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# Simulation Analysis on the Evaluation of Parking Reservation System

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## Abstract

In general, information provision is expected to contribute to disperse traffic demand from congested roads or car parks to less congested ones. On the other hand, information may not improve traffic condition if all roads are congested or all car parks are fully occupied. In such circumstances, we should try to disperse traffic demands spatially as well as temporally. In this study, Parking Reservation (PR) system is proposed to disperse parking demands temporally. The concept of PR system is similar to the reservation of popular restaurants. If the car park is popular and we know it is full in advance, then we do not have to go and check the availability of the car park. To evaluate the effects of PR system, we should clarify how drivers would behave under such systems. For this purpose, user responses under PR system are collected and evaluated using questionnaire-based analysis. Then, a road traffic simulation model with parking choice behaviour under PR system is created. Through various case studies, effects of the system from various points of views such as car park users, drivers, car park managers as well as society are discussed. Through the case studies, we found that 1) the effect of PR system may vary largely on where reserved car parks are located, 2) there is no 'hunting' phenomenon in introducing the system, i.e the larger amount of drivers are interested in using reserved car parks, the more benefit the society will obtain, and 3) PR system is really helpful for drivers who need to arrive at their destination on time.

## Keywords

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# Simulation Analysis on the Evaluation of Parking Reservation System

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## Abstract

In general, information provision is expected to contribute to disperse traffic demand from congested roads or car parks to less congested ones. On the other hand, information may not improve traffic condition if all roads are congested or all car parks are fully occupied. In such circumstances, we should try to disperse traffic demands spatially as well as temporally. In this study, Parking Reservation (PR) system is proposed to disperse parking demands temporally. The concept of PR system is similar to the reservation of popular restaurants. If the car park is popular and we know it is full in advance, then we do not have to go and check the availability of the car park. To evaluate the effects of PR system, we should clarify how drivers would behave under such systems. For this purpose, user responses under PR system are collected and evaluated using questionnaire-based analysis. Then, a road traffic simulation model with parking choice behaviour under PR system is created. Through various case studies, effects of the system from various points of views such as car park users, drivers, car park managers as well as society are discussed. Through the case studies, we found that 1) the effect of PR system may vary largely on where reserved car parks are located, 2) there is no 'hunting' phenomenon in introducing the system, i.e. the larger amount of drivers are interested in using reserved car parks, the more benefit the society will obtain, and 3) PR system is really helpful for drivers who need to arrive at their destination on time.

## Introduction

Vehicle parking on road illegally is one of the major urban traffic problems in Japan. Illegally parked vehicles, vehicles waiting on-road for a vacant parking space and searching for an available parking space have a strong influence on the flow of traffic. To help alleviate these problems, many cities provide parking availability information. Such systems are called Parking Guidance and Information (PGI) system. However, if all the alternative routes/car parks are congested, information has little effect on drivers. For example, information that all car parks are full informs drivers almost nothing. In such cases, diverting traffic demand temporally as well as spatially is required. In this paper, parking reservation system (PR system) is proposed. PR system ensures drivers to enter a car park without waiting if they have reserved their car park in advance. Drivers are requested to contact with PR system before they depart, and if a car park space is available, this space is reserved for them.

Although we have many experiences to reserve public transport systems like air or intercity railway, we do not have many cases to apply reservation schemes into private car transport. One of the preceding systems is found when XXIII Olympic Games are held at Los Angels (Post et. al, 1985). When a large event such as Olympic Games is held, there are likely to have a heavy congestion in car parks as well as on roads. A characteristic of this reservation system is that it is operated together with park and bus-ride system. People who made a reservation in advance could get a right to park at a specific car park and sit on a bus to the game site. They needed to pay additional $1.00 to reserve. As traffic planners could grasp the demand for bus in advance, they assigned the buses referring the demand. Also, they could disperse the parking demand and bus-riding demand because it was possible to force the vehicles to other car parks if all the parking spaces were reserved at one car park. Consequently, it is reported that arriving time of the vehicles dispersed according to the departure time of the bus they are designated to use, and they could save up to $150,000 by allocating buses efficiently.

