A STUDY ON TRAFFIC AND ENVIRONMENTAL EFFECTS OF COOPERATIVE DELIVERY SYSTEM IN CBD: CASE STUDY IN MARUNOUCHI AREA

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Abstract

This study assesses the effect of cooperative delivery system adopted in Marunouchi district in February 2002. A microsimulation analysis was performed to quantify the effect of the said system on freight vehicles, environment and working hours of labors. The present form of delivery system (no cooperation) was also compared to the adopted system in order to measure their differences and identify which one is more beneficial. As a result, the cooperative delivery system shows a far desirable result compared to the present system. The number of freight vehicles needed for delivery was reduced and there was a significant improvement on the loading factor of each vehicle participating the new system. There was also a substantial reduction on staff working time who joined the cooperative delivery system.

Keywords: Freight simulation; Cooperative delivery system; Urban freight transport
Topic Area: B5 Urban Goods Movement

1. Introduction

Traffic congestion and environmental problems caused by automobiles have become very serious in many urban areas. Interestingly, trucks, which have a share of 40 percent of traffic volumes on arterial roads, are believed to be the main source of these problems. The difficulty of shifting the freight transportation mode from truck to rail-based or even to ship-based in urban areas underscore the necessity to reduce the volume of trucks by improving the efficiency of freight transportation. Cooperative Delivery System (CDS) is seen as one of the schemes that could decrease the traffic volume and improve the environment in urban areas.

Private sectors have focused their interest and even tried to introduce CDS in order to decrease distribution cost, particularly delivery cost. Cooperative Delivery System, however, has not been introduced widely enough to improve traffic congestion and environmental problems in urban areas. Among the reasons is the hesitation of private sectors to get involved in order to retain their free hands of managing their enterprise. These days, however, the costs of conventional delivery system have been rising because of traffic congestion in urban area which prompted the private sectors to gradually introduce CDS in order to decrease distribution costs. In addition, public sectors have encouraged enterprises to reduce CO_2 emission caused by freight transportation.

In Japan, CDS ought to be spread as much as possible by the joint efforts of government and private sector particularly in central business districts (CBDs) where traffic congestion and environmental problem are extremely serious.

2. Existing studies and the study objective

Social experiments on cooperative delivery system have been often conducted in Japan as public and private joint projects. Normally, CDS experiments were conducted by providing depots outside of CBD - like the case in Tenjin District in Fukuoka City and Saitama New City Center in Saitama City. In Shibuya, one of busiest business centers in Tokyo and Kashiwa Station East District in Kashiwa City, on-road loading and unloading activities were strictly regulated by preparing alternative loading and unloading spaces in designated areas [(Takahashi *et al*, 2001), (Takahashi *et el*, 2000)]. There are also some studies analyzing the reduction of traffic volume, the improvement of environment and the reduction of distribution cost resulting from social experiments on cooperative delivery [(Nemoto, 1992), (Ieda *et al*, 1992)]. However, these studies have focused on individual policies such as introducing cooperative delivery system, preparing loading and unloading spaces, or regulation of on-road parking. They did not evaluated altogether the system's effects on traffic reduction, environmental impacts and distribution cost.

In February 2002, social experiment of cooperative freight delivery system was conducted in Marunouchi District in Tokyo. This experiment made possible the analysis of the CDS impacts on traffic, environment and distribution cost based upon on actual data of CBD.

In general, there are two types of cooperative delivery system. The first type is a cooperative delivery system between depots and buildings, hereinafter referred to as horizontal cooperative delivery and the other is a cooperative delivery system inside of the building, hereinafter referred to as vertical cooperative delivery. It is thought that horizontal and vertical cooperative delivery system has potential in reducing the number of freight delivery vehicles, the emission of NOx (nitrogen oxide) and PM (particulate matter) as well as the distribution cost.

The aim of this study is to analyze the effect of horizontal and vertical cooperative delivery systems on traffic congestion, air pollution and distribution cost using computer simulation. Input data of the simulation was taken from a survey on a social experiment in Marunouchi District.

3. Methodology and procedure

A Stock Point (SP) where the carriers would bring their freight for consolidation was prepared near the district. The consolidated shipments are then delivered by natural gas trucks to the different outlets by routing. At the unloading area located at the underground floors of the buildings, two staff members are waiting for the delivery trucks to arrive and then unload the freights.

The study process is illustrated in Figure 1 and detail explanation of each level is summarized below:

1) to analyze the average delivery time and the average number of delivery vehicles from SP to each building based on the data of social experiment of horizontal cooperative delivery
2) to analyze the average delivery time and the average number of vertical delivery freights inside of each building based on the data of vertical cooperative delivery experiment
3) to build simulation models that could compare the values of traffic volume, delivery and waiting time
4) to estimate the traffic volume and the working time of the staff members by simulation in case of varied horizontal and vertical cooperative delivery systems
5) to estimate the reduction of truck volume and working time of drivers or staffs
6) to estimate the impacts of CDS on environment in terms of NOx and PM
7) to evaluate altogether the impact of cooperative freight delivery system.

