A STUDY ON MODELING OF TRUCK'S BEHAVIOR AND POLICY ANALYSIS OF TRANSPORTATION SYSTEM MANAGEMENT IN C.B.D.

Yoji TAKAHASHI
Professor
Dept. of Information Engineering & Logistics
Tokyo University of Mercantile Marine
2-1-6 Etchujima, Koto-ku, Tokyo #135, Japan
Fax. +81-3-5620-6492

Tetsuro HYODO
Associate Professor
Dept. of Infomation Engineering & Logistics
Tokyo University of Mercantile Marine
2-1-6 Etchujima, Koto-ku, Tokyo #135, Japan
Fax. +81-3-5620-6492

Hirohito KUSE
Professor
Dept. of Information Engineering & Logistics
Tokyo University of Mercantile Marine
2-1-6 Etchujima, Koto-ku, Tokyo #135, Japan
Fax.+81-3-5245-7369

abstract: This paper aims to simulate freight truck's behavior and evaluate several transportation management policies to promote a cooperative pickup & delivery service. The simulation analysis has two major features: 1) the modeling of the truck's behavior is based on the Vehicle Routing Problem and 2) the simulation describes actual goods movement observed in a C.B.D. in Japan. The simulation results show the effectiveness of the methodology and we discuss the feasibility of the transportation management policies to realize the cooperative pickup & delivery service.

1. INTRODUCTION

Traffic congestion is a serious problem in Tokyo Metropolitan Area. One of the factors of the congestion is the increase of freight traffic. High frequency of goods movement based on the spread of 'Just-In-Time' type logistics causes the rapid increase of freight traffic and the decrease of loading factor of each truck. Therefore the increase of the loading factor and optimization of freight transportation system are required. To realize the efficient freight transportation, we should understand the characteristics of freight traffic. From the view point of facility planning in the area, location of truck's parking, parking time and vehicle routing are important factors to describe the freight traffic behavior.

This paper aims 1) to build the behavioral model of trucks in C.B.D. and 2) to evaluate the optimal vehicle routing system based on the behavioral model. Detail of the research process according to the above items is as follows.

1) A survey which counts the number of goods in C.B.D. is conducted. From the survey, we calculate the generation and attraction volume by floor use and by time. This statistics show the characteristics of goods movement in the C.B.D.
2) One of the policies to increase the efficiency of freight transportation is to optimize the vehicle routing. In this study, we apply METRO (MEta Truck Routing Optimizer) *(Kubo et al, 1996)* which is one of the most efficient tools to solve hard routing problems. The feature of applying the routing problem is to bring the carrier's principle (cost minimization) into the routing behavior model.
3) Simulation analyses based on METRO are examined to evaluate an effectiveness of several transportation management policies.

Finally, we focus on ability of Transportation Demand (or System) Management policies to promote the freight transportation service.

2. OBJECTIVES AND SCOPE

2.1 Background and objectives

One half of traffic volume in Tokyo Metropolitan Area is freight transportation, therefore, it is necessary for decreasing of the traffic congestion to realize the efficient freight transportation system. Especially, the principal freight transportation in central business districts is related to commercial activities. The general commercial activities are concentrated to small area and specific time so that the integration of pickup & delivery service is one of the efficient procedures *(Nemoto et al, 1992 and Deng et al, 1994)*. Actually, the cooperate pickup & delivery service which can put together many freight from different companies has been introduced to several cities in Japan *(Ieda et al, 1992 and Nemoto et al, 1994)*.

The cooperate pickup & delivery service is one of the logistics activities of private companies, that intends to decrease transportation cost. Therefore, reduction of the cost is an important necessary condition to promote the pickup & delivery service. On the other hand, role of public sector for the promotion is also essential issue. The public sector could adjust interests between the private companies and give them incentives for the promotion.

In this paper, we analyze the cooperate pickup & delivery system based on the principle of private companies as well as the role of public sector.

