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AN EVALUATION METHODOLOGY FOR URBAN FREIGHT POLICY MEASURES WITH EFFECTS OF E-COMMERCE

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Abstract

This paper presented a methodology of modelling to evaluate effects of policy measures by a city authority and countermeasures by freight carriers on urban freight transport with effects of e-commerce. Models were applied to a test road network in conditions that 10% of consumers use e-commerce for shopping. Results showed that the policy measures of implementing large truck ban or road pricing may increase total costs of trucks by retail shop delivery companies and home delivery companies. However, some countermeasures including co-operative freight transport systems, pickup points and consolidated time windows are effective not only to reduce total costs but also decrease travel times as well as CO2 and NOx emissions of trucks. Therefore, it is possible to establish efficient and environmentally friendly freight transport systems in urban areas, for cases that truck traffic is increased due to introducing B2C e-commerce.

Keywords: Models; Urban freight transport; Policy measures; E-commerce
Topic Area: B5 Urban Goods Movement

1. Introduction

Recently e-commerce has become popular with the rapid development and use of Internet for commerce. There are various types of e-commerce including B2B (Business to Business), B2C (Business to Consumers), C2C (Consumers to Consumers). For the traditional way of distribution, goods were transported from manufacturers to retailers via wholesalers, and consumers went to retail shops for purchasing commodities. In contrast for e-commerce of B2C goods can be directly transported from manufacturers to consumers by delivery companies based on the order from consumers via Internet. Therefore, it can be easily estimated that direct home delivery of goods by delivery companies will increase and person trips for shopping by private car will decrease with the deployment of e-commerce (B2C).

Visser *et al.* (2001) discussed effects of e-commerce on urban transport. They pointed out that e-commerce will stimulate home delivery which will lead to less consolidated deliveries thus to more freight traffic. More freight traffic is not good from the environmental and commercial point of views. The important factor is that home delivery based on e-commerce has very often time windows for delivery at each home. The designated time windows for home delivery will increase the urban freight transport by pickup/delivery trucks. However, less shopping traffic by car due to replacement of traditional shopping to e-shopping can relax the increase of urban truck traffic to some extent.

Regarding modelling effects of e-commerce on urban traffic, Thompson *et al.* (2001) presented a vehicle routing and scheduling model for evaluating effects on e-commerce on urban traffic in a hypothetical city. Taniguchi and Kakimoto (2003) also presented a probabilistic vehicle routing and scheduling model for evaluating effects on e-commerce on urban traffic in a test road network. They illustrated that introducing e-commerce (B2C) may lead to more traffic in urban areas and make negative impacts on the environment. However, some measures including co-operative freight transport systems of home delivery companies and designating time windows by home delivery companies and pickup points are effective to reduce the total costs as well as total running times and NOx emissions.

Following the results by Taniguchi and Kakimoto (2003), this paper tries to evaluate effects of some policy measures including large truck ban and road pricing on urban traffic and environment for relaxing the increase of traffic due to deployment of e-commerce (B2C). We will develop mathematical models for simulating urban traffic on road network and estimating the effects of policy measures by a city authority or other administrative agencies on urban transport. Taniguchi *et al.* (2001) proposed some city logistics measures for establishing efficient and environmentally friendly urban distribution systems. We will also examine the effects of some city logistics measures including co-operative freight transport systems, pickup points and relaxing the strict time windows by home delivery companies, for decreasing the negative impacts of e-commerce on the environment.

2. Probabilistic vehicle routing and scheduling model

2.1 Outline of model

This study adopts model for Vehicle Routing and scheduling Problems with Time Windows - Probabilistic (VRP-TW-P) (Taniguchi and Thompson (2002)) for evaluating the effects of policy measures on urban traffic. This model represents the behaviour of freight carriers who have their own depot and a multiple pickup/delivery trucks depart from the depot and visit some customers for collecting or delivering goods to return to the same depot. For developing models we assume:

a) The size, number and capacity of pickup/delivery trucks at the depot is known
b) The location of customers is known and the demands of customers are given
c) Only collection or delivery of goods will be carried out in an operation of a truck for visiting customers
d) Each customer identifies designated time window to be visited by a pickup/delivery truck

Figure 1 shows the model framework. The VRP-TW-P model takes into account the uncertainty of travel times on road network. This model intends to identify the optimal routing and scheduling for each delivery company. The distribution of travel times on each link of network can be given by traffic simulation model (BOX model) which will be described later. As Figure 1 indicates, updated travel times on each link will be used in the VRP-TW-P model again. Thus the iterative procedure will give a certain solution. As this procedure cannot guarantee the conversion, we need to determine a stopping criterion for iteration.

