TRAFFIC AND ENVIRONMENTAL IMPACT ANALYSIS OF LARGE-SCALE FACILITIES IN THE COMMERCIAL BUSINESS DISTRICT

Eiichiro IWAO
Tokyo University of Mercantile Marine
Department of Information Engineering and Logistics
2-1-6 Etchujima, Koto-ku,
Tokyo 135-8533, Japan
Tel/Fax: 81-3-56206462
E-mail: eiiwao@ipc.tosho-u.ac.jp

Hirohito KUSE
Tokyo University of Mercantile Marine
Department of Information Engineering and Logistics
2-1-6 Etchujima, Koto-ku,
Tokyo 135-8533, Japan
Tel/Fax: 81-3-52457369
E-mail: kuse@ipc.tosho-u.ac.jp

Abstract: The concentration of delivery trucks and passenger cars into large-scale commercial facilities has resulted in several problems such as traffic congestion and environmental pollution. One of the main causes of these problems is the shortage of parking facilities for delivery trucks to supply goods and commodities. The objective of this paper is to clarify and identify efficient methods to improve the logistics system through application of transport demand management measures at large-scale commercial facilities, which will reduce the number of delivery trucks arriving during peak hours. The paper also aims to determine improvement measures that reduce waiting time for parking of delivery trucks and passenger cars.

Keywords: urban goods movement, loading/unloading activities, environmental pollution

1. INTRODUCTION

Traffic congestion and environmental pollution have become serious problems at large-scale commercial facilities due to the heavy concentration of delivery trucks and passenger cars especially during peak-hours. The lack of parking facilities for delivery trucks to supply goods and commodities is considered to be one of the main causes of these problems.

Presently in Japan, more than 70% of delivery trucks arrive at the commercial facility before opening time, thereby creating severe traffic congestion. One of the specific issues that must be addressed is the shortage of truck parking and loading/unloading facilities in commercial districts during peak-hours. An effective way of improving the present condition is to shorten the waiting and parking time of delivery trucks to maximize utilization rates of parking facilities.

The objective of this paper is to clarify and identify efficient methods to realize an efficient logistics system that will reduce impacts of traffic congestion and environmental pollution at large-scale commercial facilities.

2. PHYSICAL DISTRIBUTION AND TRANSPORT ACTIVITIES AT COMMERCIAL FACILITIES

Physical distribution at commercial facilities can be separated into smaller activities of delivery, unloading, conveyance inside the building, checking, receiving, return to parking space, and return trip (Figure 1). In this study, delivery is defined as the activity concerned with the movement of freight from the logistics center to the designated parking space of the destination facility. On the other hand, transport activities of consumers at commercial facilities can be separated into smaller activities of car trip, parking, and return trip (Figure 2).

