# CONCEPTS AND EVALUATION OF CITY LOGISTICS INITIATIVES BY DYNAMIC TRAFFIC SIMULATION

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**Abstract**: This paper presents a methodology for evaluating city logistics initiatives using a dynamic traffic simulation with optimal routing and scheduling. This methodology was applied to a test road network. The performance of three city logistics initiatives, advanced routing and scheduling systems, co-operative freight transport systems and load factor controls were assessed in terms of total costs and $CO_2$ emissions by pickup/delivery trucks operations within the network. Results indicated that each of these initiatives was not only effective for reducing total costs but also $CO_2$ emissions. The methodology presented in this paper allows city planners to quantitatively evaluate city logistics initiatives.

## 1. INTRODUCTION

### 1.1 City Logistics Initiatives

Urban freight transport has become an important component of urban planning. The rationalisation of urban freight transport is essential for sustainable economic growth. However, there are now many problems to overcome such as traffic congestion, environment and energy conservation. Freight carriers are expected to provide higher levels of service within the framework of Just-In-Time transport systems with lower costs.

To help solve these difficult problems, several city logistics initiatives have been proposed, including:

(a) Advanced information systems (e.g. Kohler, 1997)
(b) Co-operative freight transport systems (e.g. Ruske, 1994; Taniguchi *et al.*, 1995)
(c) Public logistics terminals (e.g. Janssen and Oldenberger, 1991; Duin, 1997; Taniguchi *et al.*, 1999)
(d) Load factor controls
(e) Underground freight transport systems (e.g. Koshi *et al.*, 1992; Oishi, 1996; Visser; 1997, Duin, 1998).

Private companies with varying degrees of support provided by the public sector usually operate city logistics initiatives. To realise the full potential of city logistics initiatives, it is therefore, crucial that an effective partnership between both the private and public sector be developed and maintained.

### 1.2 City logistics evaluation criteria

This paper focuses on the evaluation of three of the five city logistics initiatives described above, advanced information systems, co-operative freight transport systems and the control of load factors. These evaluations were undertaken using a dynamic traffic simulation model developed by Taniguchi *et al.* (1998). Here, the emphasis is on evaluating the city logistics initiatives from an environmental point of view. The criteria used in this paper for evaluating each city logistics initiative relate to measuring the effects of the initiatives on congestion as well as the environmental impacts. The total travel time and the $CO_2$ emissions produced by pickup/delivery trucks are the primary indicators used in the evaluations.

### 1.3 Pickup/delivery truck routing and scheduling

This paper focuses on investigating pickup/delivery truck routing and scheduling operations in an urban area where some freight carriers are assumed to have introduced advanced routing and scheduling procedures as well as established a co-operative freight transport system. Moreover, the municipality regulates the load factors of pickup/delivery trucks. The effects of these initiatives on the relationship between the $CO_2$ emissions and the demand for freight transport were predicted. When investigating these effects the designated time for pickup and delivery plays an important role. Recently urban pickup/delivery trucks were required to arrive at their customers within a designated time period. A recent survey in Osaka and Kobe in Japan, found that freight carriers were required operate with designated arrival times or time windows for 52% of goods delivered and for 45% of goods collected in terms of weight.

Vehicle routing problems with time windows (VRPTW) have been investigated by a number of operations researchers (e.g. Solomon, 1987, Koskosidis *et al.*, 1992, Russell, 1995, Bramel *et al.*, 1996). However, most of this research has been conducted within the framework of a company's business logistics. The impacts of the behaviour of shippers and freight carriers on the general traffic conditions of the road network have not yet been investigated. However, these impacts are considered to be very important for city planners to evaluate transport policies for alleviating congestion, environmental and energy problems. This paper describes the application of a model for representing the behaviour of urban pickup/delivery trucks as well as passenger cars on a road network. Since private companies in a free market generally undertake freight transport, too much control and regulation by the public sector is not welcomed. The model allowed the effects of three city logistics initiatives, advanced routing and scheduling systems based on advanced information systems, co-operative freight transport systems and control of load factors to be investigated. Changes in $CO_2$ emissions within an urban area were estimated.

## 2. MODEL

### 2.1 Framework

Figure 1 presents a framework of the model applied. The model is composed of two sub-models, a model for vehicle routing and scheduling problem with time windows (VRPTW) for each company as well as a dynamic traffic simulation model for the fleet of pickup/delivery trucks and passenger cars on the road network within the city.