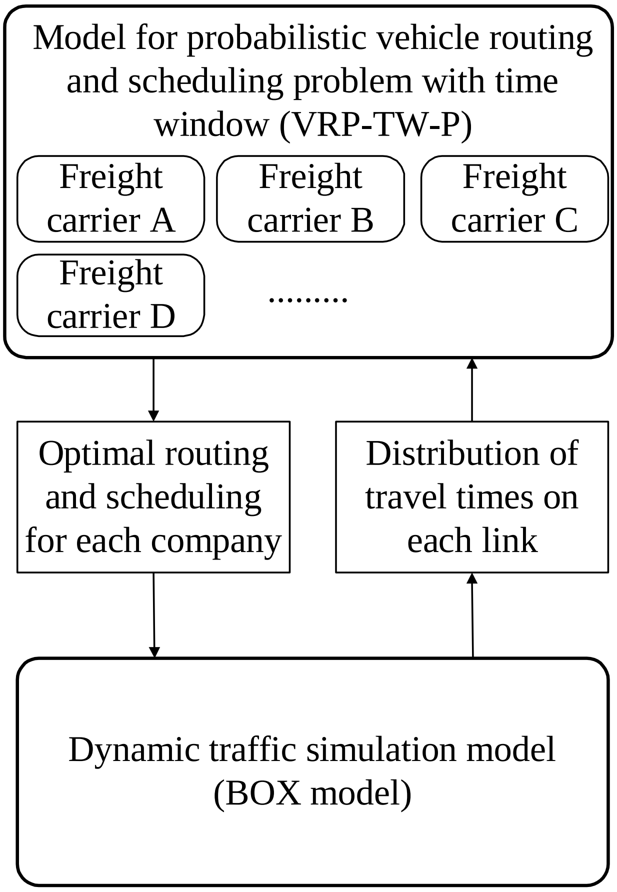

Figure 1. Model framework

2.1 Formulation of model

The VRP-TW-P model determines the optimal solution by minimising the total costs. The total costs are composed of three components; (a) the fixed cost of vehicles, (b) vehicle operating costs that are proportional to the time travelled, and (c) early arrival and delay penalties for designated pickup/delivery time at customers. The model can be formulated as follows:

Minimise

$$C(\boldsymbol{t}_0,\mathbf{X})=\sum_{l=1}^{m} c_{f,l}\cdot\delta_l(\mathbf{x}_l)+\sum_{l=1}^{m} E\left[C_{t,l}(t_{l,0},\mathbf{x}_l)\right]+\sum_{l=1}^{m} E\left[C_{p,l}(t_{l,0},\mathbf{x}_l)\right] \tag{1}$$

where,

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

$$E\left[C_{p,l}(t_{l,0},\mathbf{x}_l)\right]=\sum_{i=0}^{N_l}\int_0^{\infty} p_{l,n(i)}(t_{l,0},t,\mathbf{x}_l)\left\{c_{d,n(i)}(t)+c_{e,n(i)}(t)\right\}dt \tag{3}$$

Subject to

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

$$\prod_{l=1}^{m}\prod_{i=1}^{N_l}\{n(i)-k\}=0 \qquad \forall k=1,2,\cdots,N_l \tag{5}$$

$$\sum_{l=1}^{m} N_l = N \tag{6}$$

$$\sum_{n(i) \in \mathbf{x}_l} D(n(i)) = W_l(\mathbf{x}_l) \tag{7}$$

$$W_l(\mathbf{x}_l) \le W_{c,l} \tag{8}$$

$$t_s \le t_{l,0} \tag{9}$$

$$t'_{l,0} \le t_e \tag{10}$$

where

$$t'_{l,0} = t_{l,0} + \sum_{i=0}^{N_l} \left\{ \bar{T}(\bar{t}_{l,n(i)}, n(i), n(i+1)) + t_{c,n(i+1)} \right\} \tag{11}$$

$C(\boldsymbol{t}_0, \mathbf{X})$: total cost (yen)

