# OPTIMIZATION DECISION MODEL FOR TRUCK TERMINAL POLICY

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**Abstract:** This paper presents a planar location optimization model as a decision support for the truck terminal policy implementation in a city at a time cross section. The objective of the model is to minimize the costs due to the city logistics and the passenger travel activities. The decision variables of the model are the locations, and the capacities of the truck terminals. Additionally, the model incorporates the interaction among the traffic condition, the truck trip demand, and the policy on the truck terminals. The model structure, consequently, includes three important components, i.e. the truck trip conversion model, the distance function, and the zonal speed-density function. An illustration is applied to the Tokyo Kubu area with the 1999 Japan Road Traffic Census (JRTC) data. Finally, all the decision variables are solved by the genetic algorithm (GA).

**Key Words**: city logistics, logistics policy, truck terminal

## 1. INTRODUCTION

City logistics has become more complicate as a city grows. In many metropolitans all over the world, the road freight transportation demands have been increasing exponentially and continuously, while the road network capacity is limited. Consequently, many city logistics policies have been launched to improve freight movement efficiency. Truck terminal policy is verified to be successful in practice (Visser, 1999). The decisions on such the policy are the appropriate number, locations, and capacities of truck terminals in a specific city. Traditionally, a policy maker has made the decision by alternative selection approach. Nonetheless, this method has a drawback in that it cannot guarantee the best solution.

The location problem in city logistics typically deals with how to locate (and allocate) the transfer facilities, such as truck terminals, so that the transportation cost is minimized. Early in the $17^{th}$ century, Fermat raised a problem: " Given three points in the plane, find the fourth point such that the sum of its distances to the three given points is minimum" (Love *et al*., 1988). Weber (1909) incorporates minimization of weighted sum of distances into location theory. Consequently, the Euclidean location optimization problem is known as the Weber problem or the Fermat-Weber problem.

Facility location models can be classified into three types based on the topology used in the model, i.e. planar location models, network location models, and discrete location models (Daskin, 1995). Firstly, with planar location models, any point on the plane is available as candidate sites; theoretically, there is infinite number of candidate sites. Secondly, network location models also have an infinite number of candidate sites, but these sites are only located on nodes or links and the facility users can only move within the network. Finally, discrete location models consider a finite number of candidate sites. The models determine the optimal locations using the locations of candidate sites and the predetermined costs incurred from demand nodes to the candidate sites.

This paper presents a planar location optimization model as a decision support for the truck terminal policy implementation in a city at a time cross section. The model aggregates logistics characteristics, traffic characteristics, and road network attributes into the zonal level. Furthermore, it incorporates three interactions of the city transportation characteristics, i.e.

- the interaction between freight demand and the optimal truck trips through the truck trip conversion model,
- the interaction between the truck terminal locations and transportation cost through the distance function, and
- the interaction between the vehicle travel demand and the serviceability of the street network through the zonal speed-density function

Many methods ware proposed to solve the multi-Weber problem. Cooper (1963,1964) proposed a heuristic called alternative location-allocation (ALA). Gen and Cheng (1997) refer to ALA as the best heuristic available. Yakota, et al. (1996) and Gong, et al. (1997) introduce the hybrid revolutionary method (HEM), a kind of GA, to solve such the problem. By applying these two methods to solve a set of problems that the solutions are known, it is found that HEM surpasses ALA significantly (Gen and Cheng, 1997). This model is consequently solved by GA. However, the allocation subproblem in this model is too complex to solved by Lagrange relaxation as in HEM. Consequently, it is determined directly by enumeration method.

The study area is divided into 27 zones, 23 internal zones and 4 external zones. The internal zones cover the zones in Tokyo Kubu area. Meanwhile, the external zones are the adjacent prefectures, i.e. Saitama, Chiba, Tokyo Ward area, and Kanagawa. Based on the 1999 JRTC data, the logistics activities and traffic characteristics within the Tokyo Metropolitan Area are retrieved as an input of the model. The cost functions are derived from the Guideline for the Evaluation of Road Investment Projects (GERIP). The following sections present the model structure, the solution algorithm, the result, and the conclusion of the study area.

## 2. MODEL STRUCTURE

The policy of the city logistics can be divided into two levels, i.e. level one: the truck terminal policy and level 2: the freight forwarding policy. The decisions on truck terminal policy are the total number, the locations, and the required capacities of the terminals. Meanwhile, the decisions on the freight forwarding policy are the truck type to carry the goods and the best logistics option, e.g. forwarding directly or through the best truck terminal. In level two, the main objective is to minimize the total transportation cost, i.e. logistics cost and passenger travel cost, for a given set of truck terminals. The value of the objective function in this level is the evaluation of the GA process, which is described in detail in section 3.3.

### 2.1 Cost Structure

For a certain subproblem, the total transportation cost is integrated to evaluate the truck terminal policy. The cost is divided into the passenger transportation cost and the logistics transportation cost. Firstly, the passenger transportation cost (P) considers only the people who travel by passenger cars and buses. The other modes of passenger traveling, such as rail or water transportation, are ignored because they shall be insignificantly influenced by the truck terminal policy. The P consists of the distance dependent cost, i.e. emission and vehicle operating cost (VOC), and the time dependent cost, i.e. value of time (VOT). Remark that the environment costs concerned in the model are the emission of $NO_x$ and $CO_2$ only.