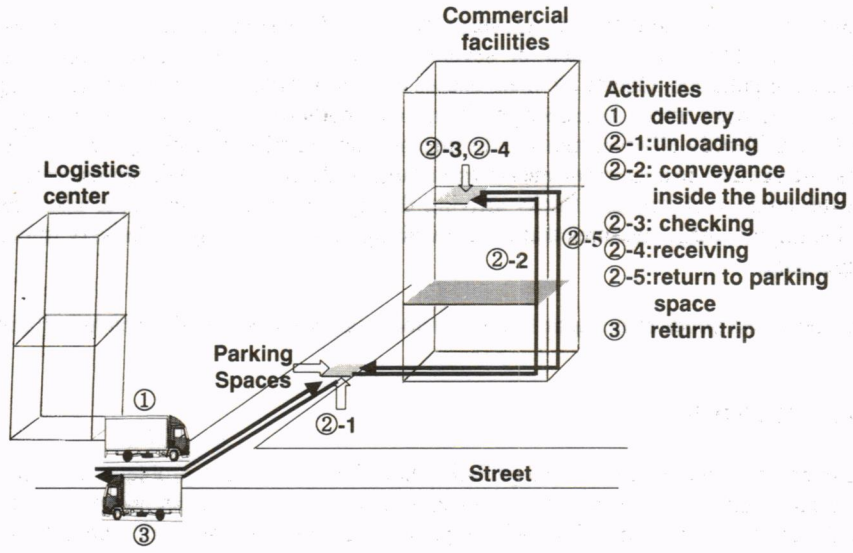

Figure 1. Physical distribution activity for commercial facilities

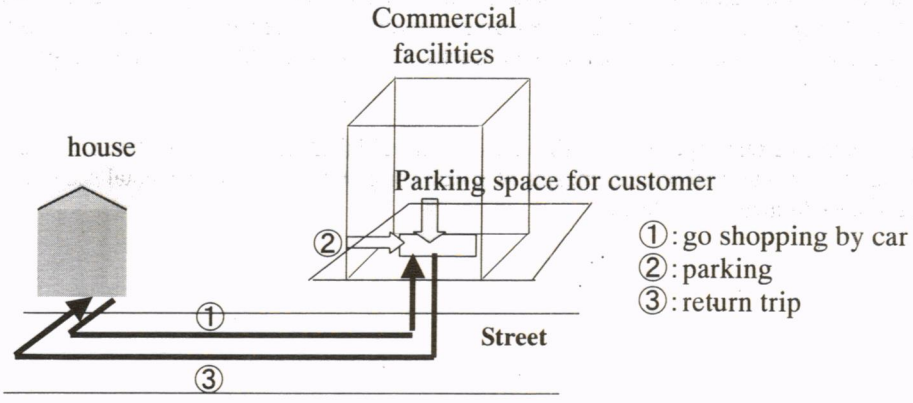

Figure 2. Transport activities of customers at commercial facilities

3. IMPROVEMENT POLICIES TO REDUCE TRAFFIC IMPACTS

3.1 Types of large-scale facilities

Large-scale facilities can be divided into three types: commercial facility, office facility and residence (Table 1). This paper analyzes traffic impacts of large-scale commercial facilities alone since traffic congestion is the most severe among the three types.

In Japan, there are three types of large-scale commercial facilities: 1) supermarket, 2) department store, and 3) specialty store. A specialty store refers to a store that sells specific goods and commodities related to an item. For example, a store that sells cameras, video cameras, and goods related to cameras is considered a specialty store.

The number of delivery trucks and passenger cars attracted by each type of commercial facility varies according to its characteristics. Thus, separate analysis on the concentration ratio of trucks and passenger cars is performed for each type of commercial facility.

Table 1. Types of large-scale facilities

	Commercial	Office	Residence
Large scale facilities	Supermarket Department store Specialty store	Office building	Estate

3.2 Improvement policies to reduce waiting time of vehicles at parking facilities

When there is a shortage of parking spaces at commercial facilities, delivery trucks have to wait on street until a parking space becomes available for use. Thus, decreasing the waiting time of delivery trucks and passenger cars can reduce the occurrence of traffic congestion. Three ways that can reduce the waiting time are: 1) reduction in the number of arriving trucks and passenger cars, 2) reduction of parking times, and 3) increase in parking capacity (Table 2).

Table 2. Relationship between activities and policies

Improvement policies to reduce waiting time		Delivery trucks	Passenger cars
①,③ Delivery activities	Reduce arriving vehicles	Consolidated delivery Cooperative delivery	Park & ride
② Parking and Loading/unloading activities	Reduce parking time	Checking & sorting system	Increase of parking charge
	Increase parking capacity	Provision of parking spaces	Provision of parking spaces

①,②,③ refer to Fig.1.and Fig.2.

To reduce the number of arriving trucks and passenger cars, it is necessary to decrease truck delivery and passenger car frequencies by increasing load factors of trucks and increasing occupancy of passenger cars. Improvement policies that focus on increasing load factors and

vehicle occupancy such as consolidated delivery, cooperative delivery and park & ride can be effective ways to reduce the number of arriving vehicles.

To decrease parking time, it is necessary to shorten the time spent for parking and loading and unloading. Improvement policies include efficient performance of checking and sorting for delivery trucks, and increasing parking charges for passenger cars to discourage long-periods of parking.