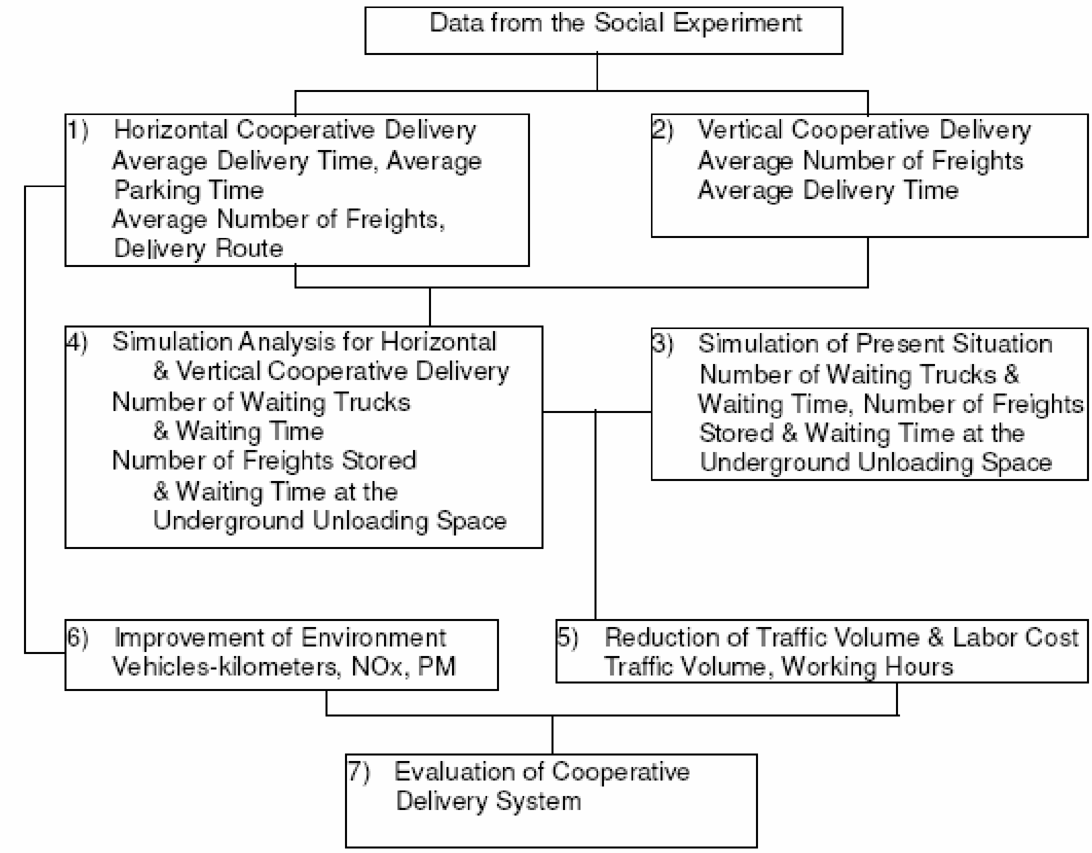

Figure 1. Procedure of the study

4. Social experiment of cooperative freight delivery

4.1 Background of the social experiment in Marunouchi district

Most of the important functions of the country had been absorbed by Tokyo, especially by the three central wards, namely Chiyoda, Chuo and Minato. Figure 2 provides a comparison numbers between the three central wards, the rest of the Tokyo wards, and Japan.

Marunouchi District, located between the Tokyo Railway Station and the Emperor's Palace, is the oldest and the biggest central business district in Japan since late 19th century, after the Meiji Revolution, up to this day. Interestingly, most large company head offices are concentrated in the Marunouchi District in pursuit of better communication and business chance. The relaxation of the 31-meter building height restriction in this district has paved the way to urban revitalization activities.