There are some conceptual analyses in introducing PR system. Hilton (1989) placed PR system as one of the method to manage the parking demand actively, and he discussed what should be considered in installing PR system. He summarised the strategy of the parking managers by considering a lot of possible cases, and concluded that elastic application of parking fee is quite important. However, his study only discusses conceptually about installing PR system.

Minderhoud and Bovy (1995) tried to evaluate the effect of PR system on the flow of traffic. They propose Dynamic Parking Management System to manage a parking demand adequately, and PR system is placed as a key system. The proposed PR system has the following characteristics,

1) All the vehicles entering into a city centre must reserve a parking lot in advance,
2) Vehicles without reservation cannot enter into the city centre,
3) Parking fee changes according to the parking demand.

To discuss the effect of PR system, they assumed the decision principles of drivers' trip generation, mode choice, route choice and parking choice, and the models are applied to the traffic simulation model. Through the case studies in Bussum (the Netherlands), it is concluded that by introducing PR system, it is expected that produced traffic volume increases but traffic demand entering to a city centre decreases. Also they pointed out that safety margin of the parking capacities for the vehicles coming or leaving later than scheduled time may have large influences on the effect of the system. One issue in their study is that the authors decide the behavioural models of the drivers and their parameters. Another is that they assume that all the car parks are assumed to be reserved car parks, and vehicles without reservation cannot enter into the centre. It is not realistic to exclude the through traffic entirely.

Although some analyses on PR system can be found, there are little researches concerning about the behavioural responses when PR system is installed. It is apparent that the effect of PR system heavily relies on how drivers behave, and is quite meaningful to model a driver's behaviour when PR system is installed. Instead of paying the additional fee and fixing their schedule, they can reduce the uncertainty of total travel time to destination. However, when there is a mismatch between demand and supply in the use of reserved car park, PR system may not function because a total capacity of car parks excluded from PR system decrease in real by introducing PR system. Therefore, the circumstances where PR system functions efficiently should be investigated. Upon these backgrounds, this paper attempts to evaluate PR system based on behavioural analysis. This paper consists of four parts. Firstly, PR system is identified with some existing researches and expected effects and apprehensive problems are summarised. Secondly, to observe driver behaviour under PR system, a questionnaire survey is conducted and parking choice model is calibrated. Thirdly, the car park choice model is installed into our existing traffic simulation model and the effects of PR system are evaluated through case studies.

## Parking Reservation System

Readers can imagine a concept of PR system by thinking about eating at a popular restaurant. Usually, people who want to have dinner at popular restaurants try to book a table in advance. In exchange for flexibility in their activity, they can get a certification to eat there without waiting. Similarly, PR system ensures drivers to enter a car park without waiting. Drivers are requested to contact with PR system in advance, and if any car park space is available, this space is booked for them. If there are no available spaces at their desired time, they have to modify their plan either using other car parks that is not included in PR system (in this study, we call such car parks *regular car parks*, and car parks that is included in PR system is called *reserved car park*), changing their activity schedule and use reserved car park, or changing their travel mode. Also, for more efficient use of car parks, it is desirable that the system accepts all the booking request of the whole area. The expected effect and apprehensive problems are summarised as follows.

### Expected effects of PR system

From a view point of reserved car park users

Instead of paying additional fee and losing some flexibility of behaviour, drivers who booked

spaces can enter the car park without waiting. As waiting time to enter a car park and wandering time to search available car parks are major reasons for the increase of travel time, the uncertainty about travel time to the destination will decrease enormously.

From a view point of regular car park users

If some of reserved car park users shift their departure time instead of using regular car parks without changing departure time, parking demand in peak hours is expected to disperse. Therefore, waiting time for entering a regular car parks as well as driving time to reach the car parks are expected to reduce.

From a view point of road network managers

If parking demand is dispersed temporally by installing PR system, an impact of parking vehicles to the flow of the traffic on the network is expected to reduce. Furthermore, as vehicles of reserved car park users can not be a 'wandering vehicles' for searching available car park spaces, practical traffic volume especially in peak hours will reduce. Also it is expected that traffic flow pattern can be controlled by strategic allocation of reserved car parks.