On the other hand, increasing parking capacity can result in a reduction of waiting time for parking. Thus, the provision of adequate parking spaces for both delivery trucks and passenger cars is considered as a direct improvement measure.

4. ANALYSIS ON THE RELATIONSHIP BETWEEN ARRIVING VEHICLES AND FLOOR AREA

4.1 Purpose of regression analysis

To analyze traffic impacts of large-scale commercial facilities, the relationship between the number of arriving vehicles and the floor area of the commercial facility should be clarified first. Regression analysis can be used to clarify the relationship between these variables for the three types of large-scale commercial facilities based on actual survey.

4.2 Data collection and regression analysis for the three types of commercial facilities

Two survey reports done by two local governments in Japan were utilized to gather data on the characteristics of commercial facilities. The "Large-Scale Commercial Facilities Survey" was used to get data on the number of delivery trucks, number of parking spaces for delivery trucks, and floor area for each commercial facility. On the other hand, the "Commercial Facilities and Traffic Survey" was used to gather data on the number of passenger cars, number of parking spaces for passenger cars, and floor area for each commercial facility. Regression analysis was then performed to determine the relationship of the floor area and the number of arriving trucks and passenger cars for each commercial facility (Table 3).

Table 3. Delivery trucks and passenger cars arriving at each facility

	Number of arriving trucks	Number of arriving passenger cars
Supermarket	1.99(vehicle/m^2)	279.55(vehicle/m^2・hr)
Department Store	8.44(vehicle/m^2)	133.99(vehicle/m^2・hr)
Specialty store	1.25(vehicle/m^2)	243.98(vehicle/m^2・hr)

$$m1 = 1.99x, \quad r^2 = 0.9153 \tag{1}$$
$$m2 = 8.44x, \quad r^2 = 0.9576 \tag{2}$$
$$m3 = 1.25x, \quad r^2 = 0.8566 \tag{3}$$
$$t1 = 279.55x, \quad r^2 = 0.5807 \tag{4}$$
$$t2 = 133.99x, \quad r^2 = 0.612 \tag{5}$$
$$t3 = 243.98x, \quad r^2 = 0.5585 \tag{6}$$

where

m1: number of delivery trucks arriving at the supermarket
m2: number of delivery trucks arriving at the department store
m3: number of delivery trucks arriving at the specialty store
t1 : number of passenger cars arriving at the supermarket
t2 : number of passenger cars arriving at the department store
t3 : number of passenger cars arriving at the specialty store
x : total floor area (m^2) of commercial facilities

Regression analysis on the relationship between parking spaces and the number of trucks and passenger cars was performed without classifying the three types of commercial facilities since the number of samples for parking spaces was inadequate (Table 4).

Table 4. Relationship of arriving vehicles and parking spaces

	Number of arriving trucks	Number of arriving passenger cars
Parking spaces	0.692 (spaces/vehicle)	1.155 (spaces/vehicle)

$$n1 = 0.692 m_i, \quad r^2 = 0.9541 \tag{7}$$

$$n2 = 1.155 t_i, \quad r^2 = 0.8625 \tag{8}$$

where

n1: number of parking spaces for delivery trucks
n2: number of parking spaces for passenger cars
m_i: number of delivery trucks arriving at the commercial facilities (i =1~3)
t_i : number of passenger cars arriving at the commercial facilities (i =1~3)

5. SIMULATION ANALYSIS

5.1 Purpose of the simulation analysis

The purpose of the simulation analysis is to determine improvement policies that minimize waiting time of delivery trucks and passenger cars. The WITNESS simulation software was used to perform the simulation analysis.

The following procedure was used: 1) Selection of the improvement measure for reducing the waiting time in each facility (Table 5), 2) Determination of parameters and variables of delivery and parking activities (Table 6), 3) Modify parameter values for each improvement policy (Table 7), 4) Calculation of the total waiting time of delivery trucks and passenger cars.