2.2 The optimum vehicle routing and cooperate pickup & delivery service

One of the public sector's role to promote the cooperate pickup & delivery service is transportation management policies in C.B.D., for example, regulation of traffic flow, parking etc. We analyze and evaluate the several transportation management policies by the modeling of freight transportation behavior.

The pickup & delivery service is the activities of private companies, so that the modeling of the behavior should be based on the principle of maximization of their profit (or minimization of cost). Here, we introduce "the optimum vehicle routing problem" for the description of the behavior, and we evaluate the transportation management policies which affect the pickup & delivery service.

"Vehicle routing problem" is one of the optimization problems which minimize total cost/distance of trucks to pickup & delivery all spatially distributed goods. The optimization problem includes several conditions; maximum driving time or loading weight of each truck etc. The general assumptions of the vehicle routing problem is as follows *(Kubo et al, 1996)* :

1) maximum loading weight of each truck is constant,
2) place & volume of demand are fixed and given,
3) distance, transportation time and cost between all places can be calculated,
4) total weight of goods which are carried by a truck in a route does not exceed the truck's

maximum loading weight,
5) the number of trucks does not exceed the given number,
6) total operation time of each truck does not exceed maximum operation time per day.

The vehicle routing problem is one of the hard problems to solve, because the solution algorithm is based on the combinatorics optimization *(Feo et al, 1994, Glover, 1989 and Kubo, 1995)*. Therefore, if there are many goods or many trucks, the number of routing combinations drastically increase and we can not lead the strict solution. "Saving method" or "sweep method" which can lead approximate solutions have been proposed *(Enkawa et al)*. In this paper, we apply the newly developed software named "METRO (MEta Truck Routing Optimizer)" *(Kubo et al, 1996)*. METRO includes many solution algorithms for vehicle routing problem and it supports an appropriate algorithm to adjust the characteristics of problems to be solved. The detail of METRO is referred to *Kubo et al.(1996)*.

3. THE FEATURE OF STUDIED AREA AND GENERATION & ATTRACTION UNIT OF GOODS

The studied area of this paper is Ginza-district where is a central commercial and business area in Tokyo (Figure-1). There are so many large departmentstores, restaurants and business offices. Amount of goods movement in Ginza-district is also huge, therefore, it may be recognized as a representative example for a cooperate pickup & delivery service.

The other reason we choose Ginza is an actual logistics facility plan nearby the district. Beside Ginza-district, there is Shiodome-area where was a large freight yard of Japan National Railway about 20 years ago. Now Shiodome-area is planned as a re-development area. One of the plans is to construct a cooperative logistics center which can handle goods from/to Ginza-district *(The Tokyo Metropolitan Government Office)*. In this paper, we hypothesize the logistics center in Shiodome-area as a large depot of cooperative pickup & delivery trucks in Ginza-district.

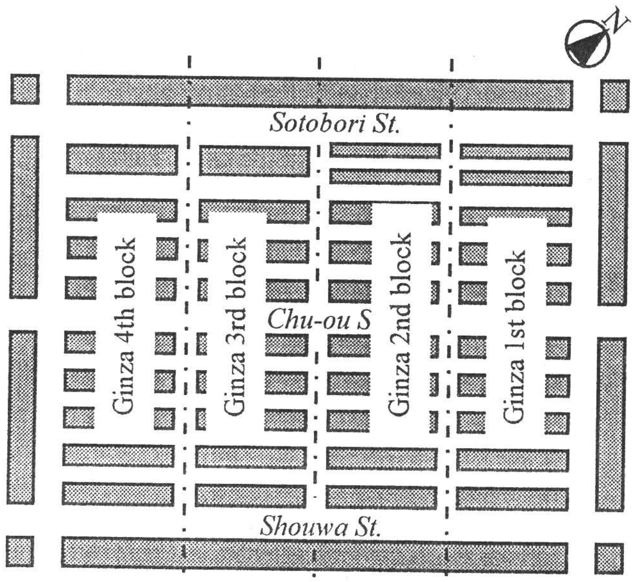


Figure-1 Map of studied area

The actual situation of good movement in Ginza-district was clarified by "Survey of Goods Movement in Ginza-district" which was conducted in 1993 by our laboratory. In the survey, we drew 218 offices randomly and asked them frequency, time and item of goods within a day (see Table-1). At the same time, we counted the number of goods which were pickup & delivered from/to buildings in the surveyed area. The area is about 200m x 600m (Figure-1).

