MODELS FOR EVALUATING CITY LOGISTICS MEASURES

Eiichi TANIGUCHI
Associate Professor
Department of Civil Engineering,
Kyoto University
Yoshidahomachi, Sakyo-ku, Kyoto,
606-8501, Japan
Fax: +81-75-753-5907
E-mail: taniguchi@urbanfac.kuciv.kyoto-u.ac.jp

Tadashi YAMADA
Associate Professor
Department of Social and Environmental Engineering,
Hiroshima University
1-4-1 Kagamiyama, Higashi-Hiroshima,
739-8527 Japan
Fax: +81-824-22-7194
yamada@naoe.hiroshima-u.ac.jp

Yasushi KAKIMOTO
Graduate student
Department of Civil Engineering
Kyoto University
Yoshidahomachi, Sakyo-ku, Kyoto,
606-8501, Japan
Fax: +81-75-753-5907
E-mail: kakimoto@urbanfac.kuciv.kyoto-u.ac.jp

Abstract: This paper presents a mathematical model for evaluating City Logistics measures with advanced vehicle routing and scheduling as well as dynamic traffic simulation. The model was applied to a realistic large scale road network for Kobe City, Japan. The performance of three City Logistics measures, advanced vehicle routing and scheduling systems, co-operative freight transport systems and load factor controls were assessed in terms of total costs, operation times and CO_2 emissions by pickup/delivery trucks operations within the network. Results indicated that each of these measures were not only effective for reducing total costs but also operation times and CO_2 emissions. The methodology presented in this paper allows city planners to quantitatively evaluate City Logistics measures.

Key Words: City Logistics, vehicle routing and scheduling, freight transport, environment, evaluation

1. INTRODUCTION

1.1 City Logistics

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.

Some researchers (e.g. Ruske, 1994; Kohler, 1997; Taniguchi and van der Heijden, 2000; Taniguchi *et al.*, 2001) have proposed the idea of "City Logistics" to solve these difficult problems. City Logistics can be defined as, "the process for totally optimising the logistics and transport activities by private companies in urban areas considering the traffic environment, the traffic congestion and the energy savings within the framework of a market economy" (Taniguchi *et al.*, 1999a). Although some of City Logistics measures listed below have only been proposed, others have already been implemented in several cities.

(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.*, 1999b)
(d) Load factor controls
(e) Underground freight transport systems (e.g. Koshi *et al.*, 1992; Ooishi and Taniguchi, 1999; Visser; 1997, Duin, 1998).

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

1.2 Evaluation Criteria for City Logistics Measures

This paper focuses on the evaluation of three of the five City Logistics measures 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 measures 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 measures on congestion as well as the environmental impacts. The total operation time and the CO_2 emissions produced by pickup/delivery trucks are the primary indicators used in the evaluation.

1.3 Vehicle 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 measures 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 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 measures, 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 operation times and 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.

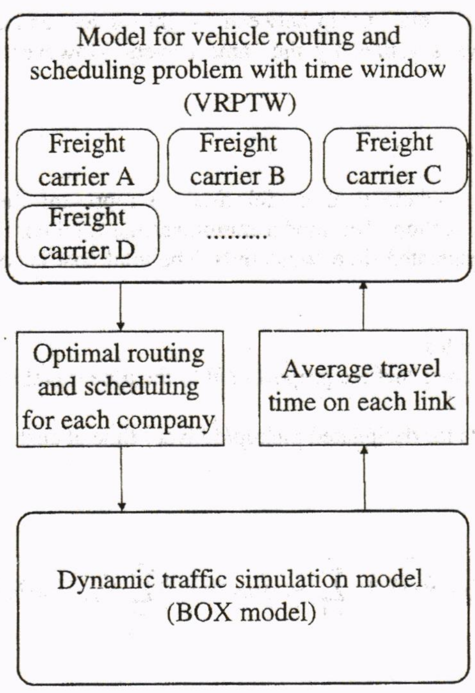

Figure 1. Model framework

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 delivers 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 tours 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 incorporates 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.