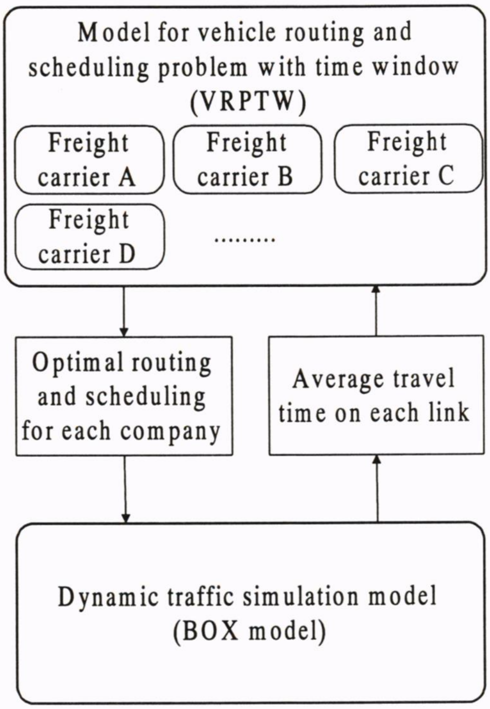


Figure 1 Model framework

The model for VRPTW is defined as follows. A depot and a number of customers are defined for each freight carrier. A fleet of identical vehicles collects goods from customers and deliver them to the depot or deliver goods to customers from the depot. For each customer a designated time window, specifying the desired time period to be visited is also specified. For example, in the case of collecting goods, vehicles depart from the depot and visit a subset of customers to pick up goods in sequence and return to the depot to unload them. A vehicle is allowed to make multiple traverses per day. Each customer must be assigned to exactly one route of a vehicle and all the goods from each customer must be loaded on the vehicle at the same time. The total weight of the goods for a route must not exceed the capacity of the vehicle. The problem is to determine the optimal assignment of vehicles to customers and the departure time as well as the order of visiting customers for a freight carrier. VRPTW explicitly incorporate the departure time of vehicles as a variable to be determined.

The optimal assignment of vehicles to customers and the departure time as well as the visiting order of customers for each freight carrier, becomes input to the dynamic traffic simulation model. The dynamic traffic simulation model is based on a macroscopic dynamic simulation BOX model (Fujii *et al.*, 1994). This model estimates the average travel time on each link in 30 minutes intervals. The VRPTW model is then re-solved using the updated average travel times on each link obtained from the BOX model. Thus, the average travel times for each link are represented by a step function, in 30-minute time intervals. The model therefore, incorporates time dependent travel times. Successive iterations of both the VRPTW model and the BOX model continue until a pre-defined stopping criterion is satisfied. The iteration does not guarantee the convergence. Therefore a stopping criteria for the iteration was determined that will be described later in equation (5).

## 2.2 VRPTW Model

This section defines the mathematical model used to represent the VRPTW that was introduced in the previous section. The model minimises the total cost of distributing goods with truck capacity and designated time constraints. The total cost is composed of three cost components:

(a) fixed costs of vehicles
(b) vehicle operating costs, that are proportional to the time travelled and spent waiting at customers
(c) delay penalty costs for designated pickup/delivery time at customers.

Let,
$m$ : maximum number of vehicles available
$\boldsymbol{t_0}$: departure time vector of vehicle $l$ at the depot
$$\boldsymbol{t_0} = \{t_{l,0} \mid l = 1, m\}$$
$n(i)$: node number of $i$ th customer visited by a vehicle
$N_l$: total number of customers visited by vehicle $l$
$\mathbf{x}_l$ : assignment and order of visiting customers for vehicle $l$
$$\mathbf{x}_l = \{n(i) \mid i = 1, N_l\}$$
$\mathbf{X}$ : assignment and order of visiting customers vector for all vehicles
$$\mathbf{X} = \{\mathbf{x}_l \mid l = 1, m\}$$
$C(\boldsymbol{t_0}, \mathbf{X})$: total cost (yen)
$c_{f,l}$: fixed cost for vehicle $l$ (yen /vehicle)
$\delta_l(\mathbf{x}_l)$: = 1; if vehicle $l$ is used
= 0; otherwise
$c_{t,l}$ : operating cost for vehicle $l$ (yen /min)
$T_l(t_{l,0}, \mathbf{x}_l)$: operating time of vehicle $l$ (min)
$c_d$ : delay penalty cost at customer (yen/min)
$t^a_{l,n(i)}(t_{l,0}, \mathbf{x}_l)$ : arrival time at node $n(i)$ of vehicle $l$ that departed from the depot at time $t_{l,0}$
$t^e_{n(i)}$ : end of time window at customer $n(i)$ (see Figure 2)
$t_{l,n(i)}$ : departure time of vehicle $l$ at customer $n(i)$
$d(t, n(i), n(i+1))$: minimum travel time at time $t$ from customer $n(i)$ to customer $n(i+1)$
$t^s_{n(i)}$ : start of time window at customer $n(i)$ (see Figure 2)
$t_{c,n(i)}$ : loading/unloading time at customer $n(i)$
$W_l(\mathbf{x}_l)$ : load of vehicle $l$ (kg)
$W_{c,l}$ : capacity of vehicle $l$ (kg).