5.2 Data requirements of the study

It is important to know first the improvement policies that can be applied according to the type of vehicle (Table 5). For delivery trucks, four improvement policies can be applied; i.e. consolidated delivery, cooperative delivery, checking and sorting, and provision of parking spaces. For passenger cars, three improvement policies can be applied; i.e. provision of additional parking spaces, park and ride system, and increasing parking charges.

Table 6 shows the input data for each type of vehicle for the three main activities of delivery, parking and return trip. These were determined from the actual surveys conducted at the three types of commercial facilities. Input data include delivery distance, delivery speed, entrance time, and parking time. On the other hand, variables in the simulation analysis include: a) number of arriving vehicles, which can be computed from Equation 1 to 3 for delivery trucks, and Equation 4 to 6 for passenger cars; and b) number of parking spaces, which can be computed from Equation 7 for delivery trucks, and Equation 8 for passenger cars.

Table 7 shows the change in the value of input data after the application of improvement policies. These changes were determined from the interview surveys conducted at the commercial facilities after the introduction of improvement policies. For example, for the delivery activity, the number of arriving vehicles decreased by an average of 50 percent after the application of consolidated delivery, cooperative delivery, and park and ride system. In addition, the average load factors of trucks increased from 17.5 percent to 35 percent after the application of consolidated delivery and cooperative delivery. On the other hand, for the parking activity, the average parking time decreased from 22.3 minutes to 15 minutes after the application of consolidated delivery and checking and sorting system, and from 85.8 minutes to 30 minutes after the parking charge was increased. The number of parking spaces also doubled after the improvement policy of providing additional parking spaces was applied.

Table 5. Improvement policies for each type of vehicle

	Consolidated delivery	Cooperative delivery	Checking & sorting	Provision of parking spaces	Park & ride	Increase parking charge
Delivery trucks	○	○	○	○	-	
Passenger cars	-	-	-	○	○	○

Table 6. Input data for each type of vehicle

	Input data	Delivery trucks	Passenger cars
① Delivery	Delivery distance	30km	30km
	Number of arriving vehicles	Equation 1～3	Equation 4～6
	Delivery speed	18km/hr	18km/hr
	Entrance time	9.0 s/vehicle	0.0 s/vehicle
② Parking	Parking time	85.8 min	22.3 min
	Parking spaces	Equation 7	Equation 8
③ Return trip	Delivery distance	30km	30km
	Delivery speed	18km/hr	18km/hr

Table 7. Change in values for each input data for simulation

		Consolidated delivery	Cooperative delivery	Checking & sorting system	Provision of parking spaces	Park & ride	Increase parking charge
① Delivery	Arriving vehicles	50% decrease	50% decrease			50% decrease	
	Load factor	17.5→35.0 %	17.5→35.0 %				
② Parking	Parking time	22.3→15.0 min		22.3→15.0 min			85.8→30.0 min
	Parking spaces				Double		

5.3 Simulation Analysis of commercial facilities

5.3.1 Assumed model for the simulation analysis

The assumed model used in the simulation analysis of the commercial facility is shown in Figure 3. The assumptions are as follows:

1) There is a large vacant lot for development near the commercial facility.
2) The developer is planning to build a building, but is contemplating on what kind of commercial facility should be selected from the three types of commercial facility.
3) Thus, the planner has to clarify the traffic impact for each type of commercial facility.

