PLANNING ON-STREET LOADING-UNLOADING SPACES CONSIDERING THE BEHAVIOUR OF PICKUP-DELIVERY VEHICLES

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Abstract: The provision and management of loading-unloading spaces for pickup-delivery vehicles are important issues in busy urban areas. In areas without loading-unloading spaces, delivery vehicles often park on the roadway lanes and this generates negative impacts in terms of road capacity and safety. The model described in this paper can be classified as a facility location problem. It determines the optimal location of loading-unloading spaces by minimizing the total cost that is comprised of delay penalty, fixed cost, operation cost, parking fee and waiting cost of both pickup-delivery vehicles as well as passenger cars. Furthermore this model takes into account both the behavior of pickup-delivery vehicles and that of passenger cars. Using a test road network the model was able to determine a configuration of parking spaces that achieved a cost reduction of approximately 16%.

Key Words: City Logistics, Loading-unloading spaces, Queuing theory, Parking Enforcement, Behavior of pickup-delivery vehicles

1. INTRODUCTION

This paper presents a methodology for determining the optimal locations of on-street loading-unloading spaces that can be used to evaluate the efficiency of enforcement for controlling illegal parking of passenger cars at loading-unloading spaces.

The provision and management of loading-unloading spaces for pickup-delivery vehicles are important issues in busy urban areas. In areas lacking such spaces, delivery vehicles often park in active traffic lanes, negatively impacting road capacity and safety. Even in areas where these spaces exist they are often occupied by passenger cars. In addition, a lack of loading-unloading spaces is a serious problem in terms of cost and service for freight carriers.
that deliver goods within urban areas. Drivers are forced to search for vacant spaces if no vacant spaces exist at the desired location.

Preliminary planning for this study included, (1) a questionnaire survey of carrier drivers and (2) a review of case studies of previous on-street loading-unloading experiments. Based on these studies we focused on the loading-unloading operations of pickup-delivery vehicles in urban areas and formulated an on-street loading-unloading spaces location planning model. This model considers the parking behavior of both pickup-delivery vehicles and passenger cars (Section 3).

Among previous studies similar to this model, there are studies on the MWLRP (modified warehouse location-routing problem). The MWLRP was a recently developed model in a research area where the main focus previously was location analysis; it focused on the interdependency between center location and routing problems. Perl and Daskin formulated the WLRP (warehouse location-routing problem) by means of mixed integer programming and then broke the MWLRP (which is an improved version of the WLRP) down into sub-problems, i.e., the MDVDP (multi-depot vehicle-dispatch problem), the WLAP (warehouse location-allocation problem) and the MDRAP (multi-depot routing allocation problem) to develop solutions. Hansen et al. improved the solutions devised by Perl and Daskin and succeeded in obtaining a more realistic solution faster. Recently studies conducted by Wu et al. that further developed the MWLRP and the MDLRP (multi-depot location-routing problem) enabled such settings as “use by multiple types of vehicles” and “limitations on the number of vehicles using the space by type of vehicle”.

Most of the studies on location-routing problems including the ones mentioned above focus on the allocation of logistics facilities and improving the operational efficiency of pickup-delivery vehicles over a relatively wide area. They obtain solutions based on the trade-off between costs for setting up and operating such logistics centers depots and the transportation/delivery costs. Our study on the other hand focuses on on-street loading-unloading spaces in urban areas with consideration of the parking behavior of passenger cars that have an impact on loading-unloading operations, and tries to obtain optimum space location based on the transportation and waiting time costs of passenger cars.
2. PRELIMINARY SURVEY ON LOADING-UNLOADING OPERATIONS

To identify the main issues for developing a loading-unloading space improvement plan, we conducted a questionnaire survey amongst drivers who are engaged in pickup and delivery services in the urban area of Kyoto City, as well as a case study on experiments related to loading-unloading.

2.1 Questionnaire Survey on Loading-Unloading Operations

The questionnaire survey on loading-unloading was performed to understand the actual situation of loading-unloading operations, and to grasp the relationship between on-street loading-unloading operations and other transportations from the viewpoint of drivers engaged in loading-unloading operations. The key items of investigation include those related to loading-unloading operations (point of operation/frequency/time, etc.), problems associated with parking and loading-unloading operations, and knowledge and awareness of dangers.