The model can be formulated as follows.

$$\min \; C(t_0, \mathbf{X}) = \sum_{l=1}^{m} c_{f,l} \cdot \delta_l(\mathbf{x}_l) + \sum_{l=1}^{m} c_{t,l} \cdot T_l(t_{l,0}, \mathbf{x}_l) + \sum_{l=1}^{m} c_d \max\{0, t^a_{l,n(i)}(t_{l,0}, \mathbf{x}_l) - t^e_{n(i)}\} \quad (1)$$

where,

$$T_l(t_{l,0}, \mathbf{x}_l) = \sum_{i=0}^{N_l} \left[ \max\{t_{l,n(i)} + d(t_{l,n(i)}, n(i), n(i+1)), t^s_{n(i+1)}\} + t_{c,n(i+1)} - t_{l,n(i)} \right] \quad (2)$$

Subject to

$$W_l(\mathbf{x}_l) \le W_{c,l} \quad (3)$$

The problem specified by equations (1) - (3) is to determine the variable vector $\mathbf{X}$, that is, the assignment of vehicles and the visiting order to customers and the variable $t_0$, the departure time of vehicles from the depot. Note that $n(0)$ and $n(N_l+1)$ represent the depot in equation (2).

Figure 2 shows the cost function for vehicle arrivals at customers. The time period $(t^e_{n(i)} - t^s_{n(i)})$ defines the width of the soft time window. If a vehicle arrives at a customer earlier than $t^s_{n(i)}$, it must wait until the start of the designated time window and a cost is incurred for waiting. If a vehicle is delayed, it must pay a penalty proportional to the amount of time it was delayed. This type of penalty is typically observed in Just-In-Time transport systems.

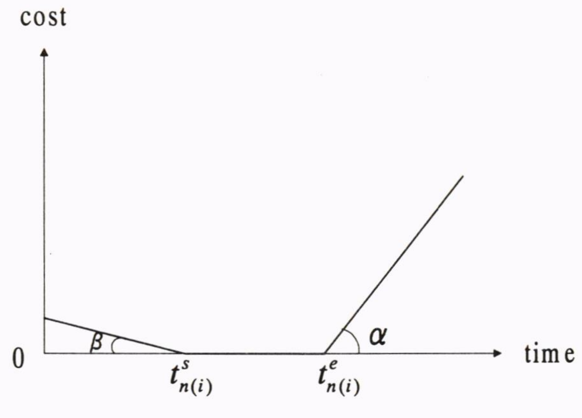


Figure 2 Cost function for soft time windows

The problem described herewith is an NP-hard combinatorial optimisation problem. It requires heuristic methods to efficiently obtain an optimal solution. Recently several researchers have applied heuristic algorithms such as Genetic Algorithms (GA) (e.g. Thangiah *et al.*, 1991), Simulated Annealing (SA) (e.g. Kokubugata *et al.*, 1997) and Tabu Search (TS) (e.g. Potvin *et al.*, 1996) to obtain approximate solutions for the VRPTW. Gendreau *et al.* (1997) reviewed the application of such modern heuristic approaches to VRP and described the potential of such methods for tackling complex, difficult combinatorial optimisation problems. The model described in this paper uses a GA to solve the VRPTW. GA was selected because it is a heuristic procedure that can simultaneously determine the departure time and the assignment of vehicles as well as the visiting order of customers. GA generally starts with an initial population of individuals (solutions) and from these a next generation is produced. Parents of subsequent generations are selected on the basis of their performance or fitness. Using the parents characteristics, a number of operations are performed (crossover and mutation) to produce successive generations and to avoid local optimal solutions. Generations are continued to be produced until a satisfactory solution is found.

### 2.3 Dynamic simulation model

The dynamic traffic simulation model is based on a BOX model that was originally developed by Fujii *et al.* (1994). The BOX model is essentially a macroscopic model but because the origin and destination of each vehicle is defined, it is actually a hybrid macroscopic/microscopic model. Vehicles are assumed to choose the shortest path when they arrive at a node using an estimated travel time. The BOX model consists of two components, a flow simulation and a route choice simulation. A sequence of boxes is used to represent each link. Groups of vehicles flowing out of a box and into the next box during the scanning interval represent the flow on links. There are two assumptions for modelling links, that is the maximum flow during a scanning interval is the same for all sections on links and no inflow and outflow is allowed in the middle of links. A consequence of the first assumption is that only the lowest section of a link can be a bottleneck, where a congestion queue starts. Two states of flow; congested flow and free flow are represented. The model deals with two types of vehicles; passenger cars and trucks. Trucks are actually converted to passenger car unit (pcu).