$\boldsymbol{t}_0$: departure time vector for all vehicles at the depot

$\boldsymbol{t}_0 = \{ t_{l,0} \mid l = 1, m \}$

$\mathbf{X}$: 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

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

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

$d(j)$: number of 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

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

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

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

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

$p_{l,n(i)}(t_{l,0}, t, \mathbf{x}_l)$: probability in which a vehicle that departs the depots at time $t_{l,0}$ arrives at customer $n(i)$ at time t

$c_{d,n(i)}(t)$: 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 : starting of possible operation time of trucks

t_e: end of possible operation time of trucks

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

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

The problem specified by equations (1) – (11) involves determining the variable $\mathbf{X}$, that is, the assignment of vehicles and the visiting order of customers and the variable $\boldsymbol{t}_0$, the departure time of vehicles from the depot. Note, that $n(0)$ and $n(N_l+1)$ represent the depot in equations (2) and (3).

Figure 2 shows the penalty for vehicle delay and early arrivals at customers. The time period $(t^e_{n(i)} - t^s_{n(i)})$ of the penalty function defines the width of the soft time window in which vehicles are requested to arrive at customers. 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 during 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 goods distribution to shops and supermarkets in urban areas. Multiplying the penalty function and the probability of arrival time as shown in Figure 2 can identify the penalty of early arrivals and delay at customers for the probabilistic model.

The problem described here is a NP-hard (Non-deterministic Polynomial-hard) combinatorial optimisation problem. It requires heuristic methods to efficiently obtain a good solution. Recently several researchers have applied heuristic algorithms such as Genetic Algorithms (GA), Simulated Annealing (SA) and Tabu Search (TS) to obtain approximate solutions for NP-hard combinatorial optimisation problem. The model described in this paper uses a GA to solve the VRP-TW-P. 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.

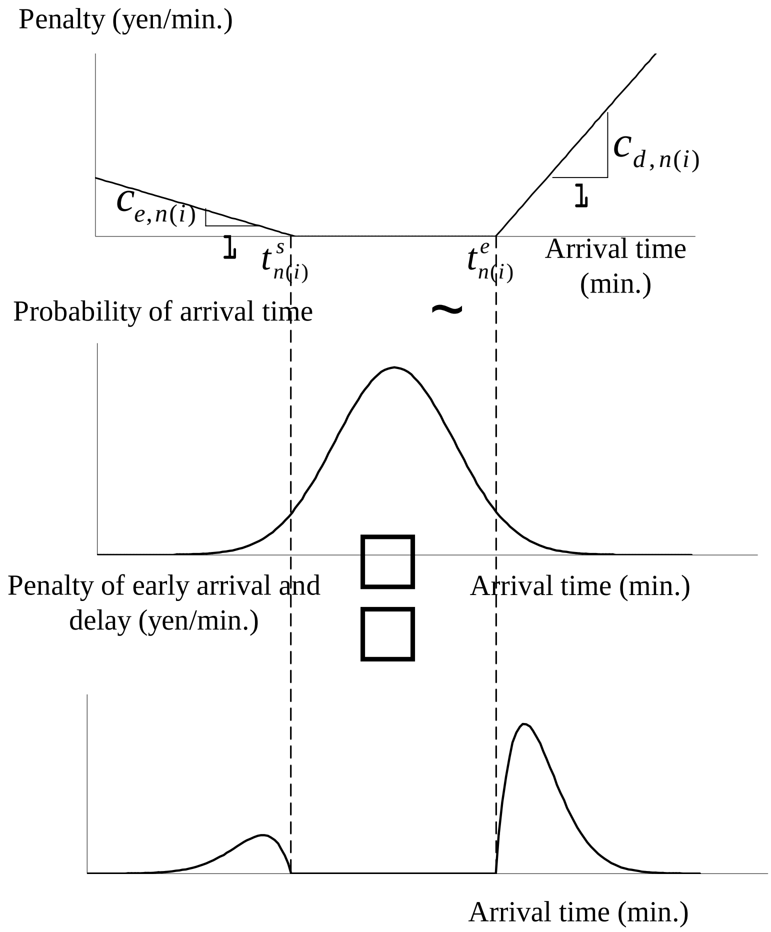

Figure 2. Penalty of early arrival and delay at customers for the probabilistic model

3. Dynamic traffic simulation model

The dynamic traffic simulation model is based on the BOX model that was originally developed by Fujii et al. (1994). The modified BOX model explicitly describes the flow of pickup/delivery trucks that depart from a depot and return to the same depot. Pickup/delivery trucks are converted to passenger car units and the first-in-first-out rule is assumed on all links. The model was further modified to identify the arrival of specific vehicles at assigned nodes (customers).