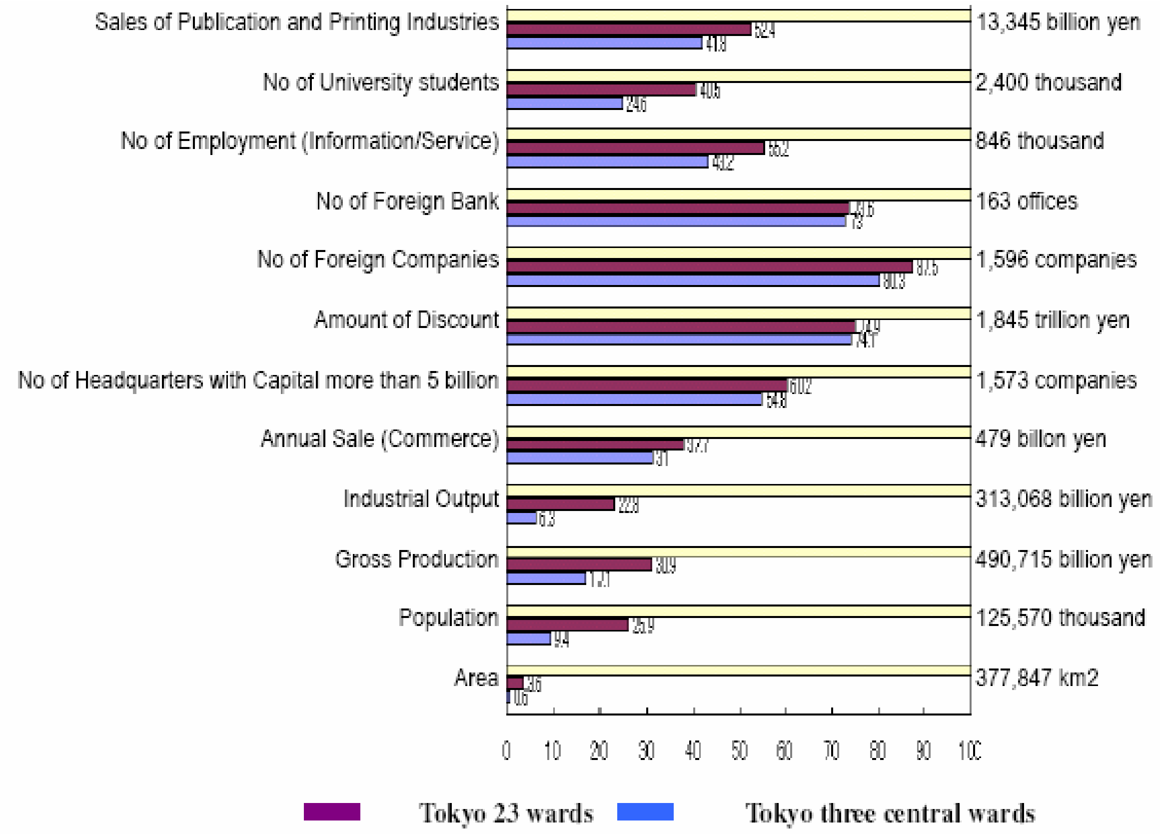

Figure 2. Tokyo's three central wards and 23 wards ratio of functions to Japan

The government of Tokyo had made up a redevelopment plan for Marunouchi District from a business-oriented district into a multi-use complex which includes business, culture and commercial functions. In September 2002, Marunouchi Building was rebuilt as the first redevelopment project in this district and will be followed by other many projects. These redevelopment projects, however, would cause some city problems that necessitated appropriate responses. This has been strongly recognized by public and private sectors. Obviously, there would be an increase in the number of delivery vehicles plying the district that would disrupt the physical environment. It is also expected that some of these trucks would load/unload their freight on-road thus disrupting the traffic flow. In addition, as building height increases, the freight deliveries would require longer staying period of trucks at the docking area. Normally, the increase in delivery time inside the building produces a long queue of vehicles outside.

In recognition of these problems, all concerned parties such as the building owners, tenants, carriers, the Metropolitan Police Agency and Ministry of Land and Transportation, has organized a committee called "An Executive Committee for Improving the Efficiency of Freight Delivery in Marunouchi District" or better known as Executive Committee. The purpose of this committee is to discuss the possibility of introducing a new freight delivery system which could improve the efficiency of freight delivery, limit air pollution, and improve parking control. In February 2002, the Executive Committee conducted a social experiment of freight transportation in Marunouchi District. The experiment area is shown in the map in Figure 3. Table 1 provides detail information of the buildings involved in the project.

Table 1. Characteristics of the buildings under study

Name of building	A	B	C	D	E
No of floor above ground	15	5	10	9	8
No of floor below ground	4	4	4	4	1
Floor space (m^2)	62906	55259	45985	51637	13379

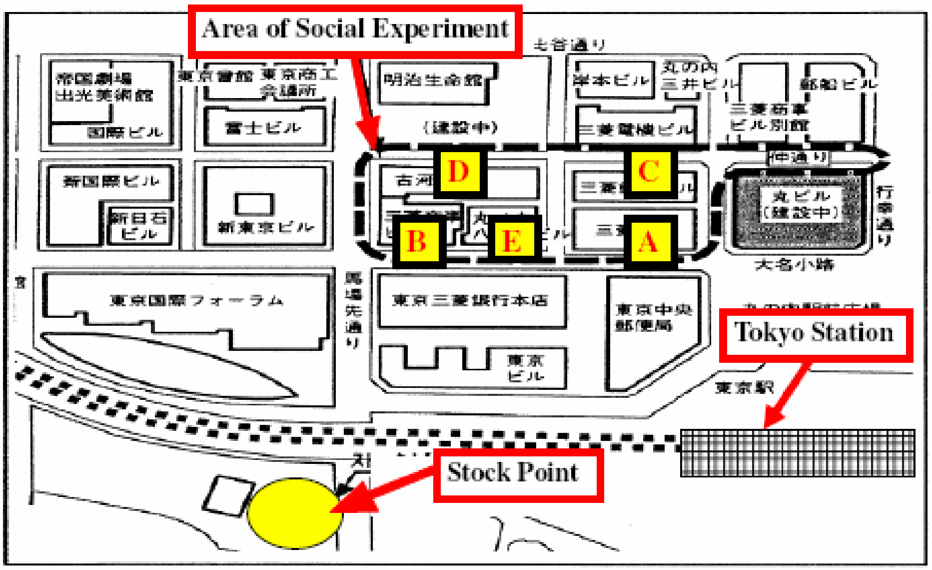

Figure 3. Map of the social experiment

4.2 Outline of the experiment

Two major components of transportation management, cooperative delivery and parking management, were included in the social experiment from February 5 until February 28 2002. Five (5) major carriers and 13 small-scale carriers had taken part in the experiment. Freight had to be carried first into the SP by the carrier participants, then, loaded unto a natural gas truck altogether and then delivered to each building.

The experiment changed the pattern of delivery from individual delivery truck separately delivering their freights to a consolidated shipment originated from the SP. Freight loaded by the natural gas trucks are handled by the two staff members assigned to each building. This process allows the truck drivers to move out of the building immediately. The guards stationed at the surrounding roads controlled the illegal on-road parking and guide cars into underground parking spaces. In addition, it was also restricted for all truck drivers to bring in their freights into the front entrance of the building. The changing pattern of delivery is illustrated in Figure 4 while Table 2 and 3 show the detailed information regarding the policy of the experiment.

Out of 232 total numbers of carriers operating in the area, 7.8 percent joined the experiment including five major and 13 minor carriers. The delivery trucks that belonged to the carriers who did not join the experiment continued to deliver their freights directly to the building establishments. They are not, however, allowed to utilize the unloading spaces reserved for the experiment. Drivers of these trucks are expected to look for parking spaces on their own.

As shown in Table 4, although the number of carriers participated accounted for only 7 percent, 22 percent of freights were covered.