Table-1 Principal items of Ginza-district survey

-Number of surveyed offices: total 218 offices: (business office:56, store: 102, restaurant & bar: 58, hotel: 1 and art gallery: 1) -Number of returns: 166 (rate of return: 76%) -Questionnaire item: 1)Floor attributes: area of floor, floor use and the number of workers 2)Goods attributes: frequency of goods movement by time, principal item, size of goods etc.

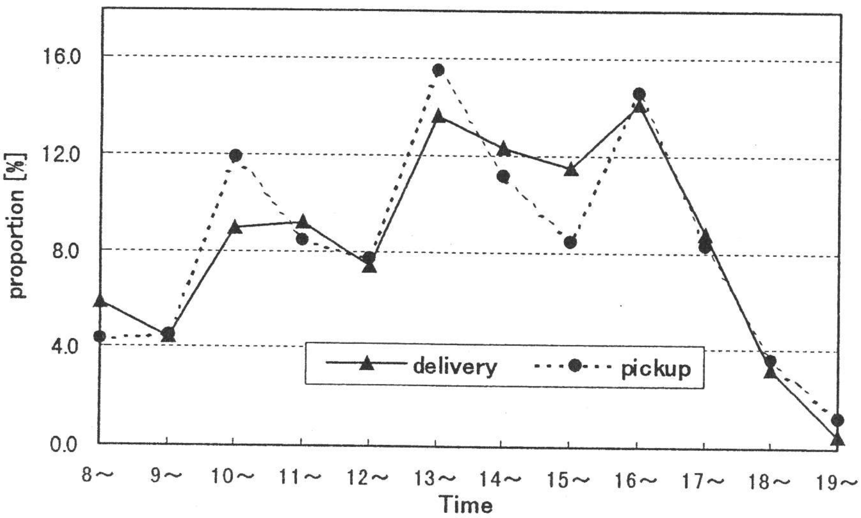


Figure-2 Distribution of goods movement by time

Figure-2 shows one of the characteristics of goods movement in Ginza from the survey data. It suggests that the temporal pattern of frequency of 'pickup' and 'delivery' is quite similar and there are three frequent time; 10:00, 13:00 and 16:00. From the aggregation results of the frequency by floor use, it is clarified that the frequency of pickup & delivery of stores is 1-2 times per day and that of restaurants is 5-6 times per day.

By using the above survey, we estimate the generation & attraction unit of goods by floor use. The result is summarized in Table-2. Then we calculate the generation and attraction volume of goods in each square by multiplying the generation/attraction unit by the area of each square by floor use. Moreover, the volume by time is led by multiplying the above volume by the proportion of each time that was observed by the survey.

Table-2 Generation & attraction unit of goods movement (kg/(100m^2·day))

	Generation	Attraction
business office	8.50	5.78
store	3.54	6.00
restaurant & bar	11.60	14.50

4 SIMULATION ANALYSIS FOR SEVERAL TRANSPORTATION MANAGEMENT POLICIES

4.1 Hypothesis of simulation analysis

We simulate pickup & delivery trucks' behavior based on the Vehicle Routing Problem in Ginza-district. Then several transportation management policies which affect the trucks' routing are compared. The hypotheses of the simulation analysis are as follows.