Sometimes there is a special relationship between freight carriers and customers such that a customer hopes to be always visited by the same drivers. However, this model does not account for such cases.

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 operation costs that are proportional to the time travelled and spent waiting at customers
(c) Delay penalty costs for designated pickup/delivery time at customers.

Minimise

$$C(t_0, \mathbf{X}) = \sum_{l=1}^{m} c_{f,l} \cdot \delta_l(\mathbf{x}_l) + \sum_{l=1}^{m} C_{t,l}(t_{l,0}, \mathbf{x}_l) + \sum_{l=1}^{m} C_{p,l}(t_{l,0}, \mathbf{x}_l) \tag{1}$$

where,

$$C_{t,l}(t_{l,0}, \mathbf{x}_l) = c_{t,l} \sum_{i=0}^{N_l} \left\{ \bar{T}(\bar{t}_{l,n(i)}, n(i), n(i+1)) + t_{c,n(i+1)} \right\} \tag{2}$$

$$C_{p,l}(t_{l,0}, \mathbf{x}_l) = \sum_{i=0}^{N_l} \left[c_{d,n(i)} \cdot \max\left\{0, t^a_{l,n(i)}(t_{l,0}, \mathbf{x}_l) - t^e_{n(i)}\right\} + c_{e,n(i)} \cdot \max\left\{0, t^s_{n(i)} - t^a_{l,n(i)}(t_{l,0}, \mathbf{x}_l)\right\}\right] \tag{3}$$

Subject to

$$n_0 \geq 2 \tag{4}$$

$$\sum_{l=1}^{m} N_l = N \tag{5}$$

$$\sum_{n(i) \in \mathbf{x}_l} D(n(i)) = W_l(\mathbf{x}_l) \tag{6}$$

$$W_l(\mathbf{x}_l) \leq W_{c,l} \tag{7}$$

$$t_s \leq t_{l,0} \tag{8}$$

$$t'_{l,0} \leq t_e \tag{9}$$

where,

$$t'_{l,0} = t_{l,0} + \sum_{i=0}^{N_l} \left\{ \bar{T}(\bar{t}_{l,n(i)}, n(i), n(i+1)) + t_{c,n(i+1)} \right\} \tag{10}$$

where,

$C(t_0, \mathbf{X})$: total cost (yen)

t_0: departure time vector for all vehicles from the depot

$t_0 = \{t_{l,0} \mid l=1, m\}$

$\mathbf{X}$: assignment and order of visiting customers for all vehicles

$\mathbf{X} = \{\mathbf{x}_l \mid l=1, m\}$

$\mathbf{x}_l$: assignment and order of visiting customers for vehicle l

$\mathbf{x}_l = \{n(i) \mid i = 1, N_l\}$

$n(i)$: i th customer visited by a vehicle

$d(j)$: number of the depot (= 0)

N_l: total number of customers visited by vehicle l

n_0: total number of $d(j)$ in $\mathbf{x}_l$

m : maximum number of vehicles available

$c_{f.l}$: fixed cost for vehicle l (yen /vehicle)

$\delta_l(\mathbf{x}_l)$: = 1; if vehicle l is used

= 0; otherwise

$C_{t.l}(t_{l,0}, \mathbf{x}_l)$: operation cost for vehicle l (yen)

$C_{p.l}(t_{l,0}, \mathbf{x}_l)$: penalty cost for vehicle l (yen)

$c_{t.l}$: operation cost per minute for vehicle l (yen /min)

$t_{l,n(i)}$: departure time of vehicle l from customer $n(i)$

$\bar{T}(\bar{t}_{l,n(i)}, n(i), n(i+1))$: average travel time of vehicle l between customer $n(i)$ and $n(i+1)$ at time $\bar{t}_{l,n(i)}$

$t_{c,n(i)}$: loading/unloading time at customer $n(i)$

$c_{d,n(i)}(t)$: delay penalty cost per minute at customer $n(i)$ (yen/min)

$c_{e,n(i)}(t)$: early arrival penalty cost per minute at customer $n(i)$ (yen/min)

N : total number of customers

$D(n(i))$: demand of customer $n(i)$ (kg)

$t'_{l,0}$: last arrival time of vehicle l at the depot

t_s : earliest time for starting truck operations

t_e : latest time for starting truck operations

$W_l(\mathbf{x}_l)$: load of vehicle l (kg)

$W_{c,l}$: capacity of vehicle l (kg)

The problem specified by equations (1) - (9) 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.

