metropolitan Region

Distribution Facility	Location	Land Area (ha)	Goods Handling Capacity (tons/day)
Adachi	Tokyo	33.3	8,335
Itabashi	Tokyo	31.4	7,262
Keihin	Tokyo	62.9	10,150
Kasai	Tokyo	49.2	7,964
Koshigaya	Saitama	73.2	-

Source: JICA (1993), TMATPG (1994)

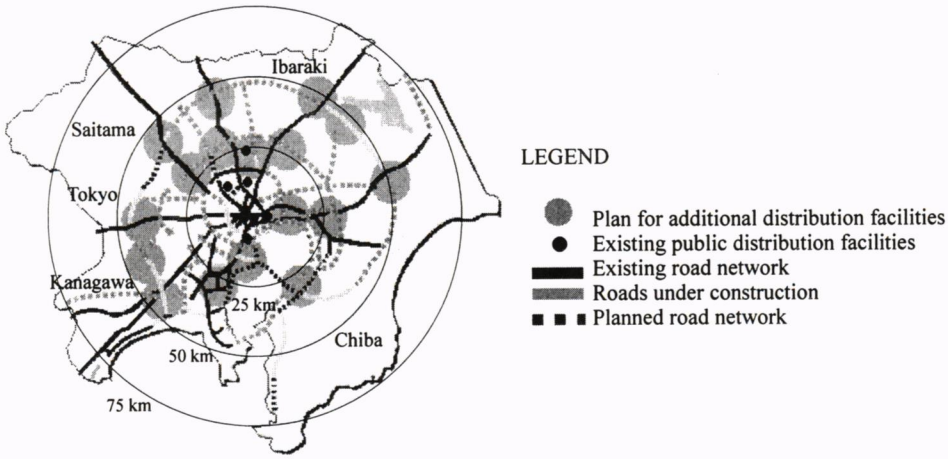


Figure 2. Planned location of regional distribution facilities showing existing and future road network

3.2 Customer Demand Points

The customer demand points were assumed located at the centroids of the 56 zones adopted in the 1994 Goods Movement Survey of Tokyo (Fig. 3). The regions included were the areas bounded by a 75-kilometer radius from the center of Tokyo, namely, Tokyo, Kanagawa, Saitama, Chiba and the southern portion of Ibaraki.

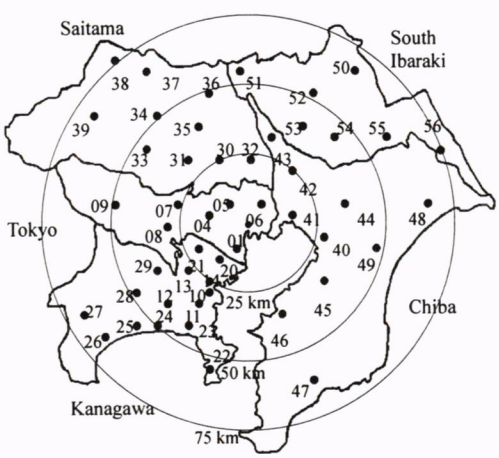


Figure 3. Map showing customer demand points (zone centroids)

3.3 Commodities Handled at Distribution Facilities

Commodities that undergo the main functions of stocking, processing and transporting are the basic items suitable for handling at distribution facilities. Thus, commodities that have high truck transport mode share, high transshipment ratio, not long nor heavy, and non-fluid are appropriate for handling at distribution facilities.

Results of the 1982 Goods Movement Survey of Tokyo showed low truck transport mode shares for mining and mineral resources thus making it unsuitable for distribution facility usage. The same can be said for mining and waste products wherein both had low transshipment ratios, and were usually transported directly. Furthermore, cement, oil-based products, and steel products were also not suitable because of form and physical limitations.

Generally, the commodities suitable for distribution facility handling are the items that belong to the agricultural and aquatic industry, metals and machinery, and light and complex industries.

Table 3. Suitable commodities handled at distribution facilities

Group	Agricultural and Aquatic Products	Metals and Machinery	Light Industrial Products	Complex Industrial Products
Items	1 Grain 2 Vegetable & Fruits 3 Other farm Products 4 Aquatic Products 5 Livestock	6 General Machines 7 Electrical Machines 8 Transport Machines 9 Precision Machines	10 Textile 11 Foodstuffs	12 Publication and print 13 Furniture, Kitchenware 14 Clothes, Personal Effects 15 Recreational Products 16 Other Daily Necessities

3.4 Distribution Facility Utilization Rate and Truck Loading Factors

With regards to the total goods amount of 13 million tons per day handled at facilities, only about 5 percent utilize distribution centers. A major amount of the commodities goes directly to the factory with a 44 percent share, followed by 19.3 share for stock, and 13.1 percent share for storage tanks (Fig.4).