The simulation model described above estimates travel times on each link and allows link costs to be determined. Drivers are assumed to compose "cognitive maps" for each link based on its estimated link cost. The cognitive maps are the drivers subjective maps of the network consisting of their expected link cost. Drivers then choose routes based on their minimum travel cost from the current node to the destination using their cognitive map. It is assumed that all drivers have some experience in driving within the defined network.

## 3. EVALUATING CITY LOGISTICS INITIATIVES ON TEST NETWORK

### 3.1 Test conditions

The model described in the previous section was applied to a test network with 25 nodes and 40 links as shown in Figure 3. This network includes three types of roads, urban expressways, arterials and streets with free running speeds of 60 km/h, 40 km/h and 20 km/h respectively. Although this network is a hypothetical one, it is similar to Kobe city in Japan. Therefore, the travel times vary for the same distance depending on the type of road used. Note, that the length of links shown in Figure 3 do not precisely indicate their geometric distance. The travel time shown in Figure 3 indicates the free travel time and it will change if the traffic is congested. Any node within the network can both generate and attract passenger car traffic. These nodes are referred to as centroids and are also candidate nodes to be visited by pickup/delivery trucks. Ten freight carriers are assumed to operate a maximum of 12 pickup/delivery trucks in this network. Each freight carrier has one depot whose location is shown in Table 1. Three different types of trucks, having a capacity of 2, 4 and 10 tons respectively can be used. However, up to four trucks of each type can only be operated by each carrier. Table 2 shows the passenger car equivalence rates, operating costs and fixed costs for each type of pickup/delivery truck. These costs are based on results from recent studies of truck operations in Japan. The number of customers for each carrier was randomly generated between 5 and 24 as shown in Table 1. The locations of depot and customers are hypothetical. The actual nodes to be visited for each carrier were also determined randomly from all nodes in the network.

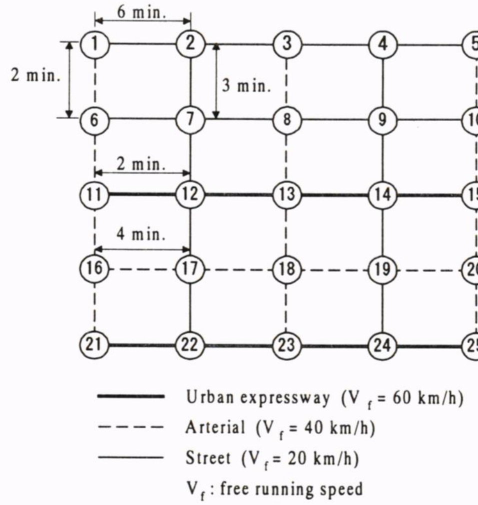


Figure 3 Test network

Table 1 Location of depot and number of customers for each freight carrier

| Freight carrier | Depot node number | Number of customers |
|---|---|---|
| A | 19 | 8 |
| B | 13 | 22 |
| C | 3 | 11 |
| D | 24 | 17 |
| E | 1 | 18 |
| F | 2 | 15 |
| G | 15 | 5 |
| H | 6 | 19 |
| I | 18 | 10 |
| J | 17 | 20 |

Table 2 Characteristics of pickup/delivery trucks

| Capacity of truck (ton) | Passenger car equivalence (pcu/veh.) | Operating cost (yen/10 min.) | Fixed cost (yen/day) |
|---|---|---|---|
| 2 | 1 | 140.2 | 10,417.5 |
| 4 | 1.5 | 175.4 | 11,523.1 |
| 10 | 2 | 232.7 | 13,789.7 |

Three types of time windows were permitted in this study, time windows with one hour, time windows for a.m. (9:00-12:00) or p.m.(13:00-17:00) and no time window. The type and starting time of each customers time window was based on a recent survey in Kobe and Osaka area. The dynamic traffic simulation provides the average travel time on each link for the scanning interval. In this study the scanning interval used was 30 minutes. When initially calculating the optimal routes and schedules, the average travel times on each link were assumed to be equal to the travel times using free running speeds.

The dynamic traffic simulation requires information on passenger car behaviour, as well as optimal routes and schedules of pickup/delivery trucks, produced by the VRPTW model. This includes the departure time and order of visiting customers. Passenger cars in this study include actual passenger cars and trucks other than those that are considered in the optimal routing and scheduling model. Passenger car Origin-Destination (OD) tables for every hour were estimated using traffic generation rates at each centroid and the probability of O-D choice. The number of passenger cars for each hour was generated using a temporal demand pattern based on a traffic census conducted in Kobe city. The probability of O-D choice was estimated using:

$$p_{ij} = \frac{q_i q_j}{l_{ij}^2} \tag{4}$$

where,

$p_{ij}$ : probability of choosing centroid $j$ for passenger car traffic generated at centroid $i$

$q_i$ : attraction rate of centroid $i$

$l_{ij}$ : distance between centroid $i$ and centroid $j$.