Secondly, the logistics cost includes the truck traveling cost and the truck terminal cost. The structure of truck traveling cost is comparable to that of the passenger travel cost. Meanwhile, the truck terminal cost comprises the investment cost and the operating cost, including both fixed cost and variable cost. Since the model does not contain the land price as a function of the location, the investment costs are calculated after obtaining the optimal locations. Comparably, the fixed operating costs are computed after obtaining the required capacity of the truck terminal. In contrast, the variable operating cost of the truck terminal, which is dependent on the volume of commodity to transfer, is merged in the objective function of the model subproblems.

#### 2.1.1 Objective Function

The objective of the subproblem is to minimize the total weekly transportation cost (C), which consists of passenger transportation cost (P) and logistics transportation cost (L) within the Tokyo Kubu area. Because the values of time during weekdays and holidays are different (GERIP, 2000), the cost is calculated on the weekly basis rather than daily basis. The weekly transportation cost is shown in equation (1).

$$C = P + L \tag{1}$$

The following indices will be used in the formulations for the entire dissertation.
*h* = truck terminal
*v* = vehicle type; *v*=1: passenger vehicle, *v*=2: small truck, *v*=3: large truck
*l* = lot size; *l*=1: small lot size, *l*=2: large lot size
*t* = time period

$k$ = a particular zone
$i$ = origin zone
$j$ = destination zone

### 2.1.2 Passenger Transportation Cost (P)

The passenger transportation cost is obtained from the summation of the travel cost of all the passenger vehicles (PT) for every time period, and OD as shown in equation (2) and (3). For a certain OD within a particular time, equation (4) shows that the $PT_{tij}$ is equal to the total number of passenger vehicles, $N_{vtij\,|v=1}$, multiplied by the corresponding unit travel cost, $UT_{vtij}$. The $N_{vtij\,|v=1}$ can be retrieved from JRTC 1999 as an input for the model. Meanwhile, the $UT_{vtij}$ depends on the average travel speed of the vehicle, which is treated to be identical for every vehicle type.

$$P = \sum_t P_t \tag{2}$$

$$P_t = \sum_i \sum_j PT_{tij} \tag{3}$$

$$PT_{tij} = N_{vtij} \times UT_{vtij} \qquad |v=1 \tag{4}$$

### 2.1.3 Logistics Transportation Cost (L)

The logistics transportation cost is obtained from the summation of the travel cost of all the logistics vehicles (LT) and the transfer cost (T) for every time period, and OD as shown in equation (5) and (6). The LT includes both the travel cost between the demand points, *i-j*, and the travel cost between the demand points and the truck terminal, *i-h*.

$$L = \sum_t L_t \tag{5}$$

$$L_t = \sum_v \sum_i \sum_j LT_{vtij} + \sum_v \sum_i \sum_h LT_{vtih} + \sum_h T_{ht} \tag{6}$$

$$LT_{vtij} = N_{vtij} \times UT_{vtij} \qquad |v=2,3 \tag{7}$$

$$LT_{vtih} = N_{vtih} \times UT_{vtih} \qquad |v=2,3 \tag{8}$$

$$T_{ht} = W_{ht} \times UH \tag{9}$$

For a logistics truck traveling between a certain OD within a particular time, equation (7) shows that the $LT_{vtij}$ is equal to the total number of logistics vehicles, $N_{vtij\,|v=2,3}$, multiplied by the corresponding unit travel cost, $UT_{vtij}$. For a logistics truck traveling between a demand point and a truck terminal within a particular time, the $LT_{vtij}$ can be determined analogously as in equation (8). The numbers of logistics vehicles, N, in equation (7) and (8) are determined by the truck trip conversion model. Finally, the transfer cost of a terminal for a time period, $T_{ht}$, is equal to the corresponding commodity volume, $W_{ht}$, multiplied by the unit handling, $UH$, cost as shown in equation (9).

## 2.2 Truck Trip Conversion Model

The truck trip conversion model converts the freight transportation demands into the optimum truck trips. Given a certain origin-destination (O-D) matrix of commodity flow, the required number of logistics trips by different truck types is determined. Accordingly, a new set of truck trips shall be recalculated as the number and locations of the truck terminals are altered. First, the trucks are classified into two types, i.e. small truck and large truck. Then, the 95$^{th}$ percentile actual capacity is determined. From the 1999 JRTC data, the capacities of the small truck and the large truck are 1,070 kg and 10,100 kg respectively. Next, the lot size is then classified into two categories, i.e. the small lot size (the weight does not exceed 1,070 kg) and the large lot size (the weight exceeds 1,070 kg).

Two freight-forwarding systems are defined in this study, i.e. direct logistics system (DLS) and truck terminal logistics system (TTLS). For the DLS, the trips consist of N1, N2, N3, and N4 as shown in Figure 1. Initially, the trucks collect the commodities by N1 trips within zone *i*, then go to zone *j* by N2 trips. Next, the same trucks distribute the commodities within zone *j* by N3 trips, then go back to zone *i* by N4 trips. Meanwhile, the TTLS consists of the trips N1, N5, N6, N7, N8, and N9. At the start, the trucks collect the commodities by N1 trips within zone *i*, go to terminal *h* by N5 trips, and return to zone *i* by N9 trips. At the terminal, the goods are reconsolidated. Next, the optimal fleet of trucks departs from the terminal *h* to zone *j* by N6 trips, distribute the goods in zone *j* by N7 trips, and return to terminal *h* by N8 trips.