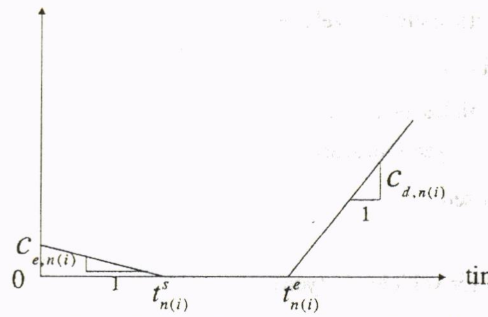

Figure 2. Cost function for soft time windows

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 techniques 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 good 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 parent's 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, which is the maximum flow during a scanning interval is the same for all sections on links and no inflow and outflow is allowed within 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 units (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. EVALUATION OF CITY LOGISTICS MEASURES FOR THE KOBE CITY NETWORK

3.1 Overview

The model described above was applied to a road network of Kobe City for evaluating three City Logistics measures including advanced vehicle routing and scheduling systems, co-operative freight transport systems and the control of load factors. The results were compared with and without these measures in terms of total costs, total operation times and

CO_2 emissions.

3.2 Data

The vehicle routing and scheduling model described in the previous section was applied to the road network in Kobe City, Japan. This case study aims at analysing the effects of implementing the model to an actual road network. In particular emphasis is on the reduction of costs, operation times and CO_2 emissions by introducing several City Logistics measures.