Table 2. Outline of the Social Experiment

Experiment Area			**Five buildings in Marunouchi, Tokyo**
Term of Experiment			February 1 to February 28 (19 weekdays), 8 am to 5 pm
Policies	Coop Delivery	Horizontal Coop Delivery	Cooperative delivery by 5 major carriers and other participants
			Delivery through SP to each building
			Natural gas trucks
			Fee from SP to offices of the buildings is 50 yen per freight
			Mail, papers, packages except cold storage and frozen foods, etc.
		Vertical Coop Delivery	Staff deliver freights from underground of the buildings to offices inside the building
			Drivers drive through buildings without delivering freights
	Parking Management		Guards control illegal on-road parking
			Ban on bringing in freights from the front entrance of buildings
			To use freights elevators for delivering
			30 min free parking at underground parking space of buildings

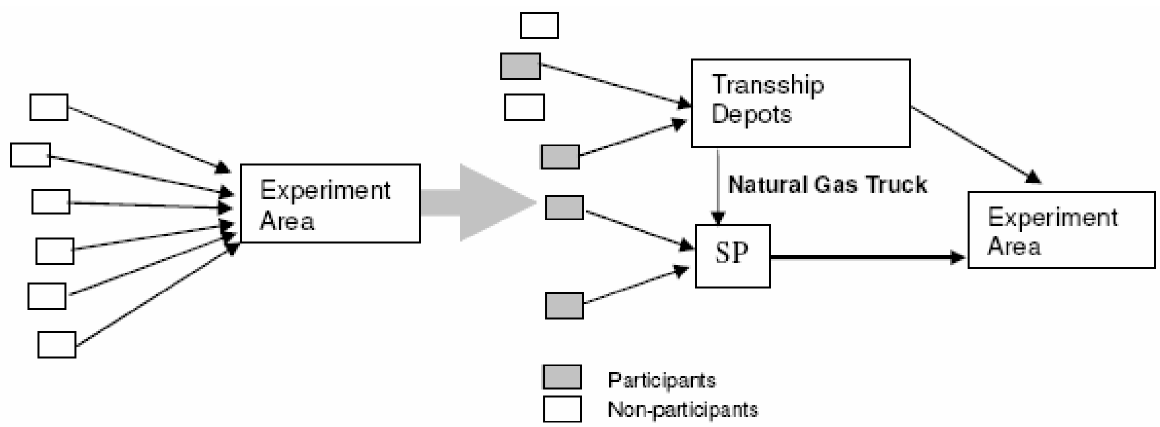

Figure 4. Delivery before and during the experiment

Table 3. Measures of observation

Daily Reports	by drivers at stock point by staffs at underground and loading space
Surveys	on-road parking and underground parking lot traffic volume utilization of freight elevators stock point
Questionnaire	for participants, non participants, tenants, building owners, office workers, shoppers, and staffs of experiment
Others	by car navigation systems and digital pedometers

Table 4. Share of participants in the experiment

	total in the area	participants	share of participants
No of carriers	232	18	7.80%
No of trucks	442	32	7.20%
No of freights	1724	383	22.20%

5. Result of the social experiment

5.1 Analysis on horizontal cooperative delivery and parking management

Only 30 percent of the freight by the carriers who joined the experiment was delivered to the SP for consolidation. According to the result of a questionnaire survey, most of the carriers prefer not to participate in the CDS to avoid leaking customers' information to their business rivals. Seventy percent of freights had been delivered directly from their own depots near the experiment area to each building without stopping at the SP.

Table 5 shows the number of trucks originating from the SP. The presence of the SP resulted in the reduction of 33 percent of the total number of vehicles supposed to deliver in the district. On the other hand, the policies such as preparing underground unloading spaces, 30 minutes free parking, ban on bringing in the freight through main entrance of buildings, and restriction of on-road parking resulted to 50 percent reduction of on-road parking and 35 percent increase of underground parking space utilization rate as shown in Figure 5.

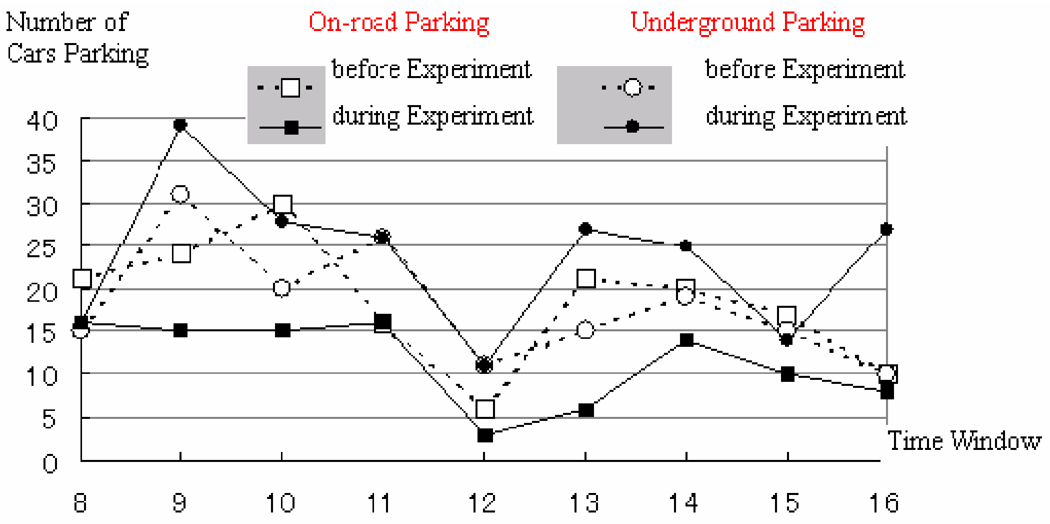

Figure 5. Change of the number of truck parking

Table 5. The number of Trucks that Transshipped Freights at SP

	No of trucks arrived at SP	No of trucks started from SP	Reduction rate of the number of trucks
Total of 19 days	186	125	33%
Average per day	9.8	6.6	33%

5.2 Analysis on behavior of horizontal cooperative delivery

Figure 6 shows the average delivery time and the average parking time at the building establishments participated the experiment. The average unloading time to all the buildings, which used to be 15 minutes before the experiment was reduced significantly to 2.35 minutes. The route of the delivery vehicles performing the horizontal delivery system is shown in Figure 7.