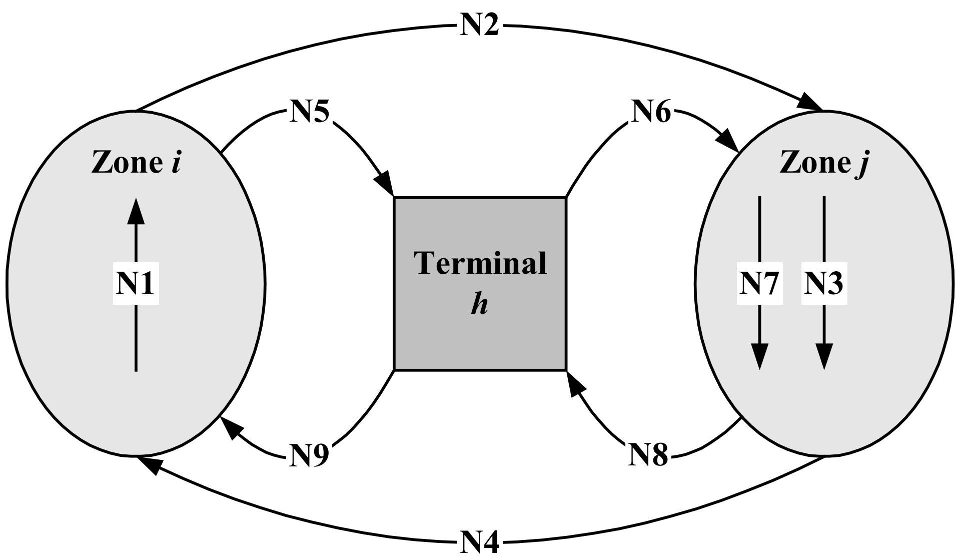


Figure 1. Possible Truck Trips to Transport Goods from Zone *i* to Zone *j*

Note that the trip N5 is analogous to the trip N2 except that the unloading activity is not concerned. The destination of the trip N5 is the terminal that yields the shortest travel time along the route zone *i*-terminal *h*-zone *j*. Due to the fact that the freight volume of an O-D pair is high, it is reasonable and easier to consider each O-D pair separately. In the other hand, the trip N6 is also comparable to the trip N2 except that the loading activity is not concerned. Meanwhile, the trip N7 is developed as the same concept as the trip N3 is.

In addition, the trips N4, N8, and N9 may carry some of the cargoes from zone *j* to zone *i* or return with empty load. How these trips carry the goods when returning depends on the empty-returning rate, *ER*. Prior experiences show that the cooperation among the truck companies can reduce the truck traffic in street network. For instance, 29 trucking companies in Fukuoka started to work together in the logistics activities in the city Central Business District (CBD) in 1978. The cooperative service can reduce the truck traffic in the CBD by 60 % (Nemoto, 1997). Therefore, the public can earns this benefit if the TTLS is promoted in the city.

The number of truck trips depends on the truck capacity, *CAP*, the total weight to load, *WL*, and to unload, *WU*, the number of locations to load, *ML*, and to unload, *MU*. Moreover, the number of loading or unloading, *G*, in a tour is limited by the time constraint. The 1999 JRTC shows that the average, $G_1$, and the 95$^{th}$ percentile, $G_2$, of the *G* value are 4.4 and 11.0 times per tour respectively. The value $G_2$ will be used only after the freights are reconsolidated at the truck terminals, when calculating the trip N6. Two truck strategies are considered to serve a particular logistics demand characteristics.

### 2.2.1 Small Truck Strategy

The small truck strategy tries to assign the small truck to carry the goods if possible, i.e. when the lot size does not exceed 1,070 kg. The number of truck trips needed for the small truck strategy, NS1, NS2,…, and NS9, are determined for every vehicle type, time period, and O-D pair as shown in the following formulations.

$$NS1_{vtij} = \max(0, ML_{ltij|l=1} - NS2_{vtij}) \qquad \forall v = 2, t, i, j \qquad (10)$$

$$NS1_{vtij} = \max(0, ML_{ltij|l=2} - NS2_{vtij}) \qquad \forall v = 3, t, i, j \qquad (11)$$

$$NS2_{vtij} = \max\left(\frac{ML_{ltij|l=1}}{G_1+1}, \frac{MU_{ltij|l=1}}{G_1+1}, \frac{WL_{ltij|l=1}}{CAP_v}\right) \qquad \forall v = 2, t, i, j \qquad (12)$$

$$NS2_{vtij} = \max\left(\frac{ML_{ltij|l=2}}{G_1+1}, \frac{MU_{ltij|l=2}}{G_1+1}, \frac{WL_{ltij|l=2}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \qquad (13)$$

$$NS3_{vtij} = MU_{ltij|l=1} - NS2_{vtij} \qquad \forall v = 2, t, i, j \qquad (14)$$

$$NS3_{vtij} = MU_{ltij|l=2} - NS2_{vtij} \qquad \forall v = 3, t, i, j \qquad (15)$$

$$NS4_{vtij} = NS2_{vtij} - \frac{1}{2}\left[\min\left(NS2_{vtij}, NS2_{vtji}\left(1 - ER_1\right)\right) + \min\left(NS2_{vtji}, NS2_{vtij}\left(1 - ER_1\right)\right)\right]$$

$$\forall v, t, i, j \qquad (16)$$

$$NS5_{vtij} = \max\left(\frac{ML_{ltij|l=1}}{G_1+1}, \frac{WL_{ltij|l=1}}{CAP_v}\right) \qquad \forall v = 2, t, i, j \qquad (17)$$

$$NS5_{vtij} = \max\left(\frac{ML_{ltij|l=2}}{G_1+1}, \frac{WL_{ltij|l=2}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \qquad (18)$$

$$NS6_{vtij} = \max\left(\frac{MU_{ltij|l=1}}{G_2+1}, \frac{WU_{ltij|l=1}}{CAP_v}\right) \qquad \forall v=2,t,i,j \qquad (19)$$