The survey results are summarized below. (Sample Size = 68)

- More than 85% of drivers surveyed performed on-street loading-unloading routinely.
- Approximately 75% of drivers surveyed felt a "pang of conscience" for parking on-street for loading-unloading. The reasons for, "not feeling a pang of conscience", included "unavoidable circumstances of the business", "custom of the trade" and "there is no other place ".
- More than 50% of the loading-unloading operations were done in a one-way street or a road with one lane in each direction that tends to cause a traffic jam due to blocking of a car lane.
- As for the reason for prowl running in search for a parking space, parking spaces used by passenger cars represents approximately 54%, while parking spaces used by pickup-delivery vehicles represents approximately 22%.
- As for the distance for delivering goods from the parking space to the customer (using a trolley), more than 60% were “10 m or less each way”.
- As for the acceptable distance from a customer to the location of loading-unloading space, 29% answered “within 10 m” 17% “within 20 m”, 17% “within 30 m”, and 17% “within 50 m”. Only a very small number of respondents (6%) answered "do not care how far it is located".

2.2 Previous Experiments

As only a limited number of experiments that included issues relating to loading-unloading were carried out in recent years (in the year 2000 and later), we studied 1) an experiment in the Shibuya area involving feeder logistics measures and parking management (Shibuya-ward, Tokyo, 2000), 2) an experiment on the conversion from on-street to off-street loading-unloading for creation of bicycle riding spaces (Nerima-ward, Tokyo, 2002), and 3) an experiment on countermeasures against illegal parking in Showa street (Taito-ward, Tokyo, 2003). Information obtained from these studies is summarized below.

- For operation/management, combined implementation of both software (ie. management) and hardware (ie. physical infrastructure) were effective in each case.
- Convenience on the part of logistics companies who use a parking facility is important (e.g. location, size, form, slope, working hours and charge, vacancy information propagation and parking space reservation)
- IT (information technology) plays an important role in monitoring/information propagation for operation and management.
- Legal positioning of the on-street loading-unloading spaces and parking time needs to be reviewed.
- Planning with consideration of the characteristics of the local area is required.
- Activities to raise awareness of drivers by supervisors and security guards, including explanation of rules, restriction on the use of on-street loading-unloading spaces by passenger cars, have turned out to be very effective.

2.3 Summary of Preliminary Surveys

Based on the preliminary survey the model developed has the following items as parameters

- Location and number of on-street loading-unloading facilities
- Form of on-street loading-unloading facilities
- Maximum available time and charges
- Information utilization methods (presentation of vacancy information or reservation system)
- Education campaigns (usage regulations for passenger cars)
- Distribution and traffic characteristics of the area
3. MODEL

A location model shall be developed and crackdown activities shall be studied according to the results of preliminary surveys, in particular, a questionnaire survey, which has found that “More than 85% of drivers surveyed performed on-street loading-unloading routinely”, “Parking spaces used by passenger cars represents approximately 54%”, and “the acceptable distance from a customer to the location of loading-unloading space”.

3.1 Framework

The model we have developed could be included in the facility location problems. The model is composed of two sub-models (Figure 1): (1) a model for on-street loading-unloading space location problems, and (2) a traffic simulation model for pickup-delivery vehicles and passenger cars on a city road network.

The upper-level model is a model planned by decision makers such as the policy planners of the municipal government. Based on the layout of on-street loading-unloading spaces planned by the upper-level model, operation of pickup-delivery vehicles as well as parking behavior of passenger cars are defined in the lower-level model. Total cost obtained by adding up the costs incurred by each vehicle is retuned to the upper-level model. The location solution of on-street loading-unloading spaces is determined by GA (genetic algorithm).

The on-street loading-unloading spaces location model (1) determines the optimal location of loading-unloading spaces by minimizing the total cost, which is composed of delay penalties, fixed costs, operation costs, parking fees and waiting costs of pickup-delivery vehicles as well as for passenger cars (Equation 1).

![Figure1. Structure of Model](image-url)
The traffic simulation model (2) takes the behavior of both passenger cars and pickup-delivery vehicles into account, as follows: 1) Passenger cars are generated based on queuing theory and approach parking spaces for passenger cars. When no parking space is available, they attempt to enter loading-unloading spaces at a level depending upon the level of enforcement. 2) Pickup-delivery vehicles have information about their customers (e.g. location, time window, and routing pattern).

\[ 
\text{Minimize:} \\
C_{total} = \sum_{l=1}^{m} C_{r,l} (t_{l,0}, x_l) + \sum_{l=1}^{m} C_{s,l} (t_{l,0}, x_l, Y_l) \\
+ \sum_{l=1}^{m} C_{p,l} (t_{l,0}, x_l, Y_l) + \sum_{k=1}^{n} C_{w,k} (z_k) 
\]  

where,

- \( C_{total} \): Total Cost
- \( C_{r,l} (t_{l,0}, x_l) \): operating cost for vehicle \( l \)
- \( C_{s,l} (t_{l,0}, x_l, Y_l) \): carriage and parking cost for vehicle \( l \)
- \( C_{p,l} (t_{l,0}, x_l, Y_l) \): penalty cost for vehicle \( l \)
- \( C_{w,k} (z_k) \): cost incurred by passenger car \( k \) by waiting to park