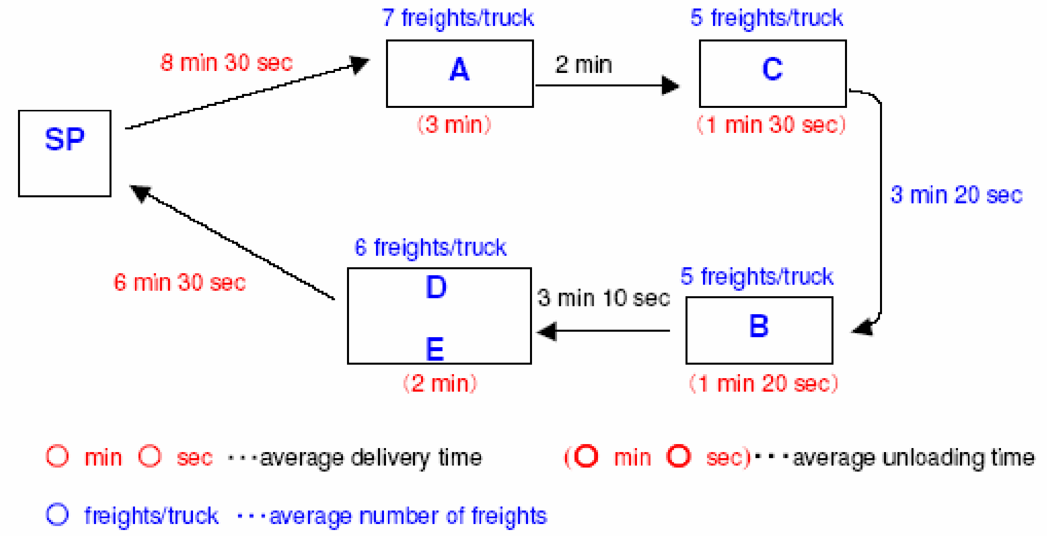

Figure 6. Horizontal cooperative delivery

5.3 Analysis on vertical cooperative delivery

All the staff members assigned at the underground unloading space of the buildings were equipped with a surveillance device called PEAMON (Personal Activity Monitor). This device records the location positioning data through its built in PHS (Personal Handy phone System) function. The location of the workers in a particular time is located through these data.

PEAMON sends data of staff members every 15 seconds to the monitor in the social experiment center. Although PEAMON could collect data on the staffs' detailed activities, a weak and disturb signal could lead to a missing data. In that case, this is substituted by the daily reports recorded by the staffs.

Table 6 shows some basic data both recorded by the PEAMON and the staff members. As can be seen from the table, the average vertical delivery time in the morning is longer as compared in the afternoon because the vehicle carries more freight in the morning. Consequently, the length of stay of the staff is also longer due to the number of freight delivered.

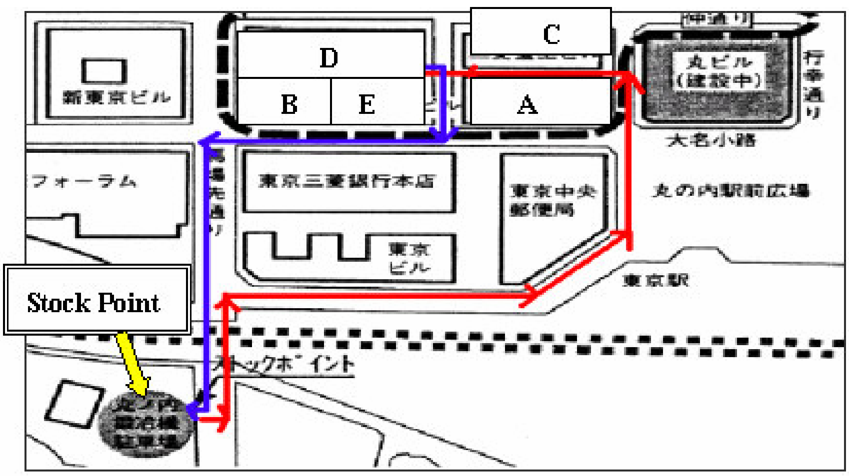

Figure 7. Delivery route

Table 6. Time averages

Variables	Average time	
	Morning	Afternoon
vertical delivery time	9 min a.m.	2 min
length of stay at a floor	3.5 min	1.5 min
number of freights at a time	11 freights	3 freights
frequency of delivery in the building	4	1

6. Simulation analysis

6.1 Simulation method and alternatives

A simulation analysis was performed to examine the impact of the adopted policies on traffic and environmental problems. Logistic simulation software called "Simul8" was adopted due to its user friendliness.

Although only 7.8 percent of carriers joined the social experiment, the simulation analysis assumed that all carriers participated in the cooperative delivery system. This was done since the objective of the study was to evaluate in detail the effects of cooperative delivery system when all of stakeholders in the study area agreed to participate in the system.