$$NS6_{vtij} = \max\left(\frac{MU_{ltij|l=2}}{G_2+1}, \frac{WU_{ltij|l=2}}{CAP_v}\right) \qquad \forall v=3,t,i,j \qquad (20)$$

$$NS7_{vtij} = MU_{ltij|l=1} - NS6_{vtij} \qquad \forall v=2,t,i,j \qquad (21)$$

$$NS7_{vtij} = MU_{ltij|l=2} - NS6_{vtij} \qquad \forall v=3,t,i,j \qquad (22)$$

$$NS8_{vtij} = NS6_{vtij} - \frac{1}{2}\left[\min\left(NS5_{vtij}, NS6_{vtji}\left(1-ER_1\right)\right) + \min\left(NS6_{vtji}, NS5_{vtij}\left(1-ER_1\right)\right)\right]$$

$$\forall v,t,i,j \qquad (23)$$

$$NS9_{vtij} = NS5_{vtij} - \frac{1}{2}\left[\min\left(NS6_{vtij}, NS5_{vtji}\left(1-ER_2\right)\right) + \min\left(NS5_{vtji}, NS6_{vtij}\left(1-ER_2\right)\right)\right]$$

$$\forall v,t,i,j \qquad (24)$$

### 2.2.2 Large Truck Strategy

The large truck strategy tries to assign the large truck to carry the goods if suitable. The value of time (VOT) of the large truck and the small truck are identical. Furthermore, the vehicle operating cost (VOC) of the large truck is at most 31% larger than that of the small truck (GERIP, 2000). Consequently, one large truck is preferable to two small trucks. Thus, the small trucks shall be used only when

- the total weight is not exceed the small truck capacity, 1,070 kg, or
- the average loading lot size or unloading lot size is less than 97 kg, at which a small truck can load the goods for 11 times.

The number of truck trips needed for the large truck strategy, NL1, NL2,…, and NL9, are determined for every vehicle type, time period, and O-D pair as shown in the following formulations.

$$NL4_{vtij} = NL2_{vtij} - \frac{1}{2}\left[\min\left(NL2_{vtij}, NL2_{vtji}\left(1-ER_{r|r=1}\right)\right) + \min\left(NL2_{vtji}, NL2_{vtij}\left(1-ER_{r|r=1}\right)\right)\right]$$

$$\forall v,t,i,j \qquad (25)$$

$$NL8_{vtij} = NL6_{vtij} - \frac{1}{2}\left[\min\left(NL5_{vtij}, NL6_{vtji}\left(1-ER_{r|r=1}\right)\right) + \min\left(NL6_{vtji}, NL5_{vtij}\left(1-ER_{r|r=1}\right)\right)\right]$$

$$\forall v,t,i,j \qquad (26)$$

$$NL9_{vtij} = NL5_{vtij} - \frac{1}{2}\left[\min\left(NL6_{vtij}, NL5_{vtji}\left(1-ER_{r|r=2}\right)\right) + \min\left(NL5_{vtji}, NL6_{vtij}\left(1-ER_{r|r=2}\right)\right)\right]$$

$$\forall v,t,i,j \qquad (27)$$

If $wl_{ltij|l=1} \le 97kg$ or $WL_{ltij|l=1} \le 1{,}070kg$, then

$$NL1_{vtij} = ML_{ltij|l=1} - NL2_{vtij} \qquad \forall v=2,t,i,j \qquad (28)$$

$$NL1_{vtij} = ML_{ltij|l=2} - NL2_{vtij} \qquad \forall v = 3, t, i, j \quad (29)$$

$$NL2_{vtij} = \max\left(\frac{ML_{ltij|l=1}}{G_1 + 1}, \frac{MU_{ltij|l=1}}{G_1 + 1}, \frac{WL_{ltij|l=1}}{CAP_v}\right) \qquad \forall v = 2, t, i, j \quad (30)$$

$$NL2_{vtij} = \max\left(\frac{ML_{ltij|l=2}}{G_1 + 1}, \frac{MU_{ltij|l=2}}{G_1 + 1}, \frac{WL_{ltij|l=2}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \quad (31)$$

$$NL3_{vtij} = MU_{ltij|l=1} - NL2_{vtij} \qquad \forall v = 2, t, i, j \quad (32)$$

$$NL3_{vtij} = MU_{ltij|l=2} - NL2_{vtij} \qquad \forall v = 3, t, i, j \quad (33)$$

$$NL5_{vtij} = \max\left(\frac{ML_{ltij|l=1}}{G_1 + 1}, \frac{WL_{ltij|l=1}}{CAP_v}\right) \qquad \forall v = 2, t, i, j \quad (34)$$

$$NL5_{vtij} = \max\left(\frac{ML_{ltij|l=2}}{G_1 + 1}, \frac{WL_{ltij|l=2}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \quad (35)$$

$$NL6_{vtij} = \max\left(\frac{MU_{ltij|l=1}}{G_2 + 1}, \frac{WU_{ltij|l=1}}{CAP_v}\right) \qquad \forall v = 2, t, i, j \quad (36)$$

$$NL6_{vtij} = \max\left(\frac{MU_{ltij|l=2}}{G_2 + 1}, \frac{WU_{ltij|l=2}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \quad (37)$$

$$NL7_{vtij} = MU_{ltij|l=1} - NL6_{vtij} \qquad \forall v = 2, t, i, j \quad (38)$$

$$NL7_{vtij} = MU_{ltij|l=2} - NL6_{vtij} \qquad \forall v = 3, t, i, j \quad (39)$$