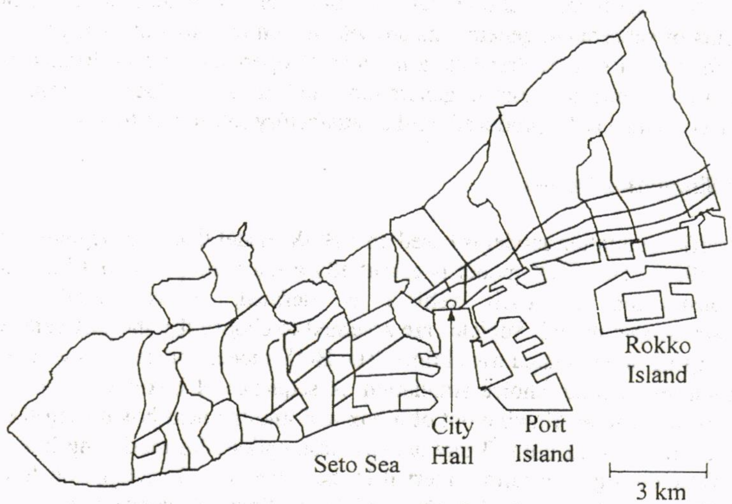

Figure 3. The central area of Kobe City studied in the evaluation

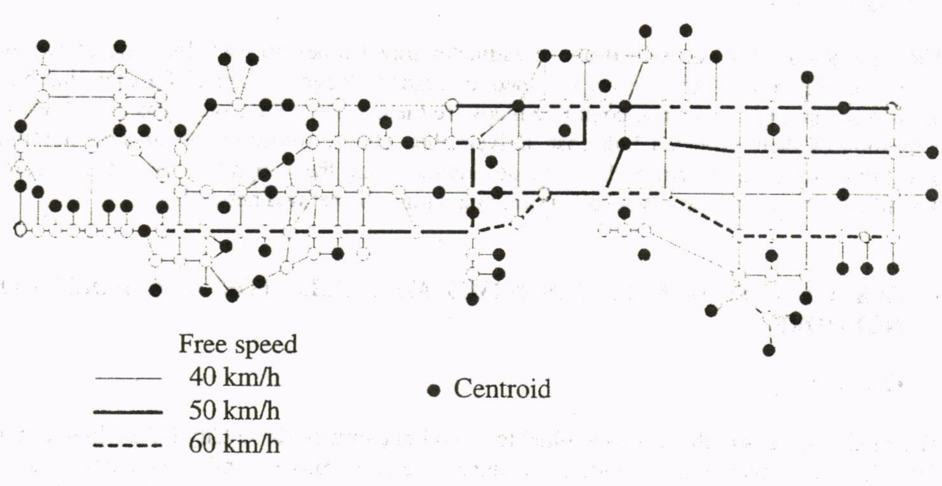

Figure 4. Road network of central area of Kobe City used in the evaluation
(107 nodes and 230 links)

Kobe City is located in West Japan, facing the Seto Sea. Its population is 1.43 million (1997). The city is the economic and cultural centre of Hyogo Prefecture. This case study deals with six wards in the central area of Kobe City. Figure 3 shows the study area. The zone with the city hall indicates the centre of city and many houses and offices are located along with the coastline. Sixty-seven zones were defined in this area, which reflects the same zoning as used in the survey of urban goods movements in Kyoto-Osaka-Kobe area in 1995. These zones are units for generation and attraction of passenger car and truck traffic. Figure 4 shows the road network used for the investigation. This network contains 107 nodes, including 67 centroids that generate and attract traffic, and 230 links. A centroid was placed in an appropriate central point such as town hall, university, and shopping centre within each zone described above. The free speed of trunk roads in the network was assumed to be 50 km/h and 60 km/h and that of other roads was 40 km/h as shown in Figure 4. Note, that this road network in Figure 4 only contains main roads in this area. Therefore, it is assumed that a link represent a group of real roads connecting two nodes.

There exist O-D traffic data for passenger cars in Kobe City given from the road traffic census in 1994. This data was rearranged for smaller zones as shown in Figure 3 than the census zones in proportion to the population within each zone. The generation of passenger cars for every hour was given as shown in Figure 5. The data is based on real observations on the national highway in Kobe City.

This case study used the freight demand data from the survey of goods movements in Kyoto-Osaka-Kobe area in 1995. The database provided us with trip chain records of pickup/delivery trucks. It includes; (a) the location of depot and customers, (b) the route, the arrival and departure time and the capacity of trucks and (c) the amount of loads transported. The trip chains whose depot and customers are located within the study area shown in Figure 4 were selected for the analysis. As many of trip chains were for delivering goods to customers, the data of delivering goods were selected. The investigation for freight carriers in the same survey specified the time windows at customers. Consequently, 81 freight carriers, who operated 200 pickup/delivery trucks, were chosen. The data indicates the current conditions of truck operations. Then the calculation and comparison with the current conditions can estimate the benefits of implementing advanced vehicle routing and scheduling plan with models. Note, that the data is based on a limited sample size and this was enlarged to apply the simulation on the actual road network.

Since the data used here provides specific trip chains of each truck, they are suitable for examining the co-operative freight transport systems. The data does not contain information on the precise route of each truck. Therefore, the shortest route was searched for given origin and destination.

The costs for operating trucks were identified based on a survey of typical Japanese freight carriers. The trucks in this study were categorised into 3 groups: (a) trucks with the capacity less than 2 tons are taken as 2-ton trucks, (b) those between 2 and 4 tons are taken as 4-ton trucks, (c) those over 4 tons are taken as 10-ton trucks. The fixed cost for 2, 4 and 10-ton trucks is 10,417.5 yen/day, 11,523.1 yen/day and 13,789.7 yen/day, respectively. The operation cost for 2, 4 and 10-ton trucks is 14.02 yen/min, 17.54 yen/min and 23.27 yen/min. The penalty cost was set 87 yen/min that is 5 times larger than the operation cost of 4-ton trucks. This is based on the survey of freight companies in Kobe City.