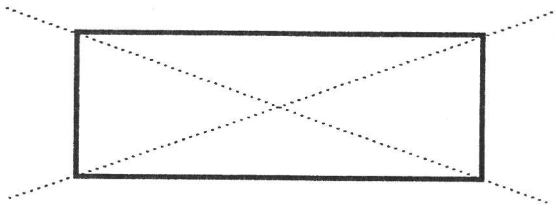


Figure-3 Division of each square

1) All goods which are generated from and attracted to Ginza-district are operated in a depot built-in Shiodome area. In other words, the cooperate pickup & delivery service covers all goods in Ginza-district and the base of the service is located in Shiodome-area. The volume of goods by time is the one of actual goods movement which is observed by Ginza-district survey.
2) To simplify the simulation study, the following four combinations of the cooperate pickup & delivery service are assumed: 1.pickup service in A.M., 2.delivery service in A.M., 3.pickup service in P.M. and 4.delivery service in P.M.
3) Each square is divided into 4 zones (Figure-3), and the generation & attraction goods volume of each zone is calculated as follows.

$$Z_{it} = \left(\sum_k W_k \times A_{ik}\right) \times p_t$$

where, Z_{it} : generation or attraction volume of the *i-th* zone in time t (A.M. or P.M.),

W_k : generation or attraction unit of the *k-th* floor use, A_{ik} : floor space of the *i-th* zone and the *k-th* floor use, p_t : proportion of generation or attraction volume in time t.

4) Maximum loading weight of each truck is 4 tons, and maximum operating duration is 6 [hour / day]. These assumptions are important constraints of the Vehicle Routing Problem.
5) Velocity of each truck on main street and one-way road is 25 [Km/hour]. This is derived from the observed average velocity in Tokyo. Whereas, velocity of the other road (across the main street or the one-way roads) is assumed as 5 [Km/hour]. This is derived from the observed velocity in Fukuoka-area where a cooperative pickup & delivery service has been operated already *(Ieda et al, 1992)*.
6) From the past Fukuoka-area's survey *(Ieda et al, 1992)*, loading & unloading time and

conveyance time are assumed as follows.

- loading & unloading time = 0.05 [min./kg]

- conveyance time = $D \times \Delta d / (18202)$ [min.]

where, D: weight of goods [kg], Δd : distance of each zone's side [m].

4.2 Evaluated transportation management policies

Figure-4 draws the present situation of transportation management in Ginza-district. In our simulation analysis, we evaluate the following transpor tation management policies which affect the cooperative pickup & delivery service.

a) Arrangement of cooperative delivery center in each square:

To promote an efficient cooperative pickup & delivery service, cooperative delivery centers are arranged in each square. The delivery centers put together goods from/to each square, and they could reduce the number of parked trucks and the increase the speed of cars on the road. On the contrary, the cooperative delivery center requires conveyance between the center and each floor. There is a trade-off relation between the increase of the conveyance and the improvement of traffic environment. In this simulation, we assume that each square has one cooperative delivery center (see Figure-5).