otherwise,

$$NL1_{vtij} = 0 \qquad \forall v = 2, t, i, j \quad (40)$$

$$NL1_{vtij} = \sum_l ML_{ltij} - NL2_{vtij} \qquad \forall v = 3, t, i, j \quad (41)$$

$$NL2_{vtij} = 0 \qquad \forall v = 2, t, i, j \quad (42)$$

$$NL2_{vtij} = \max\left(\frac{\sum_l ML_{ltij}}{G + 1}, \frac{\sum_l MU_{ltij}}{G + 1}, \frac{\sum_l WL_{ltij}}{CAP_v}\right) \qquad \forall v = 3, t, i, j \quad (43)$$

$$NL3_{vtij} = 0 \qquad \forall v = 2, t, i, j \quad (44)$$

$$NL3_{vtij} = \sum_l MU_{ltij} - NL2_{vtij} \qquad \forall v = 3, t, i, j \quad (45)$$

$$NL5_{vtij} = 0 \qquad \forall v = 2, t, i, j \quad (46)$$

$$NL5_{vtij} = \max\left( \frac{\sum_l ML_{ltij}}{G+1}, \frac{\sum_l WL_{ltij}}{CAP_v} \right) \qquad \forall v = 3, t, i, j \qquad (47)$$

$$NL6_{vtij} = 0 \qquad \forall v = 2, t, i, j \qquad (48)$$

$$NL6_{vtij} = \max\left( \frac{\sum_l MU_{ltij}}{G+1}, \frac{\sum_l WU_{ltij}}{CAP_v} \right) \qquad \forall v = 3, t, i, j \qquad (49)$$

$$NL7_{vtij} = 0 \qquad \forall v = 2, t, i, j \qquad (50)$$

$$NL7_{vtij} = \sum_l MU_{ltij} - NL6_{vtij} \qquad \forall v = 3, t, i, j \qquad (51)$$

## 2.3 Distance Function

The distance function is one of the essential elements in the model because it promotes the interaction between the existing fixed demand points and the optimal locations of the new truck terminals. Love *et al.* (1988) introduce many types of distance functions. Given the coordinates of an origin and a destination, the distance function can represent the travel distance along the street network. The parameters of the function depend upon the geometric and topology of the street network in the certain city. In this model, the centroids of the zones represent the O-D points of the freight travel demands. Despite of the coordinates, zone areas are also added into the distance function as shown in equation (52).

$$d_{ij} = g\left( A_i^{1/q} + A_j^{1/q} \right) + k\left( \left| x_i - x_j \right|^p + \left| y_i - y_j \right|^p \right)^{1/p} \qquad (52)$$

The parameters are calibrated by the normalized least square error $\sum_i \sum_j \frac{\left(d_{ij} - D_{ij}\right)^2}{D_{ij}}$

Where,

| | |
|---|---|
| $d_{ij}$ | = calculated average distance between zone $i$ and zone $j$ |
| $A_i$ and $A_j$ | = area of zone $i$ and zone $j$ respectively in km$^2$ |
| $(x_i,y_i)$ and $(x_j,y_j)$ | = coordinates of point $i$ and point $j$ respectively |
| $g, q, k, p$ | = parameters of the function |
| $D_{ij}$ | = actual average distance between zone $i$ and zone $j$ |

The result shows that $g = 0.505$, $q = 4.512$, $k = 1.181$, and $p = 1.968$ with $R^2 = 0.827$.

## 2.4 Zonal Speed-Density Function

The zonal speed-density function is derived for every zone from the existing characteristic of the zonal traffic, rather than that of the link traffic. Since each zone is differed in traffic serviceability, e.g. lane width, street network configuration, or traffic control system efficiency, the zonal speed-density function is consequently calculated for each specific zone. The parameters of the function indicate both physical conditions and the traffic operation efficiency of the road network in a particular zone. The function is developed as follows.

$$V_{tij} = \frac{D_{tij}}{T_{tij}} \tag{53}$$

$$V_{tk} = V_{tij|k=i=j} \tag{54}$$

$$D_{tkij} = D_{tij} \times DP_{kij} \tag{55}$$

$$T_{tkij} = \frac{D_{tkij}}{V_{tk}} \tag{56}$$

$$TP_{tkij} = \frac{T_{tkij}}{\sum_k T_{tkij}} = \frac{T_{tkij}}{T_{tij}} \tag{57}$$

$$VH_{tk} = \sum_v \sum_i \sum_j N_{vtij} \times PCE_v \times TP_{tkij} \tag{58}$$

$$K_{tk} = \frac{VH_{tk}}{T_t \times A_k} \tag{59}$$

where

$A_k$ = area of zone $k$
$DP_{kij}$ = distance proportion of traversing in zone $k$ when traveling from zone $i$ to zone $j$
$D_{tij}$ = average travel distance from zone $i$ to zone $j$ in time period $t$
$D_{tkij}$ = average travel distance traversing in zone $k$ when traveling from zone $i$ to zone $j$ in time period $t$
$K_{tk}$ = average zonal density within zone $k$ in time period $t$
$N_{vtij}$ = number of vehicles of type $v$ traveling from zone $i$ to zone $j$ in time period $t$
$PCE_v$ = passenger car equivalent factor of vehicle type $v$
$TP_{tkij}$ = time proportion spending in zone $k$ when traveling from zone $i$ to zone $j$ (from zonal distance passing proportion)
$T_t$ = duration of time period $t$
$T_{tij}$ = average travel time from zone $i$ to zone $j$ in time period $t$
$T_{tkij}$ = average travel time spending in zone $k$ when traveling from zone $i$ to zone $j$ in time period $t$
$VH_{tk}$ = total vehicle-hour of travel (in PCU-hour) within zone $k$ in time period $t$
$V_{tij}$ = average travel speed from zone $i$ to zone $j$ in time period $t$
$V_{tk}$ = average travel speed within zone $k$ in time period $t$