The recorded number of truck's trip and freight to each building during the experiment is shown in Table 7. This is a one day recorded figures which used as an input data of the simulation model. On the other hand, in case of existing delivery system, namely without cooperative delivery system, all trucks are expected to park at the parking lot of each building. Normally, the driver would unload the freights and subsequently deliver them to the recipients.

Table 7. Number of trucks and freights brought in each building per day

	Building / Time	A	B	C	D & E	Total
Trucks (Vehicles /Day)	8:00 ~ 9:30	19	29	24	19	91
	9:30 ~ 12:00	42	46	29	37	154
	12:00 ~ 17:00	55	57	39	46	197
	Total	116	132	92	102	442
Freights (Freight /Day)	8:00 ~ 9:30	118	116	112	73	419
	9:30 ~ 12:00	218	228	84	65	595
	12:00 ~ 17:00	120	428	88	74	717
	Total	456	772	284	212	1724

Table 8 shows the intervals between trips of delivery trucks among the buildings. According to an observation in the experiment, it was clear that the arriving intervals between trips of trucks followed an exponential distribution curve.

In contrast to the existing delivery system, truck drivers would transship their freights into the SP and natural gas trucks would deliver the consolidated shipments to the different buildings by routing. Assigned staff members of each building will then deliver these freights to the different recipients across the building floors. The two cooperative delivery schemes would not only reduce volume of truck traffic in the area but also would save working hours of drivers.

Table 8. Existing delivery

Alternatives		A	B	C	D & E
arriving interval (min/truck)	8:00 ~ 9:30	4.7	3.1	3.8	4.7
	9:30 ~ 12:00	3.6	3.3	5.2	4.1
	12:00 ~ 17:00	5.5	5.3	7.7	6.5
	Application of exponential distribution				
Average number of freights per truck	8:00 ~ 9:30	6	4	5	4
	9:30 ~ 12:00	5	5	3	2
	12:00 ~ 17:00	2	8	2	2

Table 9. Interval between trips of natural gas trucks to each building in case of the cooperative delivery (fixed interval)

Alternatives		a	b	c	d	e	f	g	h
Arriving interval (min/truck)	8:00 ~ 9:30	15	15	15	30	30	15	30	30
	9:30 ~ 12:00	30	15	15	30	30	30	15	15
	12:00 ~ 17:00	60	60	30	30	60	30	30	60
Number of arriving trucks	8:00 ~ 9:30	6	6	6	3	3	6	3	3
	9:30 ~ 12:00	5	10	10	5	5	5	10	10
	12:00 ~ 17:00	5	5	10	10	5	10	10	5
	Total	16	21	26	18	13	21	23	18

In the effort to further understand the effect of the cooperative delivery systems and come up with desirable time intervals between trips, different time intervals between trips were made as shown in Table 9. The morning time intervals between trips are composed of 15 minutes or 30 minutes while 30 minutes and 60 minutes for the afternoon. The observed high number of arriving delivery trucks in the morning decides this scheme.

6.2 Simulation analysis inside of the buildings

A simulation model was built in order to see the effect of horizontal and vertical cooperative delivery systems on the number of waiting trucks and number of waiting freights, waiting time of trucks and waiting time of freights at the underground unloading space. Table 10 shows the properties of the simulation model.

As shown in Figure 8, cooperative delivery system could almost eliminate the number of waiting trucks and truck's waiting time. As far as the number of waiting trucks and truck waiting time are concerned, alternative (***g***) shows the most promising result in building ***A*** and to the other buildings.

The simulation results with regards to the number of waiting freight and the waiting of the freights is shown in Figure 9. A look at the figure would suggest that alternative ***g*** has the highest reduction to the waiting time of freights.

Table 10. Properties of Simulation model

<table>
<tr><th></th><th></th><th>Existing Delivery</th><th>Cooperative Delivery</th></tr>
<tr><td>Number of truck parking spaces</td><td></td><td colspan="2">4</td></tr>
<tr><td>Unloading Spaces</td><td>space
capacity</td><td>0</td><td>1
100</td></tr>
<tr><td>Elevators</td><td>number
loading capacity</td><td colspan="2">1
20</td></tr>
<tr><td>Average unloading time (min/freight)</td><td></td><td colspan="2">0.33</td></tr>
<tr><td>Average vertical delivery time (min/freight)</td><td></td><td colspan="2">1</td></tr>
<tr><td>Vertical delivery staff member</td><td></td><td>0</td><td>2</td></tr>
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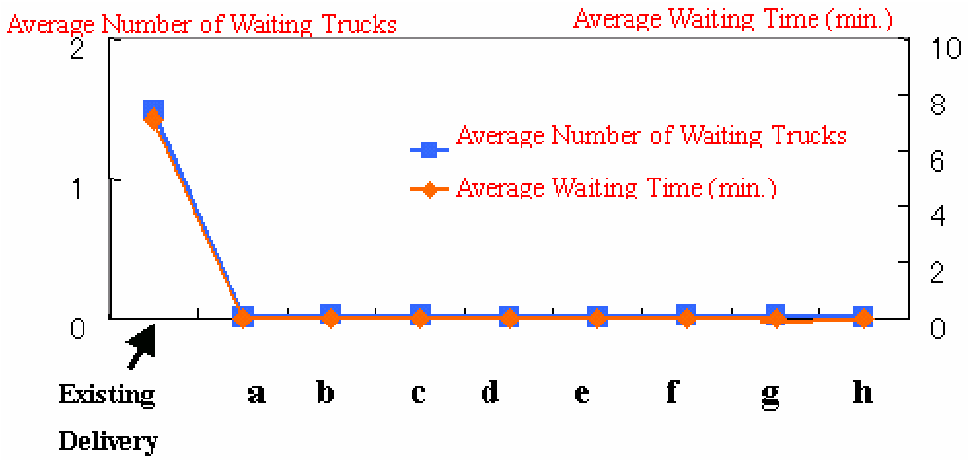