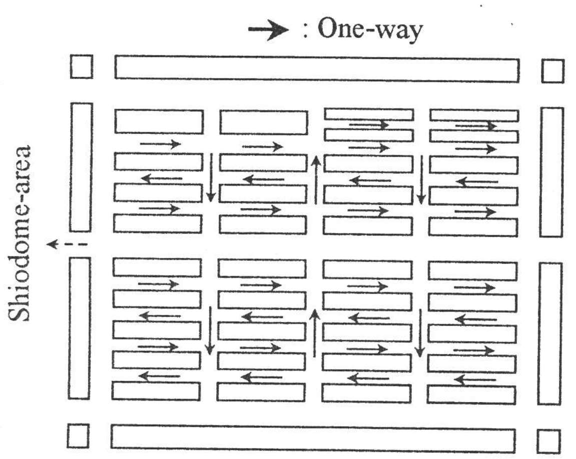


Figure-4 Present situation

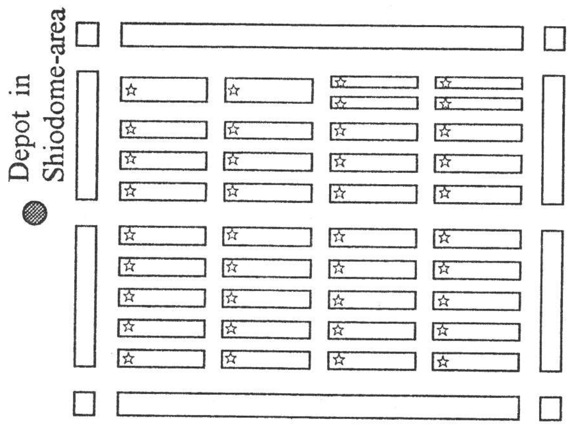


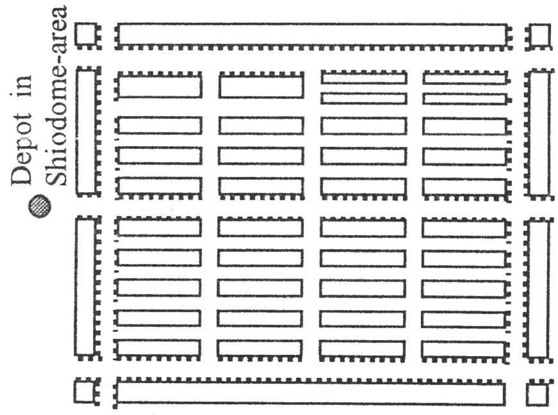
Figure-5 a) Arrangement of cooperative delivery center [☆ : delivery center]

b) Strengthening no-parking regulation:

Now all roads in Ginza-district are no-parking area, however, trucks can actually park everywhere if the parking is in a short time. Here, we assume that the no-parking regulation is strengthened on several roads and trucks and passenger cars can not park even if in a short time. This transportation policy could increase a capacity of road. The broken lines in Figure-6 mean that the regulation is operated.

c) Changing one-way operation:

One-way road is one of the major restrictions for pickup & delivery service, because it increases detour trips. One-way itself should not be operated for the efficiency of truck's routing, however, we assume the relaxation of one-way operation to compare the effectiveness of it as a transportation management policy. Figure-7 illustlates the assumed operation. As mentioned above, the velocity of trucks across one-way road, vertical roads in Figure-7, is assumed as 5 [Km/hour], because there are many signals.



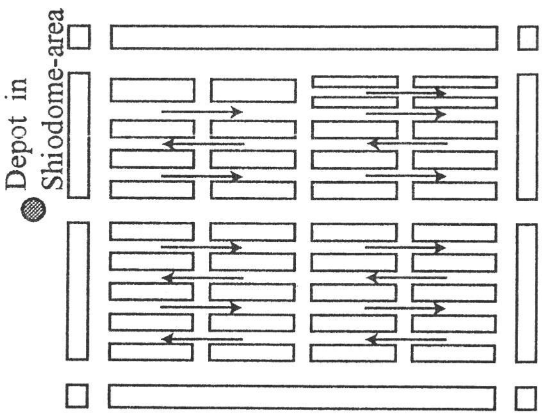


Figure-6 b) Strength no-parking regulation
[broken line = regulated area]

Figure-7 c) Changing one-way operation

4.3 Results and comments on the simulation analyses

The simulation analyses based on the Vehicle Routing Problem are examined as for four situations (pickup, delivery * A.M., P.M.). We simulated three traffic management policies, moreover, several combinations of the policies including 'present situation' are tested. The 'present situation' also means the combination of present transportation management policy and the supposed cooperative pickup & delivery service. So, the present situation with cooperative pickup & delivery service is not the same as the actual goods movement without cooperative pickup & delivery system which might not be optimal from the viewpoint of effective service.