Then, the speed-density function for zone $k$, equation (60), is determined based on $K_{tk}$ from equation (59) and $V_{tk}$ (kph) from equation (54). The parameters are shown Table 1.

$$V_k = a_1 \ln K_k + a_0 \tag{60}$$

Table 1. Zonal Speed-Density Parameters for Every Internal Zone

| Zone | $a_1$ | $a_0$ | $R^2$ | Zone | $a_1$ | $a_0$ | $R^2$ | Zone | $a_1$ | $a_0$ | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -4.126 | 39.018 | 0.738 | 9 | -4.268 | 40.933 | 0.748 | 17 | -2.338 | 27.383 | 0.700 |
| 2 | -2.647 | 29.320 | 0.755 | 10 | -5.820 | 51.216 | 0.544 | 18 | -4.961 | 41.693 | 0.757 |
| 3 | -4.962 | 45.970 | 0.704 | 11 | -3.224 | 31.804 | 0.823 | 19 | -4.072 | 37.532 | 0.630 |
| 4 | -2.915 | 31.819 | 0.766 | 12 | -3.422 | 33.128 | 0.780 | 20 | -3.038 | 29.720 | 0.890 |
| 5 | -3.346 | 32.356 | 0.940 | 13 | -6.608 | 55.599 | 0.823 | 21 | -3.432 | 33.416 | 0.718 |
| 6 | -4.863 | 42.792 | 0.848 | 14 | -3.586 | 34.992 | 0.622 | 22 | -1.941 | 23.461 | 0.576 |
| 7 | -3.445 | 33.199 | 0.815 | 15 | -2.827 | 28.965 | 0.558 | 23 | -3.947 | 36.190 | 0.846 |
| 8 | -1.826 | 23.512 | 0.637 | 16 | -3.868 | 35.637 | 0.634 | | | | |

## 3. SOLVING BY GENETIC ALGORITHM

The GA implemented in this study is mainly adopted from Gen and Cheng (1997). The environmental parameters are set as: *max_gen* = 400, *pop_size* = 40, *child_size* = 80, $p_m = 0.1$, $\alpha = 7.0$ million yens per week, $\gamma = 0.1$ km, and $\varepsilon = 2.0$ km.

### 3.1 Chromosome Representation

The float-value chromosome representation is used for such the continuous variables as follows.

$$c^p = \left[x_1^p, y_1^p, x_2^p, y_2^p, \ldots, x_m^p, y_m^p\right] \quad (61)$$

where $\left(x_h^p, y_h^p\right)$ is the location of $h^{th}$ facility in the $p^{th}$ chromosome, $h = 1,2,\ldots,m$.

### 3.2 Initialization

The feasible locations shall be within a rectangle that covers every zone centroid. Thus, the initialization process selects the location of every terminal for every chromosome with in the rectangle.

### 3.3 Evaluation

The total weekly transportation cost ($C$) within the Tokyo Kubu area, including passenger transportation cost ($P$) and logistics cost ($L$), is used to evaluate the fitness of the chromosome. The $P$ is developed based on the GERIP 2000 including the value of time, the vehicle operating cost, and the emission cost. Meanwhile, the $L$ contains not only the travel cost but also the transfer cost at the terminal. Nonetheless, the investment cost of the truck terminals is not integrated at this evaluation stage. The logistics demand is converted into truck trips and assigned into the network incrementally by 25% in each iteration. The evaluation procedure for a given set of truck terminal locations is described by the following steps.

**Step 1.** Divide the freight demand into four parts equally.

**Step 2.** Use the truck trip conversion model to convert the divided freight demand into the required number of trucks every O-D pair.

**Step 3.** Calculate the distance among zones and terminals by the distance function.

**Step 4.** Determine the number of vehicles and the existing speed in every zone and time period from 1999 JRTC.
**Step 5.** Determine the current zone speed for the no-truck condition by the zonal speed-density function.
**Step 6.** Calculate the total cost for each logistics option and then select the best one. Figure 2 diagrammatically express every possible logistics option and its travel cost structure.
**Step 7.** Assign the truck trip into the network according to the selected logistics option.
**Step 8.** Update the current zone speed.
**Step 9.** If all the logistics demands are served, then stop. Otherwise, go to step 6.