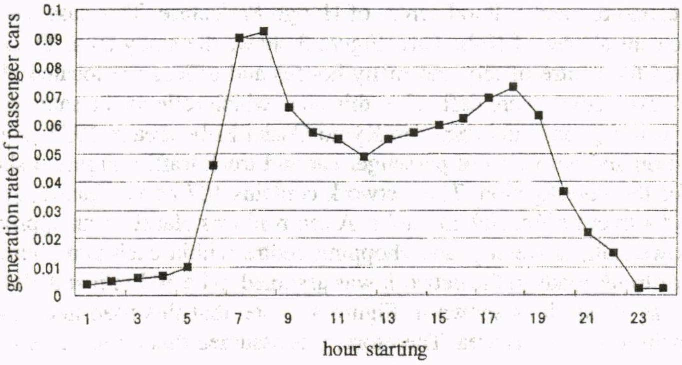

Figure 5. Generation rate of passenger cars

3.2 City Logistics Measures

Three City Logistics measures were taken into account in this study: (a) Advanced vehicle rounting and scheduling systems (AVRS), (b) Co-operative freight transport systems and (c) Load factor controls.

(Case A) Advanced vehicle rounting and scheduling systems (AVRS)
Advanced vehicle rounting and scheduling systems (AVRS) allow freight carriers to optimise their delivery systems in urban areas. As the current status of picking-up and deliverying goods is inefficient, it can be optimised using the advanced vehicle rounting and scheduling model described in the previous section. It is assumed that each freight carrier can transport all kinds of goods together that they have been carrying.

(Case B) AVRS and Co-operative freight transport systems
There are many types of co-operative freight transport systems depending on the stakeholders, depots, commodities and information systems. This study adopted the following type of co-operation between freight carriers.

- Freight carriers who are located at the same node in Figure 4 can consider co-operation
- The number of customers to be visited by pickup/delivery trucks is less than 25 for simplicity of calculation.
- More than 2 freight carriers can participate in co-operation
- All pickup/delivery trucks of the participants that have been used separately can be used together in co-operative freight transport systems
- Any kinds of companies can participate in co-operation

Under these conditions, 33 freight carriers out of 81 have been chosen to participate in co-operative freight transport systems. Two companies formed co-opertaion at 12 nodes and 3 companies co-operated at 3 nodes.

(Case C) AVRS and Load factor controls
This measure is aiming at alleviating traffic congestion by setting a lower limit of the

maximum load factor of pickup/delivery trucks in urban areas. In this study a large penalty (1,000 Japanese yen/kg) was imposed for a truck whose maximum load factor is less than 60% within the network. The maximum load factor can be defined that the percentage of maximum load in a vehicle during operation to the capacity of vehicle.

3.3 Results

Table 1 shows the change in total costs by implementing City Logistics measures. It indicates that implementing AVRS can considerably decrease the total costs of deliverying goods

Table 1. Change in total costs by implementing City Logistics measures

		Case A	Case B	Case C
	Current status	AVRS	AVRS + Co-operation	AVRS + Load factor control
Fixed cost	102,338	47,212	43,189	49,200
Change (%)		-53.9	-57.8	-51.9
Operation cost	39,202	27,965	27,388	28,432
Change (%)		-28.7	-30.1	-27.5
Early arrival penalty	4,587	212	176	363
Change (%)		-95.4	-96.2	-92.1
Delay penalty	47,116	49,259	53,944	62,496
Change (%)		4.5	14.5	32.6
Total	193,243	124,648	124,697	140,490
Change (%)		-35.5	-35.5	-27.3

"Change" indicates the change from current status. unit: thousand yen /day

Compared with the current status. In particular, the fixed cost decreased by 53.9% due to the reduction on number of pickup/delivery trucks using for deliverying goods (See Table 3) . Regarding the penalty, the early arrival penalty is almost deminished compared with current status, whereas the delay penalty slightly increased. This is attributed to the reduction of number of pickup/delivery trucks. In Case B of implementing AVRS and co-operation, both fixed and operation costs were further reduced compared with Case A. Therefore, co-operative freight transport systems were effective to the cost reduction. However, since the delay penalty increased, the total cost in Case B remained at the same level as Case A. In Case C the cost reduction was not fully achieved as in Cases A and B, since this load factor regulation forced freight carriers to use their trucks somewhat inefficiently to keep the load factor of trucks over 60%. The delay penalty in Case C was larger than Cases A and B, which means lower level of service in keeping with the designated time windows at customers in Case C.