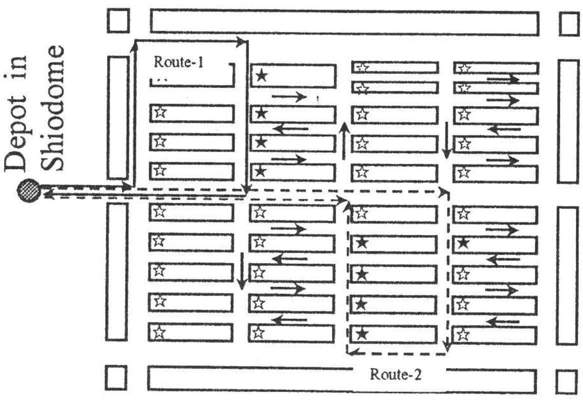


Figure-8 Example of optimum routes

Figure-8 represents optimum routes of the simulation result which assumes 'present situation + a) cooperative delivery centers' in A.M. Table-3-6 show the simulation results as for four situations. In each table, '# of trucks' means the minimum number of trucks for the pickup or delivery service in Ginza-district, 'total distance' means the total distance of pickup or delivery trucks except conveyance and 'total operating time' means 'driving time' plus 'conveyance time'. In this study, we consider 'total distance' as an index of environmental effect (energy consumption or exhaust gas etc.) and 'total operating time' & 'driving time' & 'conveyance time' as an index of operating cost of freight carriers.

The simulation results suggest that the delivery in P.M. requires many trucks. And most of the total operating time belongs to 'conveyance time', because the studied area is so small. However, the proportion of it is similar to the past survey *(Ieda et al, 1992)*. In present situation, the almost conveyance time equals to time of illegal parking on road side, therefore, it is supposed that the pickup & delivery service has a harmful influence upon a traffic condition in Ginza-district.

Table-3 Simulation result(1) [pickup, A.M.]

	# of trucks	total distance (m)	total operating time (min.)	driving time (min.)	convey-ance time (min.)
present	9	39,015	2,121	89	2,032
present + a)	9	27,870	2,886	65	2,821
present + b)	9	42,900	2,346	99	2,247
a) + c)	9	20,745	2,878	57	2,821
b) + c)	9	35,160	2,336	89	2,247

Table-4 Simulation result(2) [delivery, A.M.]

	# of trucks	total distance (m)	total operating time (min.)	driving time (min.)	convey-ance time (min.)
present	5	35,265	1,138	80	1,058
present + a)	5	25,275	1,521	59	1,462
present + b)	5	37,965	1,252	88	1,164
a) + c)	5	14,340	1,507	45	1,462
b) + c)	5	31,740	1,250	86	1,164

Table-5 Simulation result(3) [pickup, P.M.]

	# of trucks	total distance (m)	total operating time (min.)	driving time (min.)	convey-ance time (min.)
present	6	36,765	1,432	83	1,349
present + a)	6	20,985	1,922	49	1,873
present + b)	6	35,535	1,575	83	1,492
a) + c)	6	13,905	1,914	41	1,873
b) + c)	6	28,260	1,568	76	1,492

Table-6 Simulation result(4) [delivery, P.M.]

	# of trucks	total distance (m)	total operating time (min.)	driving time (min.)	convey-ance time (min.)
present	10	44,790	2,391	102	2,289
present + a)	10	28,380	3,254	67	3,187
present + b)	10	42,765	2,633	99	2,534
a) + c)	10	23,550	3,252	65	3,187
b) + c)	10	35,790	2,623	89	2,534

a) Arrangement of cooperative delivery center
b) Strengthening no-parking regulation
c) Changing one-way operation

To evaluate the effect of the transportation policies visually, we draw Figure-9,10 which represent each index value relating to 'present situation'. First, it is shown that the arrangement of cooperative delivery center reduces 'total distance' and 'driving time', however, the increase of 'conveyance time' to the delivery centers causes 36% increase of 'total operating time'. The carriers may not bear the additional conveyance cost. Thus, to realize the arrangement of the cooperative delivery center, it is necessary that customers should carry their goods from/to the cooperative delivery centers by themself. The reduction of 'driving time' means the reduction of the social cost (environmental effect or energy consumption), therefore, means of decreasing conveyance cost (private cost) should be considered for the reduction of the social cost.