This is the gravity model for trip distribution. The validation of the model is given in some transportation engineering textbook (e.g. Khisty, 1990)

The highest level of attraction rate $(q_i = 4)$ was set for centroid (node) 18 in Figure 3, since this is assumed to be a central business district. Surrounding centroids 13, 14, 15, 17, 19, 20, 23 and 24 were set at the second level $(q_i = 3)$, outer centroids 8, 9, 10, 11, 12, 16, 22 and 25 at the third level $(q_i = 2)$ and others at the fourth level $(q_i = 1)$.

The recursive relationship between the dynamic traffic simulation and the optimisation of VRPTW (Figure 1) requires a stopping criterion for obtaining a solution. The following equation was used:

$$\sum_i \sum_k \left( \frac{T_{ki}^n - T_{ki}^{n-1}}{T_{ki}^n} \right)^2 \le 0.05 \tag{5}$$

where,

$T_{ki}^n$ : travel time on link $k$ for time interval $i$ at $n$ th iteration.

### 3.2 Results

#### 3.2.1 Simulating current traffic conditions

Firstly, hypothetical traffic conditions were simulated to provide a benchmark for estimating the benefits of introducing the advanced routing and scheduling systems. The optimisation model for VRPTW was applied to the test network. The value of the objective function for the chosen solution was 1.2 – 1.5 times higher than that of the best solution and the average load factor of trucks was around 20% lower than the best solution. The best solution is the solution that minimises the value of objective function. This discrepancy was based on the survey on the improvements found by several freight companies in Kobe City. This solution is assumed to represent the current pickup/delivery truck operations before introducing advanced systems. It is difficult to validate this solution as the current conditions. However, the pickup/delivery truck traffic was estimated to account for 14% of all traffic within the network. This percentage of pickup/delivery trucks is almost identical to the actual conditions within the Kobe area.

### 3.2.2 Effects of introducing advanced routing and scheduling system

The effects of freight carriers introducing Advanced Routing and Scheduling System (ARSS) on road traffic were investigated. The ARSS provides optimal routes and schedules using the VRPTW model described in the previous section. Three cases were considered, ARSS penetration rates of 0%, 50% and 100%. In the case of 50% penetration rate, freight carriers A, B, C, D and E shown in Table 1 introduced ARSS. The demand for freight transport at each customer was increased to 1.5 and 2.0 times the base case. The demand for freight transport in the base case was hypothetically set, as the distribution of demand coincides with the actual demand distribution given by survey in Osaka-Kobe area.

Figure 4 shows the effects of the penetration rate of ARSS on $CO_2$ emissions with the demand for freight transport. In Figure 4 both the change of $CO_2$ emissions and the demand for freight transport values are normalised by the value of base case. $CO_2$ emissions were determined using an established fuel consumption relationship. Fuel

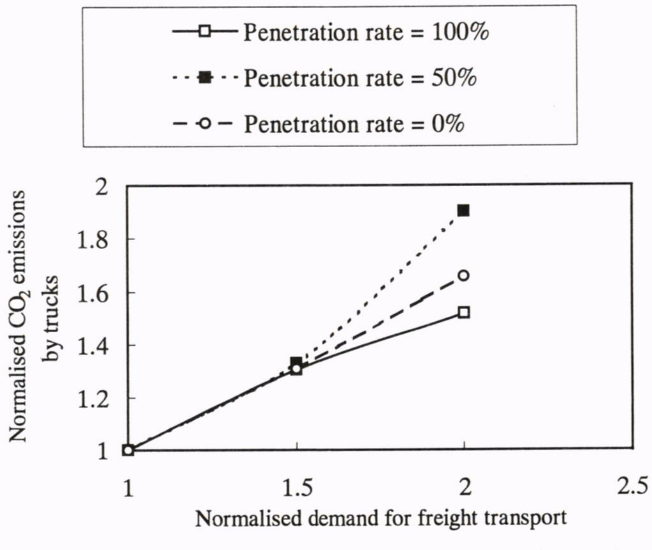


Figure 4 Effects of penetration rate of advanced routing and scheduling system on change in normalised $CO_2$ emissions with increasing demand for freight transport

consumption was estimated using the average travel speed of vehicles on each link. This estimation was carried out for passenger cars and pickup/delivery trucks respectively and then combined together. Figure 4 indicates that the normalised $CO_2$ emissions for the 100% penetration rate was reduced by 8.3% from that for the 0% penetration rate, when the demand was doubled. However, the normalised $CO_2$ emissions increased by 14% when the penetration rate was 50% compared with a zero penetration rate, when the demand was doubled. This is attributed to an increased use of larger trucks that produce more $CO_2$ emissions than smaller trucks. Table 3 shows the travel time for different types of trucks. Trucks with capacity of 10 tons travelled longer periods than the other smaller trucks when the penetration rate was 50% and the demand was double the base case. In Table 3 the total travel times of trucks for penetration rates of 50% and 100% are considerably lower that for the penetration rate of 0% in three cases of normalised demand. Therefore, it can be noted that ARSS helps alleviate traffic congestion.