Note, that the cost reduction shown in Table 1 indicates the maximum value of the case in which all freight carriers introduced AVRS and other City Logistics measures. Such cases are ideal cases. In reality, there must be difficulty to dissemminate AVRS throughout the freight carriers within the network.

Table 2. Change in operation times by implementing City Logistics measures

		Current status	Case A AVRS	Case B AVRS + Co-operation	Case C AVRS + Load factor control
Passenger cars		119,781	118,209	118,379	118,053
Change (%)			-1.3	-1.2	-1.4
Trucks	Running time	12,330	7,189	6,792	6,874
	Change (%)		-41.7	-44.9	-44.3
	Waiting time	5,714	261	258	440
	Change (%)		-95.4	-95.5	-92.3
Subtotal		18,044	7,451	7,050	7,314
Change (%)			-58.7	-60.9	-59.5
Total		137,824	125,659	125,429	125,367
Change (%)			-8.8	-9.0	-9.0

"Change" indicates the change from current status. unit: hour/day

Table 2 shows the change in operation times of pickup/delivery trucks as well as travel times of passenger cars. In all three cases the total operation times decreased due to implementing City Logistics measures. In particular the subtotal operation times of trucks decreased almost by 60%. This reduction of operation times can contribute toward alleviating traffic congestion and improving the environment. The running time of trucks was substantially reduced by 41.7% in Case A and an additional reduction was observed in Case B where co-operative systems were introduced. The load factor contol as seen in Case C, was also more effective decreasing the running time compared with Case A. The reduction of waiting time in these three cases should get special attention from the viewpoint of congestion, because trucks waiting nearby customers usually are an impediment against smooth traffic flow of other vehicles.

Table 3. Change in the number of pickup/delivery trucks by implementing City Logistics measures

maximum capacity of trucks a (ton)	Current status	Case A AVRS	Case B AVRS + Co-operation	Case C AVRS + Load factor control
0 - 4	6,947	3,054	2,695	3,098
Change (%)		-56.0	-61.2	-55.4
4 - 10	701	402	391	461
Change (%)		-42.7	-44.3	-34.3
over 10	1,575	773	762	830
Change (%)		-51.0	-51.6	-47.3
Total	9,223	4,229	3,847	4,389
Change (%)		-54.2	-58.3	-52.4

"Change" indicates the change from current status. unit: vehicles

Table 3 demonstrates the change in the number of pickup/delivery trucks by implementing City Logistics measures. The substantial reduction of the number of trucks were obtained in the three cases. A smaller number of trucks were used, the lower costs were achieved for carrying the same loads of goods as seen in Table 1. Comparing Cases A and B indicates an important fact that the co-operation can contibute to obtain larger reduction of number of trucks in all types of trucks. This led to the lower figures in fixed and operation costs in Case B in Table 1. On the contrary Case C indicates that the load factor control generates a small increase in the number of trucks, compared with Case A.

Table 4. Change in average load factor of pickup/delivery trucks by implementing City Logistics measures

		Case A	Case B	Case C
	Current status	AVRS	AVRS + Co-operation	AVRS + Load factor control
Average load factor (%)	29.9	46.1	47.4	50.1
Change (%)		54.4	58.7	67.7

"Change" indicates the change from current status.

Table 4 indicates the change in the average load factor of pickup/delivery trucks by implementing City Logistics measures. Obviously Case C resulted in the highest load factor in three cases. The average load factor remained about 50% in Case C, although the maximum load factor of trucks was regulated to be over 60%. The maximum load factor can be measured when the truck starts from depot for delivering goods to customers. It is interesting that the average load factor in Cases A and B became much higher than current status and close to Case C. This implies that AVRS is very powerful in producing efficient vehicle routing and scheduling with higher load factors of trucks.