The travel times on each link vary within the day. The output of the BOX model is the updated distribution of travel times on each link. The BOX model calculates the distribution of travel times based on link travel times. The distribution of travel times representing the interval of one hour was formulated by using the four-hour data on travel times. For example, the distribution of travel times representing the time interval, 8:00-9:00 a.m. can be formulated by using data between 6:30 – 10:30 a.m. Then this empirical distribution was used in the VRP-TW-P model.

4. Case studies

4.1 Test conditions

Figure 3 shows test road network that was used for case studies. Main network has 25 nodes and 80 links. Each node of the main network has a sub network of 9 nodes and 24 links. All nodes in the main network represent centroid that generates and attracts passenger cars. It is assumed that retail shop is located at every node of main network and residents of sub network go for shopping to the retail shop. There are two types of areas on main network: (a) high population density area (node 7-19 in Figure 3) and (b) low population density area (other nodes in Figure 3). The high population density area contains 130-170 households per node and generates 220 vehicles/day per node, whereas the low population density area contains 80-120 households per node and generates 175 vehicles/day per node. The main network has 26,550 households in total. Consumers also live in node where a depot is located.

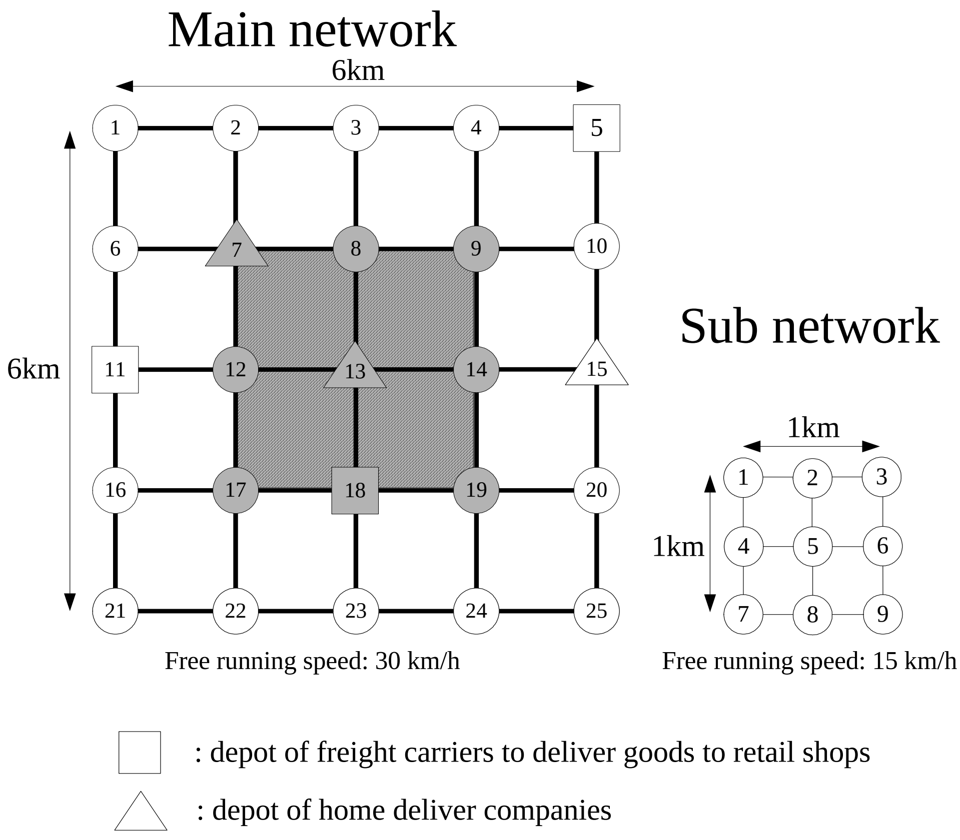

Figure 3. Test road network

It is assumed that the penetration rate of e-commerce is 10%. It means that 10% of residents use e-commerce and 90% of residents go for shopping to the retail shop that is located at the same node. The demand per household is assumed to be 5 kg and e-commerce users buy 50% of commodities (5 kg) via Internet and buy 50% of commodities (5 kg) by traditional shopping at the retail shop. Based on a survey on modal choice for daily shopping at Kyoto, we assumed that 70% of people go to the retail shop on foot or by bicycles, and 30% of people use cars.