- \( m \): total number of vehicles in a area
- \( t_0 \): arrival time vector for all vehicles to an area
  \( t_0 = \{ t_{0,l} | l = 1, m \} \)
- \( x_i \): assignment and order of visiting spaces for vehicle \( l \)
  \( x_i = \{ s(i) | i = 1, S_i \} \)

- \( s(i) \): i the space visited by all vehicles
- \( S_i \): total number of spaces
- \( Y_i \): assignment and order of all customers for vehicle \( l \)
  \( Y_i = \{ y_{l,i}(i) | i = 1, S_i \} \)
- \( y_{l,i}(i) \): assignment and order of visiting customers from space \( s(i) \) for vehicle \( l \)
  \( y_{l,i}(i) = \{ h(j) | j = 1, H_{l,i}(i) \} \)
- \( h(j) \): j th customer visited from a space
- \( H_{l,i}(i) \): total number of customers visited from space \( s(i) \) for vehicle \( l \)
- \( n \): total number of passenger cars in a area
- \( z_k \): waiting time until passenger car \( k \) parks

The traffic simulation model (2) takes the behavior of both passenger cars and pickup-delivery vehicles into account, as follows: 1) Passenger cars are generated based on queuing theory and approach parking spaces for passenger cars. When no parking space is available, they attempt to enter loading-unloading spaces at a level depending upon the level of enforcement. 2) Pickup-delivery vehicles have information about their customers (e.g. location, time window, and routing pattern).
3.2 Behavior of Pickup-delivery vehicles

In the first stage a pickup-delivery vehicle selects a loading-unloading space ($p^*$) in consideration of total time, which is composed of driving time to a space from the current position and carrying time for delivering goods by trolley to the customer from the parking space.

When a vehicle arrives at the customer’s location ($p^*$), the model compares the time for parking and delivering goods to the current customer from the closest loading-unloading space, to the time for choosing a different loading-unloading space and subsequently delivering the goods to the customer. The vehicle then selects the quickest scenario. In other words, if the loading-unloading space ($p^*$) is occupied by passenger cars or another pickup-delivery vehicle, the vehicle elects to either deliver after waiting until the space ($p^*$) is available, or to deliver after moving to another space. The loading-unloading space choice behavior model of pickup-delivery vehicles is formulated as follows:

$$ p^* \text{ Satisfy } T_{p_l, p^*, y_{l,i,p}} = \min_{p=1}^{P} \{ T_{l,p,y_{l,i,p}} \} $$

$$ \text{where,} $$

$$ T_{p_l, p^*, y_{l,i,p}} = T_{r,l}(P_l, p) + T_{s,l}(y_{l,i,p}) $$

$$ T_{f,p^*}(p) = \min \left[ T_{s,l}(y_{l,i,p^*}) + g(p^*) \text{, } \min_{1 \leq p \leq P_{p}} \{ T_{l,p,y_{l,i,p}} \} \right] $$

$$ \text{where,} $$

$p$ : loading – unloading space number; $p = \{1, \ldots, P_{p}\}$

$P_p$ : total number of loading – unloading spaces; given

$l$ : vehicle number; given

$P_l$ : present position of vehicle $l$

$y_{l,i,p}$ : assignment and order of visiting customers for vehicle $l$ from space $p$

$T_{r,l}(P_l, p)$ : time incurred by vehicle $l$ for delivering goods to customers from space $p$

$T_{s,l}(y_{l,i,p})$ : time incurred by vehicle $l$ for carrying goods to customers from space $p$

$T_{f,p^*}(p)$ : time incurred by vehicle $l$ for carrying goods to customers $y_{l,i,p^*}$ if space $p$ is occupied

$g(p)$ : waiting time estimate function of waiting time at space $p$ when space $p$ is occupied
3.3 Behavior of Passenger Cars

Illegal parking of passenger cars in loading-unloading spaces occurs frequently; the result of our preliminary survey also suggests that enforcement of passenger cars is a key to the loading-unloading spaces operation.

In this research, passenger cars are generated based on queuing theory and approach parking spaces for passenger cars. When no parking space is available, they attempt to enter loading-unloading spaces at a level dependent upon the level of enforcement. To represent the difference of traffic characteristics by area, the values of the average arrival rate and the average service rate are defined for each block (Figure 2).