Table 5. Change in CO_2 emissions by implementing City Logistics measures

		Case A	Case B	Case C
	Current status	AVRS	AVRS + Co-operation	AVRS + Load factor control
Passenger cars	174.1	173.3	173.6	173.2
Change (%)		-0.4	-0.3	-0.5
Trucks	42.2	29.5	28.3	28.3
Change (%)		-30.2	-33.0	-32.9
Total	216.3	202.8	201.8	201.6
Change (%)		-6.2	-6.7	-6.8

"Change" indicates the change from current status. unit: ton-C/day

The CO_2 emissions are of impotance in relation to greenhouse effects on the global warming problem. Table 5 shows the CO_2 emissions in three cases. The CO_2 emissions were determined using an established fuel consumption relationship. Fuel consumption was estimated using the average travel speed of vehicles on each link. This table clearly indicates that the total CO_2 emissions in Cases A, B and C reduced substantially by about 6%. For pickup/delivery trucks, CO_2 emissions were almost two thirds of current status in each of the three cases. If we compare Cases A and B, the co-operative systems in Case B can contribute to obtain further decrease in CO_2 emissions than Case A. As well the load factor controls in Case C was effective to reduce CO_2 emissions. Therefore, it can be stated that City Logistics measures in these three cases were effective not only for reducing freight costs but also for alleviating traffic congestion by decreasing the operation times as well as improving the environment.

4. CONCLUSIONS

A mathematical model was developed for evaluating City Logistics measures from various point of views. This model was composed of the vehicle routing and scheduling model and the dynamic traffic simulation model. The model was applied to a realistic road network of the central area in Kobe City, Japan. The following conclusions were derived from investigations on the traffic behaviour within the network.

(a) Three City Logistics measures, including advanced vehicle routing and scheduling systems, co-operative freight transport systems and load factor controls, are effective not only to reduce the total costs but also to decrease the operation times and CO_2 emissions. Therefore, these measures can contribute to the establishment of efficient and environmental friendly logistics systems in urban areas.

(b) Advanced vehicle routing and scheduling systems (AVRS) are a most powerful tool for reducing the total costs that can be generated by the reduction of number of trucks and optimisation of visiting order of customers and route choice. Co-operative freight transport systems and load factor controls are also effective for obtaining further reduction of total costs than AVRS.

This study deals with the realistic truck operations in real road network. However, there are some limitations of the model. Further investigations are required to cope with more realistic cases: for example, (a) multi-commodity flows, (b) variable travel times on each link of the network. Some additional costs could be taken into account for the practical application including: (a) costs for installing advanced information systems, (b) costs for participating the co-operative freight transport systems and (c) administrative costs for enforcing the load factor controls.

REFERENCES

Bramel, J. and Simchi-Levi, D. (1996) Probabilistic analysis and practical algorithms for the vehicle routing problem with time windows. **Operations Research 44**, 501-509.

Duin, J.H.R. van (1997) Evaluation and evolution of the city distribution concept. **3rd International Conference on Urban transport and the Environment for the 21st Century**, Terni, Italy, pp. 327-337.

Duin, J.H.R. van (1998) Simulation of underground freight transport systems. **4th International Conference on Urban transport and the Environment for the 21st Century,** Lisbon, Portugal, pp. 149-158.

European Commission, Directorate General for Transport (1997) Urban goods transport. final report of COST 321.

Fujii, S., Iida, Y. and Uchida, T. (1994) Dynamic simulation to evaluate vehicle navigation. **Vehicle Navigation & Information Systems Conference Proceedings**, pp. 239-244.

Gendreau, M., Laporte, G. & Potvin, J.-Y. (1997) Vehicle routing: modern heuristics, Chapter 9. In E. Aarts & J. K. Lenstra (eds.) **Local search in combinatorial Optimization**, John Wiley & Sons, pp. 311-336.