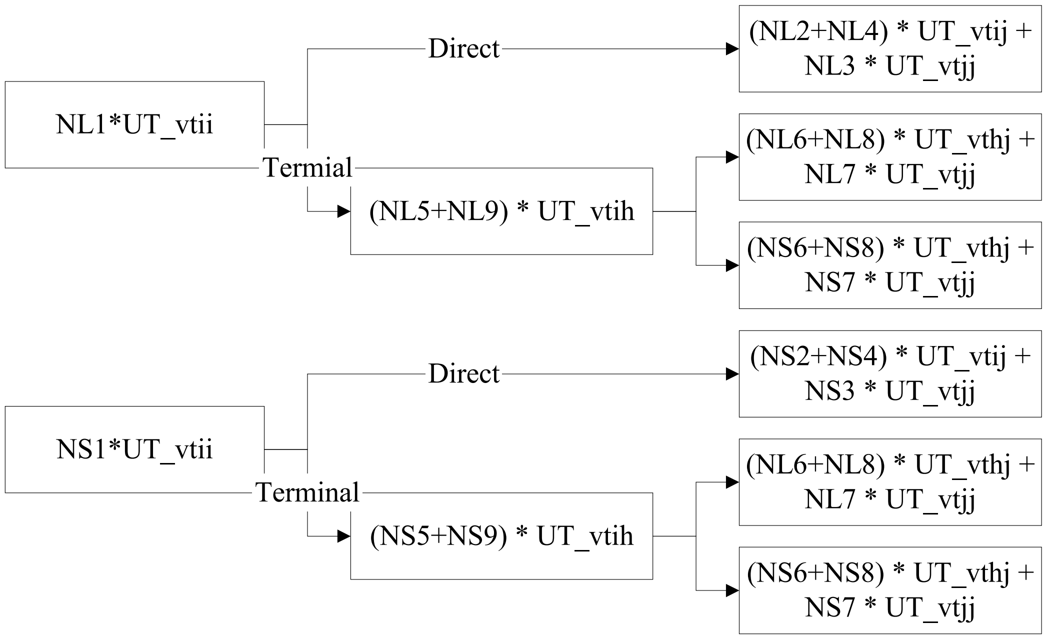


Figure 2. Decision Tree for Selecting the Best Logistics Option

### 3.4 Crossover

Two crossover strategies are utilized. When the generation is odd, the *free mating*, which selects two parents randomly, is employed. Otherwise, the *dominating mating*, which selects the best chromosome as a fixed parent and randomly select another chromosome from the population pool, is used. Once two parents are selected as $c^{p1} = \left[x_1^{p1}, y_1^{p1}, x_2^{p1}, y_2^{p1}, ..., x_m^{p1}, y_m^{p1}\right]$ and $c^{p2} = \left[x_1^{p2}, y_1^{p2}, x_2^{p2}, y_2^{p2}, ..., x_m^{p2}, y_m^{p2}\right]$, a new child of the next generation will be produced as $c = \left[x_1, y_1, x_2, y_2, ..., x_m, y_m\right]$. The genes in the child is obtained as follows:

$$x_h = r_h \cdot x_h^{p_1} + (1 - r_h) \cdot x_h^{p_2} \tag{62}$$

$$y_h = r_h \cdot y_h^{p_1} + (1 - r_h) \cdot y_h^{p_2} \tag{63}$$

where $r_h$ is an independent random number in (0,1).

### 3.5 Mutation

Two mutation strategies are utilized. When the generation is odd, the *subtle mutation*, which produces a new child by applying a small random perturbation to the chromosome of the parent, is employed. Otherwise, the *violent mutation*, which produces a new child in the same process as in the initialization procedure, is used. Once a chromosome is selected at the rate of $p_m$ as $c^p = \left[x_1^p, y_1^p, x_2^p, y_2^p, ..., x_m^p, y_m^p\right]$, a child will be produced as $c = \left[x_1, y_1, x_2, y_2, ..., x_m, y_m\right]$. The genes in the child obtained by *subtle mutation* is expressed as follows:

$$x_i = x^k{}_i + \text{random value in } [-\varepsilon,\varepsilon] \tag{64}$$

$$y_i = y^k{}_i + \text{random value in } [-\varepsilon,\varepsilon] \tag{65}$$

where $\varepsilon$ is a small positive real number. Meanwhile, the genes in the child obtained by *violent mutation* is expressed as follows:

$$x_i = \text{random value in } [x_{min}, x_{max}] \tag{66}$$

$$y_i = \text{random value in } [y_{min}, y_{max}] \tag{67}$$

### 3.6 Selection

This study uses the enlarged sampling space (ES) and the ($\mu$+$\lambda$) selection (Bäck, 1994) with *relative prohibition* to avoid the degeneration of the evolution process. Once $s_p$ is selected into the next generation, any neighborhood of $s_p$ is prohibited to select. The neighborhood of a chromosome $s_p$ is defined as follows.

$$\Omega(s_p,\alpha,\gamma) \triangleq \left\{ s \mid \left\| s - s_p \right\| \leq \gamma, D(s_p) - D(s) < \alpha, s \in R^{2m} \right\} \tag{68}$$

Note that $\gamma$ defines the neighborhood of $s_p$ in term of location. Meanwhile, $\alpha$ defines the neighborhood of $s_p$ in term of fitness. The algorithm regards the neighborhood in equation (68) as a *prohibited neighborhood*.

## 4. RESULT

The model is applied to nine scenarios, i.e. DLS and TTLS with one terminal to eight terminals. When there is only one truck terminal in the study area, only few freight demands are served through the truck terminals. Once the number of the truck terminals increase, the TTLS can compete with the DLS in the wider region. Consequently, the overall city logistics cost can be reduced due to the advantages of the use of truck terminals, e.g. the goods can be repackaged in a suitable truck type, better cargo cooperation, and shorter total travel distance.

Additionally, the passenger travel activity can also gain the benefit by less zonal traffic density and higher average travel speed. Table 2 demonstrates the weekly transportation cost between Tokyo Kubu area and the adjacent prefectures. The result obviously confirms that the transportation cost drops as the total number of the truck terminals increases. Nevertheless, the PT begins to increase as the number of truck terminals greater than six terminals. The terminal construction cost is derived from a research report on encouragement of Multi-

Carrier-Cooperative Pickup/Delivery Service by the Association for Planning and Transportation (1992). Prices are converted for 1999.