Average existing truck loading-factors for a 4-ton type vehicle in Tokyo shows only a 42.1 percent loading. Trucks within the 5-ton to less than 10-ton truck range have the highest loading factor of 72.8, followed by trucks above the 10-ton range with a 65.7 percent loading efficiency (Fig. 5).

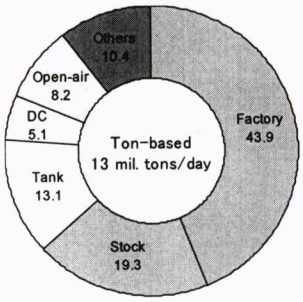


Figure 4 – Facility usage

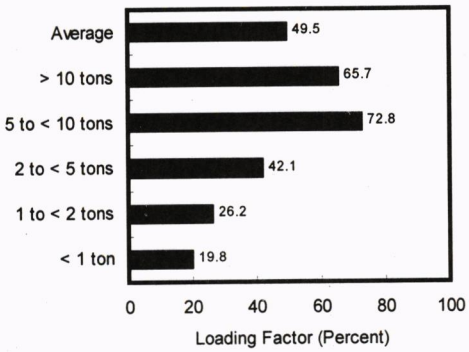


Figure 5 - Truck loading factors

4. APPLICATION

4.1 Base Condition

It was possible to determine reasonable locations of distribution facilities by using the proposed procedure. The complexity of locating distribution centers was substantially reduced using the graphic display generated by the METRO system.

Looking at the cost trade-off in Figure 6 and the cost comparison in Table 4, the optimal number of distribution facilities for the base condition is five. However, the difference in the total cost between four facilities to five facilities is only 2.9% indicating that both values may be reasonable solutions. However, it is interesting to note that once there are more than 16 distribution facilities, there is little opportunity to reduce transportation cost implying that adding more distribution facilities provide little added benefit.

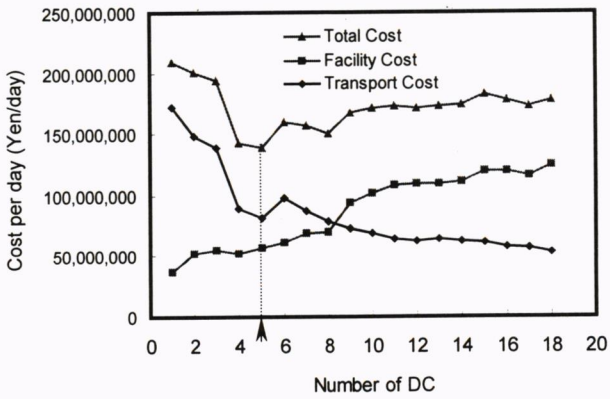
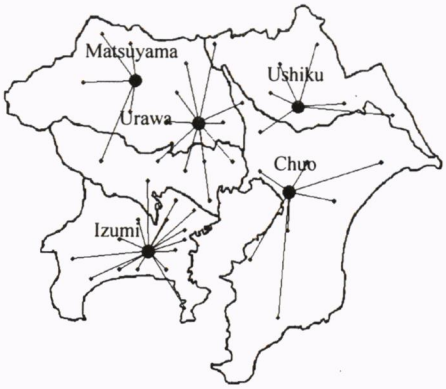


Figure 6. Cost trade-off
(Base condition)

Table 4. Cost comparison as the number of distribution facility increases

No. of DC	Transport Cost	% change from optimal	Facility Cost	Total Cost	% change from optimal	Average Customer Travel Distance
1	172,084,941	224.9	36,913,848	208,998,788	51.1	52.0
2	148,543,658	180.5	52,019,876	200,563,534	45.0	40.0
3	138,939,857	162.3	55,406,838	194,346,695	40.5	35.0
4	89,663,848	69.3	52,730,360	142,394,208	2.9	27.5
5	81,303,310	53.5	57,021,634	138,324,943	0.0	24.5
6	98,132,573	85.3	61,522,301	159,654,874	15.4	22.5
7	87,375,075	65.0	69,556,345	156,931,420	13.5	20.0
8	79,289,438	49.7	70,761,601	150,051,039	8.5	19.0
9	73,457,546	38.7	94,124,117	167,581,663	21.2	18.0
10	69,753,032	31.7	101,540,112	171,293,145	23.8	16.5
11	64,977,736	22.7	108,456,987	173,434,722	25.4	15.5
12	62,447,759	17.9	109,037,955	171,485,714	24.0	14.5
13	64,318,416	21.4	108,961,615	173,280,032	25.3	14.5
14	62,816,659	18.6	110,891,237	173,707,896	25.6	13.5
15	61,920,127	16.9	120,157,324	182,077,451	31.6	13.0
16	57,694,188	8.9	119,890,730	177,584,918	28.4	12.0
17	56,715,629	7.1	116,406,559	173,122,188	25.2	12.0
18	52,965,004	0.0	124,335,185	177,300,189	28.2	10.5