Note, that $CO_2$ emissions significantly depend on the speed of vehicles. Therefore $CO_2$ emissions are not proportional to the distance travelled by vehicles.

Table 3 Change in travel time of different types of trucks by advanced routing and scheduling system

| Penetration rate of ARSS (%) | Capacity of truck (ton) | Normalised demand for freight transport 1.0 | 1.5 | 2.0 |
|---|---|---|---|---|
| 0 | 2 | 1,155 | 958 | 640 |
| | 4 | 1,249 | 1,424 | 1,291 |
| | 10 | 743 | 1,138 | 1,524 |
| | Subtotal | 3,147 | 3,520 | 3,455 |
| 50 | 2 | 1,600 | 930 | 732 |
| | 4 | 608 | 1,200 | 895 |
| | 10 | 713 | 986 | 1,584 |
| | Subtotal | 2,921 | 3,116 | 3,211 |
| 100 | 2 | 947 | 1,039 | 623 |
| | 4 | 1,164 | 851 | 976 |
| | 10 | 774 | 1,129 | 1,349 |
| | Subtotal | 2,885 | 3,019 | 2,948 |

(unit: min.)

### 3.2.3 Effects of co-operative freight transport system

There are various types of co-operative freight transport systems, for example, co-operation in building and operating a common depot, co-operation in carrying goods by common pickup/delivery trucks and co-operative use of information systems. Here, co-operation in carrying goods is examined as shown in Figure 5. This figure demonstrates co-operation between two freight carriers D and H, with each freight carrier having numerous customers to visit. In this co-operative freight transport system, each freight carrier collects goods from customers within its neighbourhood. As a result the total travel distance and the required number of trucks will be reduced. Here, it is assumed that ARSS is fully used by all ten freight carriers in both cases with and without co-operative freight transport.

Figure 6 shows the effects of co-operative freight transport system on the $CO_2$ emissions by freight carriers D and H who participate in the system with the increase of demand for freight transport. This figure demonstrates that the $CO_2$ emissions produced by freight carriers who participated in the co-operative system can be considerably reduced. The level of $CO_2$ emissions produced by these freight carriers involved in co-operation remains at almost at the same level as the base case when doubling the demand for freight transport, while it doubles from the base case without co-operation. Table 4 shows that total travel times for all truck types are reduced in all of the demand cases considered. This produces benefits relating to better traffic flow conditions on the network. In Figure 6 the $CO_2$ emissions with co-operation slightly decrease when the normalised demand keeps increasing after 1.5. It can be attributed to the reduction of travel time of 10-ton trucks that produce much more $CO_2$ emissions than small trucks as shown in Table 4. Table 5 shows the total costs of freight carriers D and H. The total costs are reduced by 23-29% after implementing a co-operative freight transport system for the three demand levels. Therefore, co-operative freight transport systems are effective in reducing costs at various levels of demand.

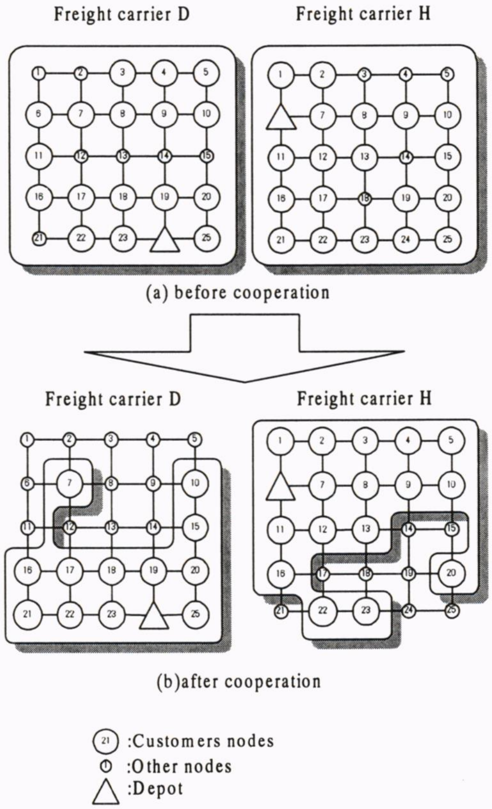


Figure 5 Change in customers to be visited by introducing a cooperative freight transport system