4.2 Freight carriers

There are two types on freight carriers within the network: (a) retail shop delivery companies who deliver goods from their depots to retail shops and (b) home delivery companies who deliver goods from their depots to each home. Three freight carriers within the network, who deliver goods from their depots to retail shops, operate 12 trucks with load capacity of 10 tons as well as 12 trucks with load capacity of 4 tons. Time windows of retail shops to be visited by trucks was determined based on a survey in Kyoto-Osaka-Kobe area. Three home deliver companies within the network can operate 50 small trucks with load capacity of 2 tons. Time window of each home to be visited by trucks was randomly determined from 8 a.m. to 10 p.m. with the width of one hour.

4.3 Urban freight policy measures

This study tries to examine effects of two types of urban freight policy measures: (a) large truck (10ton trucks) ban in urban areas, (b) road pricing of charging based on travel distance of large trucks. If large truck ban is implemented for the test network in this study, retail shop delivery companies can only use 4ton trucks. It is assumed that road pricing measures allow city authorities to charge 200 yen/km on 10ton trucks, proportional to the distance travelled by the trucks.

Table 1. Case studies

Case	Policy measures by city authority	Countermearsures by retail shop delivery companies	Countermearsures by home delivery companies
0	no	no	Ba, Co, Pp, Tw
1	Large truck ban	no	Ba, Co, Pp, Tw
2	Road pricing	no	Ba, Co, Pp, Tw
12	Large truck ban except for trucks in co-operative freight transport systems	Co-operative freight transport systems	Ba, Co, Pp, Tw
22	Road pricing	Co-operative freight transport systems	Ba, Co, Pp, Tw

Ba: no countermeasure, Co: Co-operative freight transport systems,
Pp: Pickup points, Tw: Consolidated time windows

Once these policy measures are introduced, retail shop delivery companies and home delivery companies take some countermeasures to reduce their delivery costs. Retail shop delivery companies are to introduce co-operative freight transport systems. Home delivery companies are to take one out of four countermeasures including (a) co-operative freight transport systems, (b) a pickup point where consumers come to pick up their goods is facilitated in the centre of sub network, (c) consumer' time windows are designated for 3 hours by home delivery companies. Table 1 shows cases for the combination of these policy measures by city authorities and countermeasures by retail shop delivery companies and home delivery companies.

5. Results

Figure 4 shows total costs of both retail shop delivery companies and home delivery companies with countermeasures by only home delivery companies and no countermeasures by retail shop delivery companies. Note that total costs are composed of fixed costs, operation costs and early arrival and delay penalties. It indicates that total costs increased by implementing large truck ban (Case 1) and road pricing (Case2) compared with base case (Case 0) mainly due to the increase of costs of retail shop delivery companies. This increase of costs was generated by the increase of number of trucks used for operation, since retail shop delivery companies had to use more 4-ton trucks due to large truck ban. Figure 4 also illustrates that countermeasures by home delivery companies, including co-operative freight transport systems, pickup points and consolidated time windows are effective to reduce total costs. In particular, co-operative freight transport systems worked very effectively to reduce total costs of home delivery companies. Therefore, it is essential to point out that implementing large truck ban or road pricing may make total costs of delivery increase, and requires some countermeasures by home delivery companies to restrain the increase of costs.

Figure 4. Total costs of retail shop delivery companies and home delivery companies with countermeasures by only home delivery companies and no countermeasures by retail shop delivery companies (Cases 0, 1 and 2)