Figure 8. Average number of waiting trucks and average waiting time at the underground unloading space of *building A*

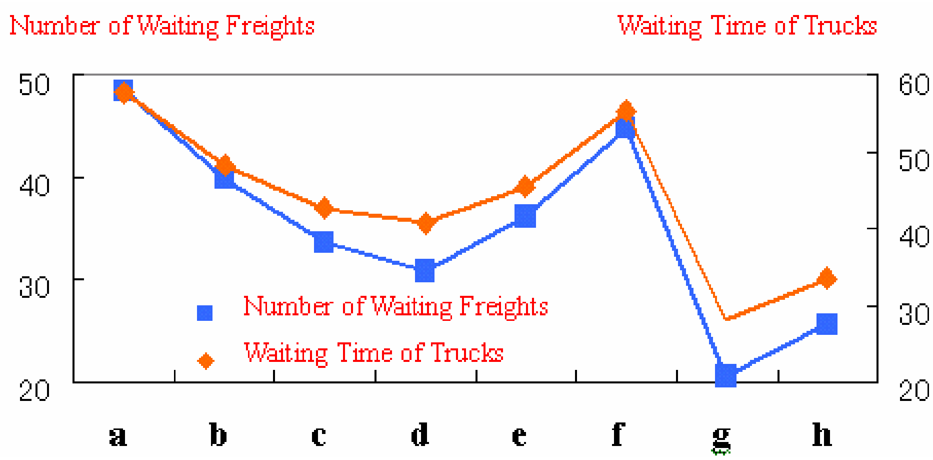

Figure 9. Average number of waiting freights and freights waiting time at the underground unloading spaces of alternatives

Table 11. Comparison between the existing delivery and cooperative delivery system

	Building	A	B	C	D & E
Average no of waiting Trucks	Existing Delivery	2	5	1	1
	Alternative *g*	0	0	0	0
Average waiting time of truck	Existing Delivery	7.1	17.1	1.5	1.2
	Alternative *g*	0	0	0	0
Average no of waiting freights	Existing Delivery	-	-	-	-
	Alternative *g*	20	38	1	1
Average waiting time of freight	Existing Delivery	-	-	-	-
	Alternative *g*	28.1	27.2	2.7	0.9

Table 11 reflected the comparison between existing delivery system and alternative ***g***. The said alternative shows a better result as compared to the existing system. Variables "average no. of waiting freights" and "average waiting time of freight" are not available in the table for the case of the present system because the drivers personally deliver the freights to the recipients. There is no waiting time at the underground unloading space in that case.

7. Effects on traffic, environment and working time of the cooperative delivery

7.1 Effect of the reduction of traffic volume in the area

The results of alternative ***g*** show that at least 23 trucks are necessary in order to ship the freights going into the district. Thirteen (13) trucks are needed in the morning while ten (10) for the afternoon. Again, the number of trucks required in the afternoon is less than that of the morning because of the less number of goods to be shipped in the afternoon. Comparing the 23 trucks needed to deliver the goods for the case of cooperative delivery system is far less than 442 trucks normally delivering goods in Marunouchi. In short, the horizontal cooperative delivery system could reduce the number of delivery trucks into 5%.

According to a traffic survey in the area, the share of freight vehicles to all traffic is approximately 32 percent. This value was obtained through equation 1:

$$V = V_p + V_t \qquad (1)$$

where *V* is the total vehicle volume, *Vp* is the volume of passenger car, and *Vt* is the volume of freight vehicle. The cooperative delivery system deals only with the delivery of goods and it is therefore important to isolate the number of vehicles collecting goods. In order to quantify the effect of the cooperative delivery to the total traffic, it was assumed that percent of the truck traffic is delivering freights while the remaining half is collecting. Equation 2 would isolate the number of freight vehicle delivering goods from collecting:

$$V' = V_t / 2 \times \alpha \qquad (2)$$

where *V'* is the number of freight vehicle delivering freights, *Vt/2* is half the number of total freight vehicle, and a is the reduction rate of freight vehicles due to the implementation of cooperative delivery which is .05. With this assumption, the reduction rate of cooperative delivery system on the total traffic in the area can be computed by following equation 3:

$$V'' = V_p + V_t / 2 + V' \qquad (3)$$

where *V* is the total number of freight vehicle reduction induced by cooperative delivery system. The final equation that would give the value of the ratio of vehicle reduction as an effect of the cooperative system is given below:

$$R = V'' / V x100 \qquad (4)$$

Using the equations above, a 15 percent reduction in all total vehicle volume was arrived. This is a significant number that would result in traffic flow improvement since freight vehicles have often been blamed to cause traffic jams due to their unpredictable nature of loading and unloading freights at any given space.

7.2 Reduction of environmental emissions

The length of a roundtrip from and to the SP through four buildings is approximately 1.8 kilometers, assuming that all cooperative delivery vehicles will follow the route shown in Figure 7. The estimation of nitrogen oxide and particulate matter were done by utilizing indicators given to delivery vehicles by a report entitled “Technical Methods of Road Environment Assessment” and published by Institute of Highway Economics. The said report has a value of 0.118 g/km for NOx and 0.007 g/km for PM.