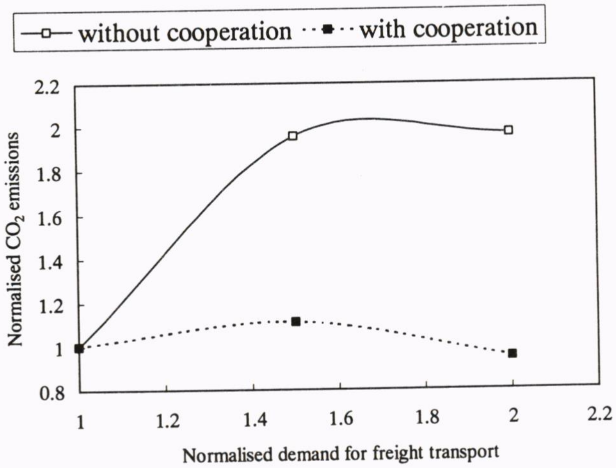


Figure 6 Effects of cooperative freight transport system on change in normalised $CO_2$ emissions by freight carriers D and H with increasing demand for freight transport

Table 4 Change in travel time of different types of trucks for freight carriers D and H by cooperative freight transport system

| | Capacity of truck (ton) | Normalised demand for freight transport 1.0 | 1.5 | 2.0 |
|---|---|---|---|---|
| Wighout coperation (min.) | 2 | 105 | 239 | 160 |
| | 4 | 368 | 0 | 170 |
| | 10 | 236 | 572 | 538 |
| | subtotal | 709 | 811 | 868 |
| With cooperation (min.) | 2 | 94 | 75 | 150 |
| | 4 | 160 | 177 | 152 |
| | 10 | 364 | 371 | 309 |
| | subtotal | 618 | 623 | 611 |
| Change by cooperation (%) | | -12.8 | -23.2 | -29.6 |

Table 5 Change in total cost of freight carriers D and H by cooperative freight transport system

| Normalised demand for freight transport | 1 | 1.5 | 2 |
|---|---|---|---|
| Cost without cooperation (yen) | 154,337 | 190,135 | 225,996 |
| Cost with cooperation (yen) | 118,218 | 139,257 | 159,853 |
| Change by cooperation (%) | -23.4 | -26.8 | -29.3 |

### 3.2.4 Effects of controlling load factor

An initiative of controlling load factors of pickup/delivery trucks is examined in this section. The average load factor of trucks is defined as follows:

$$F = \frac{\sum_l \sum_i W_{l,i}}{\sum_l W_{c,l} \cdot n_l} \tag{6}$$

where,
$W_{l,i}$ : load of vehicle $l$ with a load at $i$ th trip (kg)
$W_{c,l}$ : capacity of vehicle $l$ (kg)
$n_l$ : number of trips by vehicle $l$ with a load.
This load factor incorporates only vehicles travelling with a load.

First the load factor of the base case was calculated, in which ARSS is fully used by ten freight carriers, but no regulation for load factors was applied. The average load factor defined by equation (6) that excludes vacant truck was 37.6% in base case, ranging from 33.9% for the worst freight carrier to 45.1% for the best freight carrier. Then, three cases of regulating the load factor were investigated:

Case (1): The average load factor must be over 35%
Case (2): The average load factor must be over 37.5%
Case (3): The average load factor must be over 40%

Results showed that the average load factor increased to 43.9% for case (1), 44.8% for case (2), and 46.1% for case (3) as shown in Table 6. The average load factor for the base case (no regulation) was 37.6%. Therefore, the average load factor was eventually improved from base case by 6.3 points, 7.2 points, and 8.5 points for cases (1), (2) and (3) respectively. Table 6 shows the maximum load factor that is defined as the average of the maximum value of the load factor of a vehicle in the travel chain from and to the depot. The maximum load factor also improved with the increase in the average load factor.

Figure 7 shows the effects of controlling load factors on $CO_2$ emissions produced by pickup/delivery trucks with increasing demand for freight transport. This figure highlights a clear reduction of $CO_2$ emissions by restricting the average load factor to be above a certain level. $CO_2$ emissions increase by up to 1.7 times when the demand is double the base case without regulation, but rise only 1.4 times when the average load factor is over 35%. Therefore, controlling the average load factor of pickup/delivery trucks is an

Table 6 Load factor of pickup/delivery trucks

| Regulation | Type of load factor | Normalised demad for freight transport | | |
|---|---|---|---|---|
| | | 1 | 1.5 | 2 |
| No regulation | Average (including vacant truck) | 22.6 | 24.2 | 25.9 |
| | Average (excluding vacant truck) | 30.5 | 34.3 | 37.6 |
| | Maximum | 46.1 | 46.9 | 51.1 |
| Over 35% | Average (including vacant truck) | 28.2 | 27.2 | 30.5 |
| | Average (excluding vacant truck) | 38.7 | 38.4 | 43.9 |
| | Maximum | 53.4 | 55.4 | 60.4 |
| Over 40% | Average (including vacant truck) | n.a. | 31.0 | 30.1 |
| | Average (excluding vacant truck) | n.a. | 42.6 | 46.1 |
| | Maximum | n.a. | 58.3 | 64.2 |