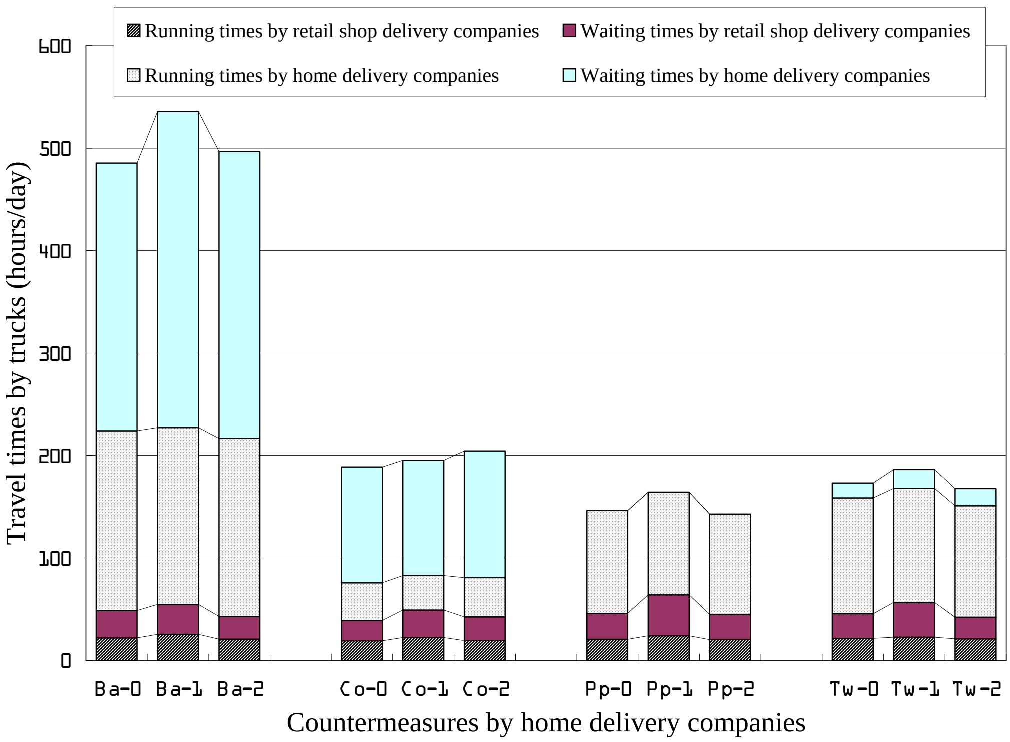

Figure 5. Travel times by trucks (Cases 0,1 and 2)

Figure 5 reflects effects of policy measures by city authority and countermeasures by home delivery companies on travel times by trucks. This figure indicates that large truck ban and road pricing led to increase of travel times of trucks. In Case 1 the number of trucks was increased due to large truck ban and these trucks arrived at retail shops earlier than the start of time window which resulted in increasing waiting times at retails shops. Figure 5 also illustrates three countermeasures taken by home delivery companies are effective to decrease travel times by trucks, which leads to alleviate traffic congestion on the network. It is interesting that the co-operative freight transport systems can considerably reduce running times of trucks compared with base case and the pickup points as well as consolidated time windows can largely reduce waiting times.

Figure 6 shows CO_2 emissions by trucks as well as passenger cars. Figure 6 indicates that CO_2 emissions are slightly decreased by implementing large truck ban and road pricing. In Case 1 CO_2 emissions by retail shop delivery trucks were considerably reduced with the use of 4 ton trucks instead of 10 ton trucks due to large truck ban. Therefore, the policy measure of large truck ban is effective for reducing CO_2 emissions, although it increases total costs as shown in Figure 4. Three countermeasures by home delivery companies are also able to decrease CO_2 emissions by trucks of home delivery companies in running and idling conditions.