Figure 7 shows the location and respective sizes when the number of facilities is equal to five. Since the size of the facility depends on the number and the demand of the customers it serves, distribution facilities that serve larger areas with large demands are bigger than facilities serving areas with smaller demands. Thus, facilities located at Izumi in Yokohama and Urawa in Saitama which serve customers in Tokyo are considerably larger than the facilities located at Matsuyama in Saitama, Chuo in Chiba, and Ushiku in Ibaraki.



Facility No.	Location		Size (ha)
	Region	*City Name*	
1	Yokohama	Izumi	39.5
2	Saitama	Urawa	76.1
3	Saitama	Matsuyama	6.2
4	Chiba	Chuo	18.2
5	Ibaraki	Ushiku	9.8

Figure 7. Location plan and sizes for five distribution facilities

4.2 Sensitivity Analyses

Sensitivity analyses were performed to evaluate scenarios such as increase in loading factors due to consolidation at distribution centers, increase in the demand of consumers, and changes in parameter values. Figure 8 (a)-(d) shows the sensitivity of total cost to the number of distribution centers after estimating the behavior of the total cost by regression analysis. It is remarkable that the total cost function is very flat around its minimum implying that the solution can be an optimal range of values.

In Figure 8 (a), as the goods demand increases, the optimal number of distribution centers remains nearly the same since both the transport and facility costs were affected almost on even terms by an increase in size. Increasing the demand will increase the amount of goods that will be handled at distribution centers thus expanding the facility area. Similarly, the amount of goods that needs to be transported increases resulting to higher transport costs.

In Figure 8 (b), as the truck load factor increases, the optimal number of facilities decreases. A load factor of 100%, which can be realized by freight consolidation, decreases the optimal number of distribution centers to only 4. On the other hand, a load factor of only 25% increases the optimal number of facilities to 10.

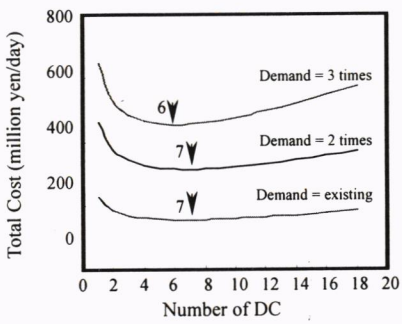


Figure 8 (a) – Sensitivity of total cost as demand increases

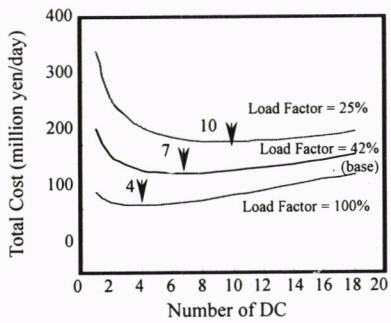


Figure 8 (b) – Sensitivity of total cost as load factor increases

Sensitivity curves in Figure 8 (c) show that when the facility factor increases, total cost becomes more sensitive to the number of distribution centers. A higher facility factor will decrease the optimal number of distribution centers due to the steep change in facility cost. For a facility factor of zero, the optimal number of facilities is 16. This is reduced to 3 distribution centers when the facility factor is increased to 0.5.

Figure 8 (d) shows that, as unit transport cost decreases, the number of distribution centers also decreases and the total cost becomes more sensitive around this optimum. Lower unit transport cost due to increases in travel speeds from 15 kph (base case) to 20 kph decreases the optimal number of distribution facilities from 7 to 6. On the contrary, a

higher unit transport cost resulting from a decreased travel speed of 10 kph will increase the optimal number of distribution facilities to 9. Faster travel speeds mean higher levels of customer service thus making the number of facilities minimal. However, with a decrease in travel speeds, there will be a corresponding decrease in the amount of service level. To counter this effect, additional distribution facilities are needed to maintain or improve existing customer service standards.