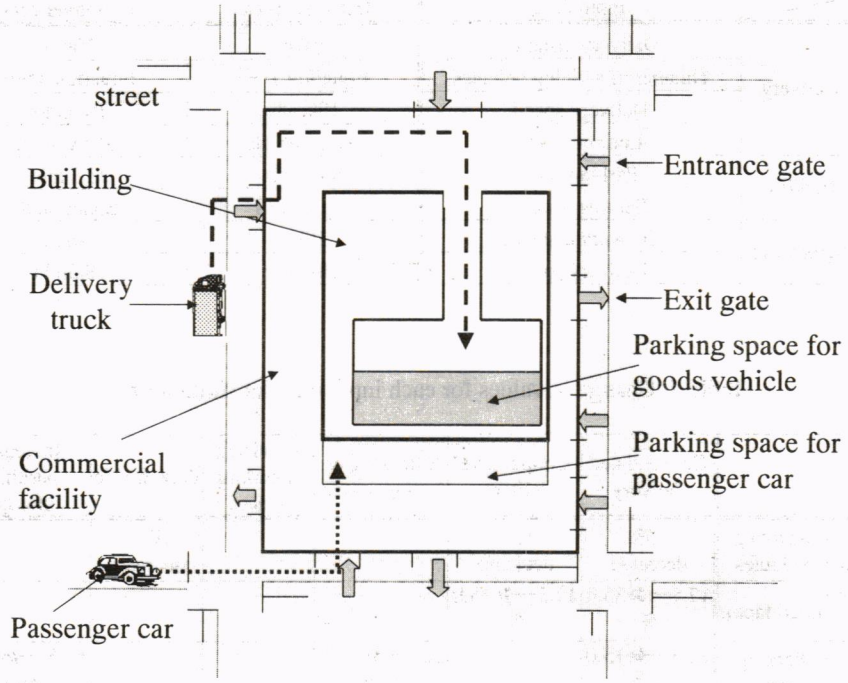

Figure 3. Assumed model for the commercial facility

5.3.2 Analysis on the waiting time for a supermarket

(1) Waiting time of passenger cars

For the case of the supermarket, three improvement policies were evaluated and compared with the present condition. These are: increase parking charge, provision of additional parking spaces, and park & ride.

The efficiencies of the three improvement policies can be estimated as shown in Table 8, where 1.00 indicates the present condition. The simulation results reveal that the average waiting time for park & ride can be reduced by 76.0 percent.

Table 8. Waiting time of passenger cars (supermarket)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Increase of parking charge	1.00	1.00	0.94	0.98
Provision of parking spaces	1.00	1.00	0.94	0.98
Park & ride	0.49	0.02	0.21	0.24

(2) Waiting time of delivery trucks

Four improvement policies were evaluated and compared with the present condition for the case of the supermarket. These are: performance of checking and sorting, provision of additional parking spaces, cooperative delivery, and consolidated delivery.

The efficiencies of the four improvement policies are shown in Table 9, where 1.00 indicates the present condition. Simulations results indicate that the average waiting time for consolidated delivery can be reduced by 82.0 percent.

Table 9. Waiting time of delivery trucks (supermarket)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Checking and sorting system	1.00	1.00	1.00	1.00
Provision of parking spaces	0.68	0.99	0.99	0.89
Cooperative delivery	0.83	0.10	0.11	0.35
Consolidated delivery	0.35	0.09	0.09	0.18

5.3.3 Analysis on the waiting time for a department store

(1) Waiting time of passenger cars

For the case of the department store, three improvement policies were evaluated and compared with the present condition. These are: increase parking charge, provision of additional parking spaces, and park & ride.

The efficiencies of the three improvement policies are shown in Table 10, where 1.00 indicates the present condition. The simulation results reveal that the average waiting time for park & ride can be reduced by 57.0 percent.

Table 10. Waiting time of passenger cars (department store)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Increase of parking charge	1.00	1.00	1.00	1.00
Provision of parking spaces	1.00	0.84	1.00	0.95
Park & ride	0.41	0.69	0.20	0.43

(2) Waiting time of delivery trucks

For the case of the department store, four improvement policies were evaluated and compared with the present condition. These are: performance of checking and sorting, provision of additional parking spaces, cooperative delivery, and consolidated delivery.

The efficiencies of the four improvement policies can be estimated as shown in Table 11, where 1.00 indicates the present condition. Simulations results indicate that the average waiting time for consolidated delivery can be reduced by 72.0 percent.