(unit: %)

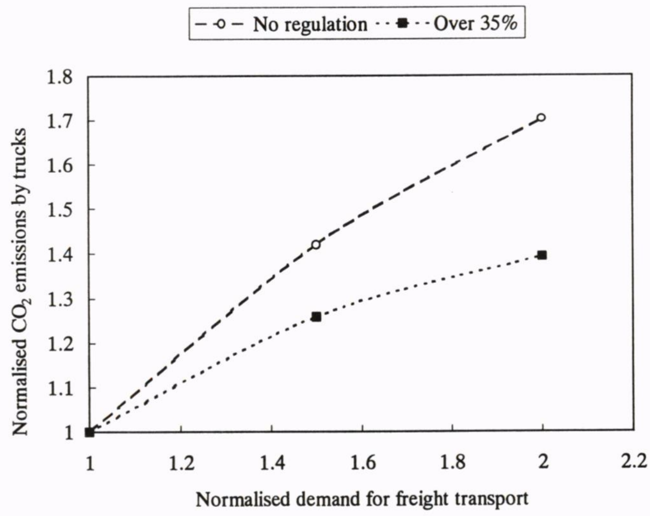


Figure 7 Effects of controlling load factor on normalised change in $CO_2$ emissions by trucks with increasing demand for freight transport

Table 7 Change in cost by controlling load factor

| | Normalised demand fro freight transport | | | | | |
|---|---|---|---|---|---|---|
| | 1.0 | | 1.5 | | 2.0 | |
| | Cost (yen) | Change from base case (%) | Cost (yen) | Change from base case (%) | Cost (yen) | Change from base case (%) |
| No regulation | 511,272 | | 612,970 | | 629,608 | |
| Over 35% | 527,556 | 3.2 | 611,485 | -0.2 | 621,288 | -1.3 |
| Over 40% | n.a. | | 594,520 | -3.0 | 640,001 | 1.7 |

effective measure to depress the increasing $CO_2$ emissions associated with the increase of demand for freight transport. The total costs for freight carriers change slightly and are within the range of –3.0 - +3.2% as shown in Table 7.

Actually the load factor controls have been implemented as test cases in Amsterdam and Copenhagen since 1998. In Amsterdam the police is in charge of checking the load factor of trucks on roads. In Copenhagen the city authority can check the load factor of each truck of the companies that participate in the project. These companies need to present a report on the load factor every month and then they are allowed to use public loading/unloading space in the city centre.

## 4. CONCLUSIONS

This paper presented a methodology for evaluating several city logistics initiatives using dynamic traffic simulation with optimal truck routing and scheduling. This methodology was applied to a test road network and three city logistics initiatives were evaluated: (1) Introducing advanced routing and scheduling system, (2) Implementing co-operative freight transport system, and (3) Controlling the load factors of pickup/delivery trucks in urban areas. The main criterion for the evaluation used in this paper was $CO_2$ emissions produced by pickup/delivery trucks when the demand for freight transport at customers was increased. The following findings were derived from the evaluation of three city logistics initiatives.

(1) Introducing advanced routing and scheduling systems helps reduce $CO_2$ emissions when the demand for freight transport increased. The normalised $CO_2$ emissions reduced by 8.3% when the penetration rate rose to 100% from 0%, when the demand level was doubled.

(2) Co-operative freight transport systems can considerably reduce $CO_2$ emissions by reducing the distance travelled by trucks. $CO_2$ emissions produced by freight carriers with co-operation remained at almost same level as base case when the demand for freight transport was doubled, while they increased to almost double the base case without co-operation. The co-operative freight transport system was effective not only in reducing the total costs of freight carriers but also in alleviating the environmental impacts of urban freight transport.

(3) Controlling load factors of pickup/delivery trucks also produces benefits by reducing the total costs and $CO_2$ emissions. This measure is expected to help depress the rate of $CO_2$ emissions associated with the increase of demand for freight transport.

Therefore, all three city logistics initiatives were found to be effective for reducing the increase in total costs of freight carriers and the $CO_2$ emissions produced by pickup/delivery trucks for increasing levels of demand for freight transport. There should be some relationship among these three initiatives. Further investigations are required to identify the relationship when implementing some of these initiatives together.

The conclusions described here are based on the case studies on a test road network. Further investigations will be necessary to compare these results with actual conditions in Kobe City. Moreover, further in-depth studies are required to generalise these results to be applicable in other situations.

The methodology presented in this paper allows city planners to quantitatively evaluate the environmental impacts of city logistics initiatives with increasing levels of urban freight transport.

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