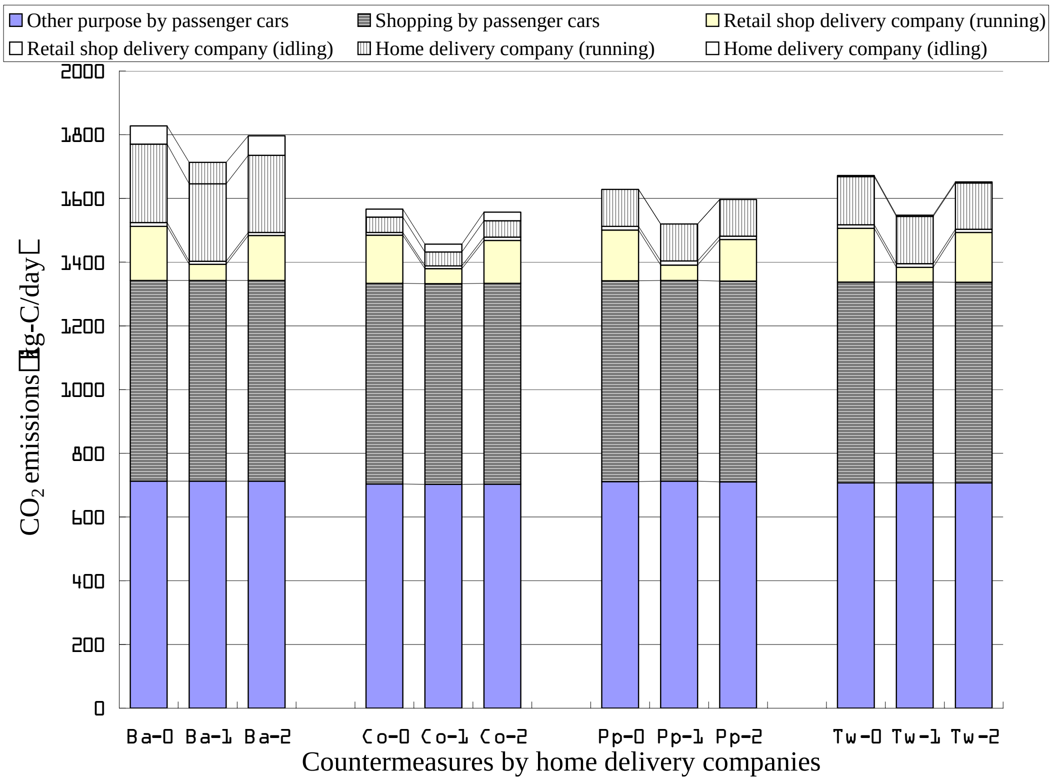

Figure 6. CO_2 emissions by trucks (Cases 0,1 and 2)

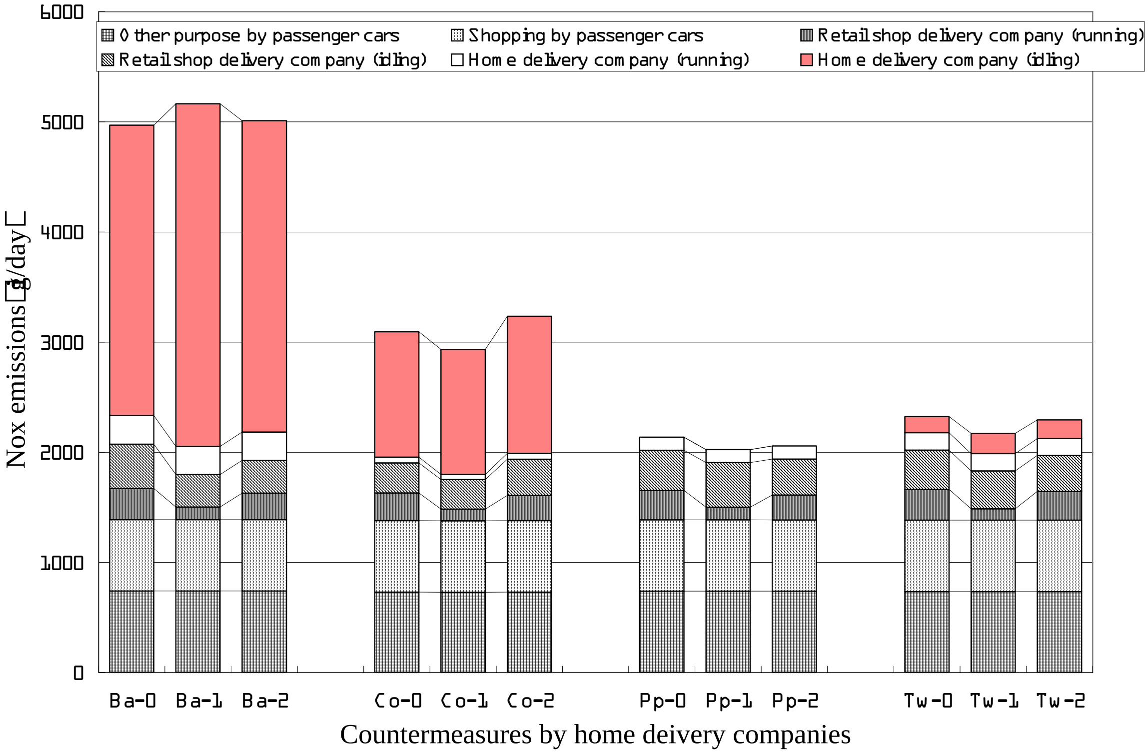

Figure 7. NOx emissions by trucks (Cases 0,1 and 2)

Figure 7 shows NOx emissions by trucks as well as passenger cars. Figure 7 indicates that for base case NOx emissions by trucks of retail shop delivery companies are reduced due to large truck ban and road pricing. But total NOx emissions are increased, since NOx emissions by idling of trucks of home delivery companies. In terms of NOx emissions in this case, reducing idling time of home delivery trucks is crucial. In fact three countermeasures by home delivery companies are successful to cut NOx emissions in idling of trucks.