If cooperative delivery system is adopted using CNG trucks, the NOx coming from all delivery vehicles can be reduced to 95 percent while PM can be eliminated. Unlike ordinary freight vehicles, CNG trucks do not emit PM and therefore causes less harm to urban environment. Table 12 shows the different level of emissions depending on the type policy while Figure 10 depicts the two different types of transporting freight in the district.

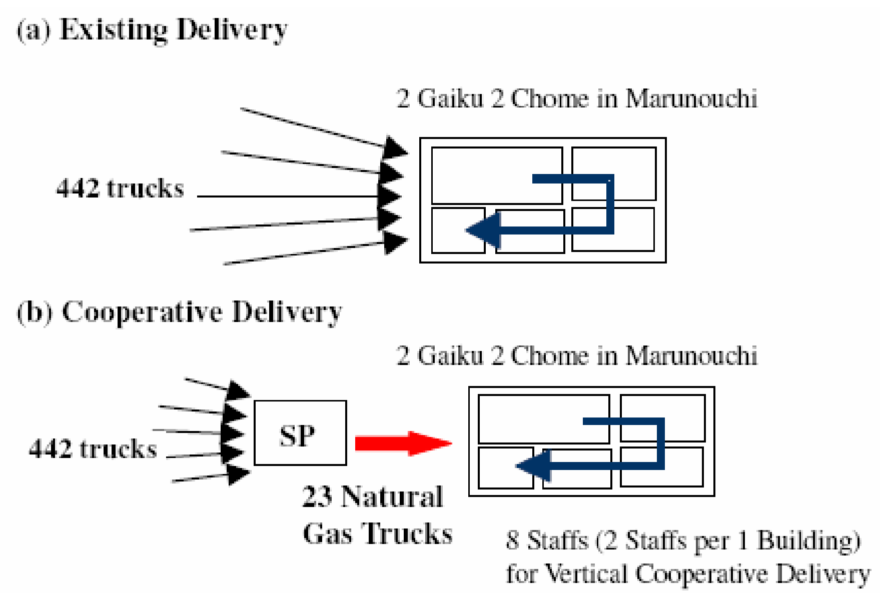

Figure 10. Comparison between Existing and Cooperative Delivery

7.3 Reduction of working time

Logistics cost is composed of fuel, depreciation, and personal expenses among others. In this study, however, the focus is on personal expenses and working time of both truck drivers and staffs for cooperative delivery. The average travel time of each vehicle taking into account the present situation can be computed by combining all the average travel time shown in Figure 6. Assuming that each vehicle also would follow the ideal route drawn in Figure 7, the average travel time of each vehicle would be 23 minutes and 30 seconds. By utilizing the data of Table 4, the average number of freights per vehicle would be 4 while 75 freights per vehicle for the case of ***g*** (cooperative delivery system).

Table 12. Environmental Emissions

Type of emitted chemicals	Existing delivery	Cooperative delivery by existing trucks	Cooperative delivery by CNG trucks
NOx	92.84 (g)	4.83 (g)	.48 (g)
PM	5.51 (g)	0.29 (g)	0 (g)

Note: NOx indicators for ordinary truck is .118 g/km while .0118 g/km for CNG truck

A survey conducted before the social experiment shows that the delivery vehicles' average waiting time before getting a loading space or parking space is 6.8 minutes. The introduction of vertical cooperative system, however, reduced this number to zero. Furthermore, the said system has an average unloading time of 0.33 minute per freight and 1 minute per freight for the vertical delivery as shows in Table 10.

Table 13 shows the comparison between the existing delivery system and the newly introduced system. The vertical delivery time was calculated as the total working time of eight (8) staff members employed to the four (4) building establishments. As expected, the cooperative delivery system has a less working time (4,950 min) compared to the existing system (15,744 min) as shown in Table 13. A total of 10,794 minutes was saved.

Table 13. Reduction of Working Time by Cooperative Delivery

	Existing Delivery (min)	Cooperative Delivery(min)	Time Saved (min)
Delivery Time in the area	442 trucks x 23.5 = 10,387	23 trucks x 23.5 = 5,401	- 9,847
Unloading Time in the building	442 trucks x 0.33 x 4 freights = 583	23 trucks x 0.33 x 75 freights = 569	- 14
Vertical Cooperative Delivery	442 persons x 1 x 4 freights = 1,768	8 persons x 480 (Staffs' Labor Time) = 3,840	+ 2,072
Waiting Time for parking	442 trucks x 6.8 = 3,006	23 trucks x 0 = 0	- 3,006
Total	15,744	4,950	- 10,794

8. Conclusion

The study carried out several analyses in order to assess the effect of cooperative freight delivery system. The number of delivery vehicle required in order to serve the freight demand of the district was quantified. Results of the simulation tend to suggest that there would be enormous increase of load factor of the delivery vehicles should all the carriers join the system. Reduction in traffic volume in the area as an effect of the new system was also determined. Long queues of delivery vehicles at the unloading space of the building could be shortened if not totally eliminated. This is also true about their waiting time. Substantial reduction of vehicle emission was achieved as a result of introducing innovative freight vehicles was also discussed. There was also a high number of working time saved from labor due to the vertical cooperative system.

The study was able to present the benefits that might be derived from this kind of project. The growing public awareness to the negative impact of freight vehicles and the continuing search of private sector to minimize their operating expenses could give way to the growth of cooperative delivery system.

A study that would cover a wider area for cooperative delivery system is deemed necessary in order to gain strong evidence to the benefits offered by this system. In addition, the procedure and feasibility of acquiring land to house the Stock Point needs to be examined.

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