Janssen, B.J.P., and Oldenburger, A.H. (1991) Product channel logistics and city distribution centers; the case of the Netherlands. **OECD Seminar on Future Road Transport Systems and Infrastructures in Urban Areas,** Chiba, Japan, pp. 289-302.

Khisty, C.J. (1990) **Transportation engineering**. Prentice Hall, Englewood Cliffs, New Jersey.

Kohler, U. (1997) An innovating concept for city-logistics. **4th World Congress on Intelligent Transport Systems**, Berlin, Germany, CD-ROM.

Kokubugata, H., Itoyama, H. & Kawashima, H. (1997) Vehicle routing methods for city logistics operations. **IFAC/IFIP/IFORS Symposium on Transportation Systems**, Chania, Greece, eds. M. Papageorgiou & A. Pouliezos, pp. 755-760.

Koshi, M., Yamada, H. and Taniguchi, E. (1992) New urban freight transport systems. **Selected Proceedings of 6th World Conference on Transport Research**, Lyon, France, pp. 2117-2128.

Koskosidis, Y.A., Powell, W.B. and Solomon M.M. (1992) An optimization-based heuristic for vehicle routing and scheduling with soft time window constraints. **Transportation Science 26**, 69-85.

Ooishi, R. and Taniguchi, E. (1999) Effects and profitability of constructing the new underground fright transport system. In: **City Logistics I**, 1st International Conference on City Logistics, Cairns, (E. Taniguchi and R.G. Thompson, eds.), Institute of Systems Science Research, Kyoto, pp.303-316.

Potvin, J.-Y., Kervahut, T., Garcia, B.-L. & Rousseau, J.-M. (1996) The vehicle routing problem with time windows; Part I: tabu search. **INFORMS Journal on Computing 8**, 158-164.

Ruske, W. (1994) City logistics --- Solutions for urban commercial transport by cooperative operation management. **OECD Seminar on Advanced Road Transport Technologies**, Omiya, Japan.

Russell, R.A. (1995) Hybrid heuristics for the vehicle routing problem with time windows. **Transportation Science 29**, 156-166.

Solomon, M. M. (1987) Algorithms for the vehicle routing and scheduling problems with time window constraints. **Operations Research 35**, 254-265.

Taniguchi, E., Yamada, T., and Yanagisawa, T. (1995) Issues and views on cooperative freight transport systems. **7th World Conference on transport Research**, Sydney, Australia.

Taniguchi, E., Yamada, T., Tamaishi, M and Noritake, M. (1998) Effects of designated time on pickup/delivery truck routing and scheduling. **4th International Conference on Urban transport and the Environment for the 21st Century,** Lisbon, Portugal, pp. 127-136.

Taniguchi, E., Thompson, R.G. and Yamada, T. (1999a) Modelling city logistics. In: **City Logistics I** (E. Taniguchi and R.G. Thompson, eds.), Institute of Systems Science Research, Kyoto, pp.3-37.

Taniguchi, E., Noritake, M., Yamada, T. and Izumitani, T. (1999b) Optimal size and location planning of public logistics terminals. **Transportation Research 35E(3)**, 207-222.

Taniguchi, E. and van der Heijden, R.E.C.M. (2000) An evaluation methodology for city logistics. **Transport Reviews**, **20(1)**, 65-90.

Taniguchi, E, Thompson, R.G., Yamada, T. and van Duin, R. (2001) **City Logistics --- Network Modelling and Intelligent Transport Systems**, Pergamon.

Thangiah, S. R., Nygard, K. E. & Juell, P. L. (1991) GIDEON: a genetic algorithm system for vehicle routing with time windows. **Seventh IEEE International Conference on Artificial Intelligence Applications,** IEEE Computer Society Press, Los Alamitos, CA, pp. 322-328.

Visser, J.G.S.N. (1997) Underground networks for freight transport: a dedicated infrastructure for intermodal short-distance freight transport. **Proceedings of 3rd TRAIL Year Congress on Transport, Infrastructure and Logistics**, Delft, The Netherlands.