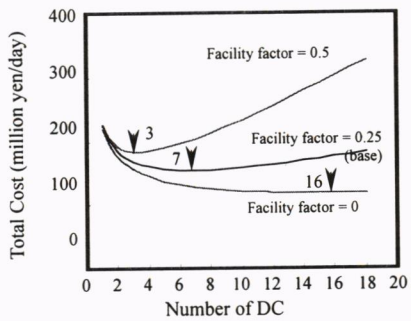


Figure 8 (c) – Sensitivity of total cost as facility factor increases

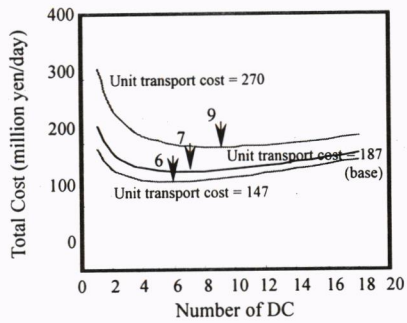


Figure 8 (d) – Sensitivity of total cost as unit transport cost increases

4.3 Summary

We were able to understand the behavior of the optimal number of distribution facilities after performing sensitivity analyses. The optimal value changes as parameter values change. Nonetheless, it was clarified that as the number of distribution facility increases to 16, there was little opportunity to reduce transportation cost and that adding more distribution facilities provided little added benefit.

The primary responsibility of each distribution facility is to provide a satisfactory level of customer service for those being served by that facility. Distribution facilities provide a time utility, and so it is important to have what the customer wants at the time it is wanted. Furthermore, better customer service results in a reduction in the costs of lost sales.

Giving primary importance on Just-In-Time distribution, it can be said that supplying the maximum number of facilities will certainly shorten lead times resulting to improved customer service levels since additional stocking locations reduce average travel distances from the distribution facilities to the consumers. Hence, the maximum number of distribution facilities should be 16. A look at Table 4 shows that sixteen distribution facilities adequately dispersed far apart can service all the zones in the Tokyo Metropolitan Region within a 12-kilometer radius. The proposed facility plan for the sixteen distribution facilities is shown in Figure 9.

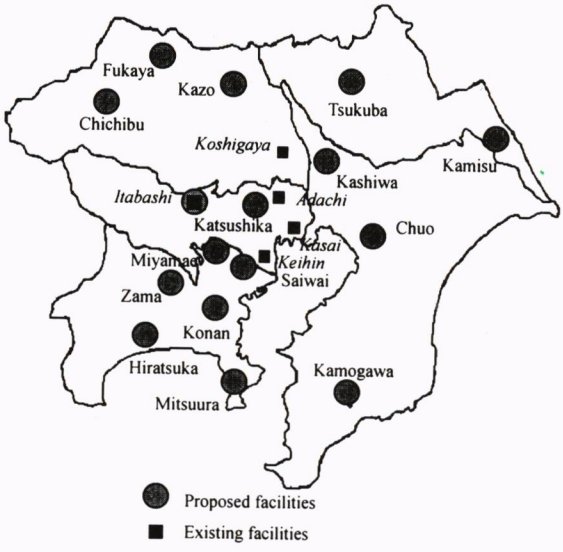


Figure 9 – Resulting facility plan
for sixteen distribution facilities

5. CONCLUSION

In this paper, we considered only two types of costs involved with a given set of facility locations. The first is the transportation cost, that is, the cost of transporting commodities between a distribution center and a customer demand point. The transportation cost was assumed to be directly proportional to the amount of commodities to be transported and the travel distances from the facility to the customer. The second cost is the facility cost, or the cost of establishing a facility at a given site.

The paper discussed the utilization of the location procedure in urban planning given actual data obtained from the Goods Movement Survey of Tokyo. It was able to provide suitable locations for new public distribution centers that would minimize transport and facility costs. The most important requirement of the location model is that it identifies sensible facility locations. As long as the locations are adequately dispersed far apart and serve customers within a reasonable distance or time, transportation cost will be approximately the same. Although, the results of the study are merely a guide to urban planning decision making, it can provide good initial solution to start a detailed analysis and compare and evaluate alternative distribution facility sites.

Further improvements can be done in the methodology by incorporating actual transportation links which consider existing road traffic conditions. Desirable locations from the standpoint of the freight industry and the public as well, point to sites with good access because they minimize the amount of travel on local streets. Guidelines for

locating new development proposals for distribution facilities should state that these facilities should be located as far as possible from residential and other sensitive land uses, and should be adequately served by an arterial road network, thereby ensuring that intrusion into residential streets does not occur.

Policies should define the extent to which government planning should influence and control the location of physical distribution facilities and the extent to which government should be involved in the design, construction, and operation of these distribution facilities. Furthermore, measures that outline the extent to which location of physical distribution facilities should be influenced by desired urban form, and the extent to which distribution facilities are allowed to impact on the environment and surrounding community should be established.

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