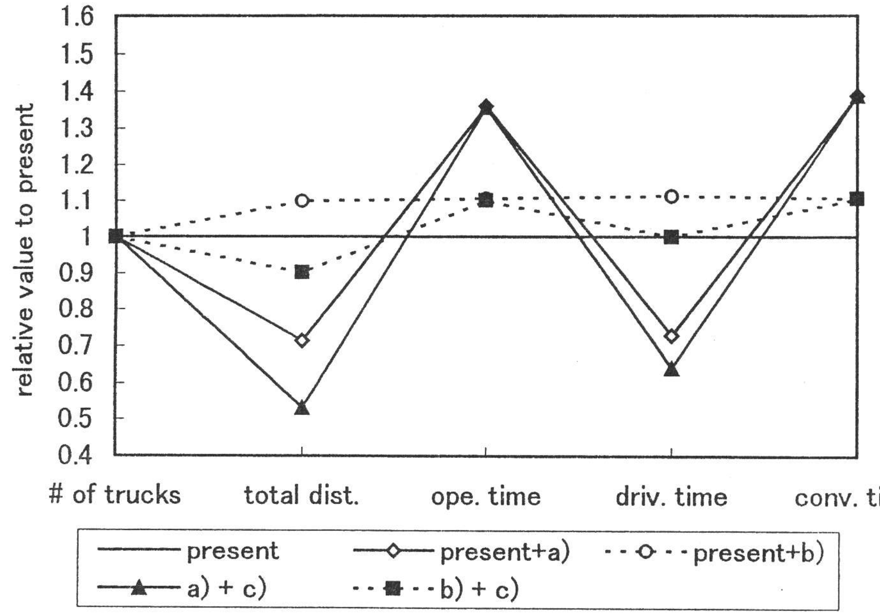


Figure-9 Comparison result between indices (present=1) [pickup, A.M.]

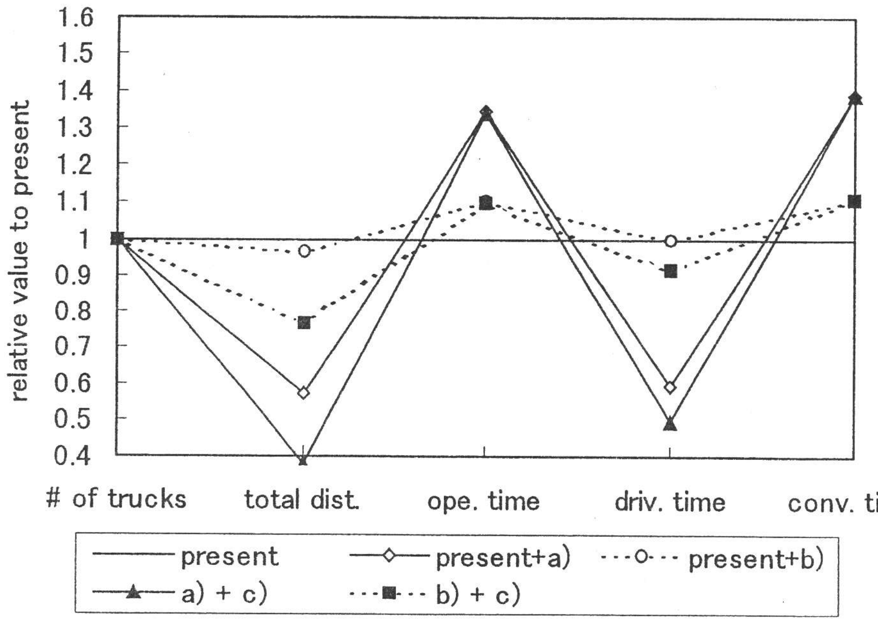


Figure-10 Comparison result between indices (present=1) [delivery, P.M.]