When the number of passenger cars parking in a block exceeds the number of parking spaces in the area, waiting for a vacant parking space occurs. A passenger car waiting then begins to park in loading-unloading spaces or starts moving to other block according to a given probability. While passenger cars park in loading-unloading spaces, pickup-delivery vehicles cannot use this parking space until the passenger cars leave them. As we have seen in Section 2, the tug-of-war over loading-unloading spaces between passenger cars and pickup-delivery vehicles as well as between pickup-delivery vehicles make it possible for us to study setting standard rules, the effect of education campaigns, and the effects of information technology utilization such as propagation of vacancy information and a reservation system.

![Figure 2. Application of Queuing Theory to Behavior of Passenger cars](image)

- Customers of vehicle A
- Customers of vehicle B
- Customers of vehicle C
- Candidate divisions of loading-unloading spaces
- $i$: Block number
- $\lambda_{pi}$: Average arrival rate of passenger cars at Block $i$
- $\mu_{pi}$: Average service rate of passenger cars at Block $i$
4. Effects of Enforcement to illegal parking

The result of the simulation performed to investigate the effect of controlling passenger cars that encroach into pickup-delivery vehicle parking area is described in this section.

4.1 Scenarios and Conditions

In Japan, loading-unloading facilities are chronically in short supply especially in urban areas. In addition, use of loading-unloading space by passenger cars is obstructive to smooth delivery behavior of the pickup-delivery vehicles (2.1). Insufficient loading-unloading facilities and the use of loading-unloading facilities by passenger cars induce prowl driving by pickup-delivery vehicles in search for a parking space and this gives serious adverse effect on transit traffic. As indicated in 2.3, the use of loading-unloading spaces by passenger cars has been restricted effectively. Therefore, further reinforcement of this type of control shall be studied according to the following scenarios.

We applied our model to a test road (Figure 3) where several scenarios were investigated;

**Scenarios:**
(1) Passenger cars do not use any loading-unloading spaces
(2) 10% of passenger cars attempt to use loading-unloading spaces in violation of the law
(3) 20% of passenger cars attempt to use loading-unloading spaces in violation of the law

**Conditions:**
(1) Number of pick-up delivery vehicles: Ten vehicles were defined. Each vehicle picks-up and delivers to multiple customers (5-10)
(2) Number of customers and time-windows: Forty costumers were defined and were designated soft time windows

![Figure 3 Test Road Network](image-url)
4.2 Numerical Results

Figure 4 shows that the total cost of Scenario 2) was reduced by approximately 16% compared to Scenario 3). In the graph (Figure 4) the right end represents the least stringent level of control, which means that 20% of passenger cars attempting to use loading-unloading spaces. The left end represents the severest level of control which means that no passenger cars attempt to use loading-unloading spaces.

When control is enforced, the waiting time cost of passenger cars increases. On the contrary, when the control is relaxed, passenger cars tend to occupy the pickup-delivery vehicle parking spaces which results in an increase of pickup-delivery vehicle driving costs and costs for delivering goods to the customer by trolley.

As more stringent control is applied to the illegal parking of passenger cars, the cost required for pickup-delivery vehicles decreases. This is because with an increased availability of loading-unloading space nearer to the destination, distance for carrying by trolley from spaces to customers and waiting time for parking in the loading-unloading facilities is reduced. On the other hand, the cost for the other type of vehicles increases. This is because passenger cars, which cannot find a parking lot in the general parking facilities, will have difficulty in finding a parking lot in the loading-unloading facilities, too. This only results in a longer waiting time for parking in the general parking facilities. Thus, there is a trade-off relationship between the two types of vehicles and the total cost is minimized when the severity of control is at mediocre level with the scenario 3, while the total cost becomes the highest when control is the severest. To sum up, it is confirmed that while the cost related to the pickup-delivery vehicles can be reduced by reinforcement of control on illegal parking of passenger cars, the total cost may rise as a result of disadvantage caused by the control which is too stringent.

![Figure 4 Numerical Results](image-url)
5. CONCLUSIONS

This paper presented the results of surveys concerning loading-unloading spaces and the outcomes of a model that determines the optimal location of loading-unloading spaces. The following findings were presented:

The results of the preliminary surveys show that not only hardware aspects (improvement of infrastructure) but also software aspects (infrastructure management including utilization of information technology for propagation of vacancy information and reservation, setting standards on usage time limitations and charges and education campaigns on regulations) need to be reviewed at both the planning and evaluation level.

A model that determines the optimal location of loading-unloading spaces by minimizing the total cost was presented, taking into account both of the behavior of pickup-delivery vehicles and that of passenger cars. By applying the model to test road network, the total cost was reduced by approximately 16% dependent upon the level of enforcement.

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