Figure 8 shows total costs of retail shop delivery companies and home delivery companies with co-operative freight transport systems by retail shop delivery companies (Cases 0, 12 and 22). In base case of Case 12 total costs was successfully reduced with co-operative freight transport systems of retail shop delivery companies. In contrast the base case of Case 1 in Figure 4 contains substantial increase due to the increase of number of trucks used for operation. Therefore, co-operative freight transport systems are helpful to establish efficient freight transport systems.

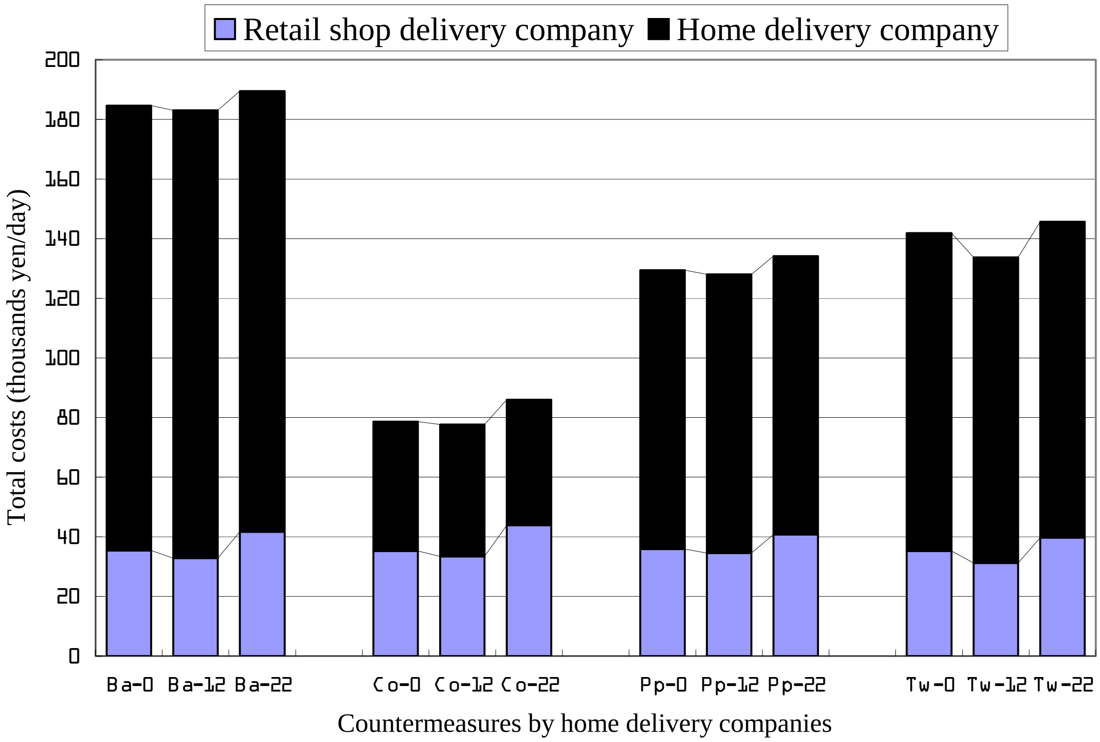

Figure 8. Total costs of retail shop delivery companies and home delivery companies with co-operative freight transport systems by retail shop delivery companies (Cases 0, 12 and 22)

In terms of travel times CO_2 and NOx emissions of trucks in Cases 12 and 22, similar results were obtained as in Cases 1 and 2.

6. Conclusions

This study presented a methodology of modelling to evaluate effects of policy measures by a city authority and countermeasures by freight carriers on urban freight transport with effects of e-commerce. Models were applied to a test road network in conditions that 10% of consumers use e-commerce for shopping. Results showed that the policy measures of implementing large truck ban or road pricing may increase total costs of trucks by retail shop delivery companies and home delivery companies. However, some countermeasures including co-operative freight transport systems, pickup points and consolidated time windows are effective not only to reduce total costs but also decrease travel times as well as CO2 and NOx emissions of trucks. Therefore, it is possible to establish efficient and environmentally friendly freight transport systems in urban areas, for cases that truck traffic is increased due to introducing B2C e-commerce. As well, it is important to establish partnerships between city authorities and freight carriers to contribute from both public and private sides to tackle these complicated problems.

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