Table 11. Waiting time of delivery trucks (department store)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Checking and sorting system	1.00	1.00	1.00	1.00
Provision of parking spaces	0.69	0.25	0.98	0.64
Cooperative delivery	0.69	0.20	0.13	0.34
Consolidated delivery	0.56	0.16	0.11	0.28

5.3.4 Analysis on the waiting time for a specialty store

(1) Waiting time of passenger cars

For the case of the specialty store, three improvement policies were evaluated and compared with the present condition. These are: increase parking charge, provision of additional parking spaces, and park & ride.

The efficiencies of the three improvement policies are shown in Table 12, where 1.00 indicates the present condition. The simulation results reveal that the average waiting time for park & ride can be reduced by 63.0 percent.

Table 12. Waiting time of passenger cars (specialty store)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Increase of parking charge	1.00	1.00	1.00	1.00
Provision of parking spaces	0.98	0.62	1.00	0.87
Park & ride	0.41	0.42	0.27	0.37

(2) Waiting time of delivery trucks

Four improvement policies were evaluated and compared with the present condition for the case of the specialty store. These are: performance of checking and sorting, provision of additional parking spaces, cooperative delivery, and consolidated delivery.

The efficiencies of the four improvement policies are shown in Table 13, where 1.00 indicates the present condition. Simulation results indicate that the average waiting time for consolidated delivery can be reduced by 75.0 percent.

Table 13. Waiting time of delivery trucks (specialty store)

Improvement policy	1ha	3ha	5ha	Average
Present condition	1.00	1.00	1.00	1.00
Checking and sorting system	1.00	1.00	1.00	1.00
Provision of parking spaces	0.60	0.73	1.00	0.77
Cooperative delivery	0.35	0.20	0.28	0.28
Consolidated delivery	0.31	0.17	0.28	0.25

5.4 Reduction in waiting time due to improvement measures

Table 14 shows a summary of the reduction in waiting time for passenger cars due to the various improvement measures that were evaluated. A major reduction can be observed by introducing the park & ride system to all the commercial facility type. For example, a 76% reduction in waiting time can be expected at a supermarket, 57% at a department store, and 63% at a specialty store. Thus, the park & ride system is the most efficient measure to reduce waiting time of passenger cars. In contrast, increasing parking charges, and provision of additional parking spaces have relatively minimal effects on the reduction of waiting time.

A summary of the reduction in waiting time for delivery trucks due to the various improvement measures evaluated are shown in Table 15. Major reductions can be expected by introducing consolidated delivery to all the commercial facility type. An 82% reduction in waiting time can be expected for a supermarket, 72% for a department store, and 75% for a specialty store. Thus, consolidated delivery is the most efficient measure to reduce waiting time of delivery trucks. Cooperative delivery ranks second in terms of reducing waiting time. A 65% reduction can be observed for a supermarket, 66% for a department store, and 72% for a specialty store. Checking and sorting system, and provision of additional parking spaces have relatively minimal effects on reducing waiting time.

Table 14. Reduction in waiting time due to improvement measures (passenger cars)

Improvement policy	Commercial facility		
	Supermarket (From Table 8 average)	Department store (From Table 10 average)	Specialty store (From Table 12 average)
Increase of parking charges	2.0%	0.0%	0.0%
Provision of parking spaces	2.00%	5.0%	13.0%
Park & ride	76.0%	57.0%	63.0%

Table 15. Reduction in waiting time due to improvement measures (delivery trucks)

Improvement policy	Commercial facility		
	Supermarket (From Table 9 average)	Department store (From Table 11 average)	Specialty store (From Table 13 average)
Checking & sorting system	0.0%	0.0%	0.0%
Provision of parking spaces	11.0%	36.0%	23.0%
Cooperative delivery	65.0%	66.0%	72.0%
Consolidated delivery	82.0%	72.0%	75.0%

6. CONCLUSION

This paper analyzed improvement measures that minimize waiting time for parking of delivery trucks and passenger cars. Results of the simulation analysis indicate that introducing suitable improvement measures can reduce the total waiting time for delivery and parking activities.

The paper also clarified that traffic impacts vary according to the type of commercial facility. The paper offered a basic methodology of impact analysis for both passenger cars and delivery trucks.

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