Table 2. Transportation Cost between Tokyo Kubu Area and the Adjacent Prefecture in Billion Yens per Week

| Number of Terminals | Passenger Travel Cost (PT) | Logistics Travel Cost (LT) | Terminal Construction Cost | Total Cost (C) |
|---|---|---|---|---|
| Direct | 352.68 | 43.50 | - | 396.18 |
| 1 | 352.40 | 42.83 | 0.03 | 395.27 |
| 2 | 351.69 | 41.96 | 0.06 | 393.70 |
| 3 | 351.54 | 41.81 | 0.07 | 393.41 |
| 4 | 351.45 | 41.76 | 0.09 | 393.29 |
| 5 | 351.35 | 41.14 | 0.12 | 392.61 |
| 6 | 350.99 | 41.02 | 0.13 | 392.13 |
| 7 | 351.20 | 40.96 | 0.14 | 392.30 |
| 8 | 351.37 | 40.94 | 0.16 | 392.46 |

It is found that the optimum number of truck terminals is six. Figure 3 exhibits the truck terminal locations graphically. Finally, Table 3 shows the locations of the truck terminals and their required daily and peak-hour capacities in tons.

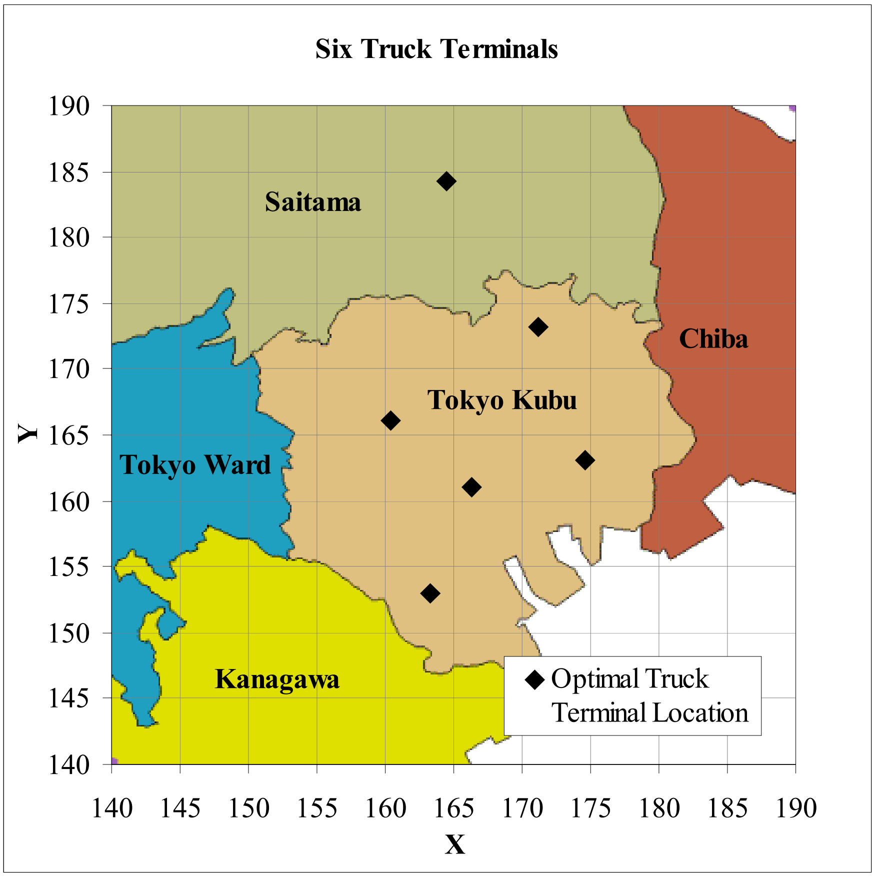


Figure 3. Optimal Truck Terminal Locations

Table 3. Coordinates and Required Capacities of the Truck Terminals in a Weekday in Tons

| Number of Terminals | Terminal | X | Y | Daily Freight Transfer Volume | Peak-Hour Freight Transfer Volume |
|---|---|---|---|---|---|
| Six | 1 | 166.3 | 161.1 | 6,675 | 743 |
| | 2 | 174.5 | 163.1 | 3,227 | 334 |
| | 3 | 164.5 | 184.3 | 5,979 | 645 |
| | 4 | 160.4 | 166.1 | 4,526 | 792 |
| | 5 | 171.2 | 173.2 | 9,174 | 1,177 |
| | 6 | 163.4 | 153.0 | 13,352 | 1,678 |

## 5. CONCLUSION

This paper introduces an optimization decision model for the truck terminal policy as a strategic planning for a city at a time cross section. Certainly, the result indicates a guideline for the optimum number of terminals and the approximate locations, not the exact ones. The objective function is to minimize the total transportation cost for both passenger and freight movement. The cost, therefore, includes the vehicle operating cost, value of time, emission, terminal construction cost and transfer cost.

Furthermore, this model integrates the interactions among the terminal locations, the freight transportation demand, and the traffic condition by employing the truck trip conversion model, the distance function, and the zonal speed-density function. Given a total number of truck terminal, the optimal location of every terminal and its corresponding required capacity are determined.

Besides, this approach can also be enhanced for the long run planning by superimpose the transportation information at the further time cross sections into the model. However, the further study of how the traffic service in the future will affect the zonal speed-density function is needed. Ardekani *et al*. (1992) investigates ten geometric and control features that potentially affect the quality of urban traffic services. Those features are block length, extent of one-way street, number of lanes per street, intersection density, signal density, speed limit, cycle length, extent of on street parking, degree of signal actuation, and degree of signal progression. Then, stepwise regression analyses were performed to identify the significantly influencing attributes.

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