Second, 'b) strengthening no-parking regulation' also causes similar results as 'a) arrangement of cooperative delivery center' (see Figure-10,11). However, in Figure-9, 'total distance' and 'driving time' are increased than the present situation. This means that the result of the policy is influenced by the distribution of goods movement. Truck driver conveys goods by himself in this case. Therefore the regulated area should be appropriate, otherwise, this regulation policy causes harmful result.

Third, 'c) changing one-way operation' generally reduces 'total distance' and 'driving time'. As mentioned above, location of one-way road should be designed under the consideration of passenger cars or passed traffic. So we do not suggest the examined case as an identical operation. However, it is represented that the change of road network design can increase the efficiency of goods movement, even if the design is limited to freight transportation.

We summarize the results of each policy in Table-7. The following comments are derived from the table.

1) The index of social cost, 'total distance', suggests that almost policies are effective except 'present + c)strengthening no-parking regulation'.
2) The carriers could accept 'a)arrangement of cooperative delivery center' if the customers bear the conveyance cost.
3) If an effective road network which can reduce detour of truck route is designed, the carriers could accept 'b) strengthening no-parking regulation'. However, the distribution of customers' demand should be considered for the regulation.

Table-7 Summary of the results of each policy

	# of trucks	total distance (m)	total operating time (min.)	driving time (min.)	conveyance time (min.)
present + a)	±	−	+	−	+
present + b)	±	+	+	±	+
a) + c)	±	−	+	−	+
b) + c)	±	−	+	±	+

a) Arrangement of cooperative delivery center
b) Strengthening no-parking regulation
c) Changing one-way operation

5. CONCLUSION

This study simulated the behavior of a pickup & delivery truck and evaluated the several transportation management policies in C.B.D. Especially, the developed simulation method based on the Vehicle Routing Problem is an advanced feature. The principal results of this paper are summarized as follows.

1) We suggest the simulation methodology which includes the Vehicle Routing Problem and clarify the effectiveness.
2) By the simulation study, we represent the quantitative indices as for the several transportation policies which can promote a cooperative pickup & delivery service in C.B.D..
3) The necessary conditions of the policies are examined from the several viewpoints; carriers' behavior, environmental effect and customers' cost.

The simulation assumes a hypothetical cooperative pickup & delivery service which is now in planning stage. Therefore we can not check the predictability of our simulation. And the studied area is small so as to simplify the analysis. They are further topics to be studied.

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REFERENCES

Deng,Y.P., Takada,K. and Michiyoshi,T.(1994)A cooperative delivery depot that reduces and smoothes goods distribution in urban areas -A theory for establishing a transportation system capable of reducing CO_2 emission-.
City Planning. No.29. 73-78 (in Japanese)

Enkawa, Itoh(1996)
Methods of Production Management. Asakura-shoten (in Japan)

Feo,T.A., Resende,M.G.C. and Smith,S.H.(1994) A greedy randomized adaptive search procedure for maximum independent set.
Operations Research.42. 860-878

Glover,F.(1989) Tabu search I.
ORSA Journal on Computing. 1. 190-206

Ieda,H., Sano,K. and Tsuneya,S.(1992)A macroscopic collection/delivery model of goods transport and its application on a inter-carrier cooperative cargo logistics.
Infrastructure Planning Review. No.10. 247-254 (in Japanese)

Kubo,M.(1995)Discrete Structure and Algorithm IV,
Meta-Heuristics **(ed.Murota)**. Kindai-Kagakusya (in Japanese)

Kubo,M. and Mouri,H.(1996)Distribution support system METRO and its application. **Operations Research**.Vol.41 No.8. 429-435 (in Japanese)

Nemoto,T(1992)Area wide inter-carrier consolidation of freight in urban areas. **City Planning**, No.27. 349-354 (in Japanese)

Nemoto,T. and Taniguchi,E.(1994)Operation policies for logistics systems in urban area.*Physical Distribution System in Urban Area.* 97-118 (the 28th Symposium of Infrastructure Planning) (in Japanese)

The Tokyo Metropolitan Government Office(1993) **Feasibility study of underground logistics systems in urban business district**. (in Japanese)