From a view point of car park owners

As it is possible to know in advance how many cars are expected to park, car park owner plan personnel allocation in time and spaces more efficiently. Furthermore, potential demand can be observed by reservation system is quite useful to have long-term strategy like expansion plan of the facilities.

**Apprehensive Problems in installing PR system**

Booking procedure and devices

Potential users of PR system must at first access to the system to book a space. One of the most popular procedures would be by telephone. However, if the car park of the first preference is unavailable, the operator will give them an advice which car parks can be reserved. In this case, the operator has to explain the location, fare, opening times of the car park by mouth. Also, it is preferable to have two-way communications to make a booking. Booking procedure by the internet sounds the best way because it can be a two-way communication system, and is possible to provide graphical information like location of the car parks. However, booking only by the internet may also limit the potential users. Of course, we do not have to limit the booking device only one, but intense analysis is needed to decide which devices to use.

Number of standby car park spaces

As travel time from an origin to the reserved car park may change because of traffic condition on the road, not all the reserved vehicles arrive on time. Similarly, not all the vehicles leave the car park on time because there must be some uncertainty in duration of activities. As the main benefit of PR system is to park without waiting, car park owners should try their best to guarantee this condition. Therefore, they need to have some standby car park spaces. Of course, smaller number is better in a sense of efficient use of parking spaces. Investigations of optimal number of these safety margins are very important. To complement these monetary losses together with maintaining PR system, an additional cost for booking or higher rate of parking fee must be applied. As drivers behaviour may change enormously by the amount of parking fee, this should carefully be decided.

Parking fee strategies

To encourage reserved car park users to arrive and leave on time, it would be one idea to apply additional fare for unplanned parking behaviours like staying longer than reserved time. However as is mentioned, change of monetary policy may effect on booking demand. Therefore, in-depth analysis should be done to decide about penalty fare. One of the worst cases of unplanned booking is no-show. If the reserved users are not identifiable in the system, then it is impossible to claim the penalty to them. To avoid these troubles, services with membership would be realistic for PR system.

Coexistence of reserved car parks with regular ones

With PR system, reserved car park users can park their vehicles without waiting instead of paying additional fee. Such system may only function when parking demands are really high. As there are little benefits in booking car parks in off peak hours, the use of reserved car parks may be limited in peak hours. Consequently, the flexible operations of car parks are needed. There may be another idea to allow for drop-in parking to reserved car parks if there is any space.

Locations of reserved car parks

If it is possible to decide the locations of the reserved car parks, PR system may contribute to spatial dispersion of parking demand. For example, by making all the car parks around congested

city centre as reserved, it would be possible to retrain the vehicles to come into this area. This idea is similar to Minderhoud and Bovy(1995).

As is summarised, there are so many figures to be decided in installing PR system. Also there is a danger to result in more congested situation by installing the system, especially when the additional cost is enough to discourage the people to use it. Moreover, because the capacity of regular car parks reduces, illegal on-road parking vehicles may increase, and traffic condition may get worse.

## Travel behaviour under PR system (Kurauchi et al., 2001)

### Questionnaire surveys

Stated preference data concerning about driver's behaviour in the presence of PR system are collected through questionnaire surveys. Authors have conducted a series of panel surveys to observe the effect of installing parking guidance and information system (PGI system), and the questions about PR system are asked in these surveys (Kurauchi et. al, 1995). The behavioural questions used here are asked at the fifth wave. An additional consideration is required in analysing panel data (Kitamura, 1990). As inquiries about PR system are stated preference questions, there are no reasons for asking these inquires by panel surveys. However, as it is expensive to conduct a new questionnaire survey, the questions are included in these surveys. Consequently, an additional consideration for panel survey is required. As a limitation of spaces, the detailed modification method is not explained here. Further modification methods adopted are found in Kurauchi, et.al, 2001.

Detail settings of stated preference questions are summarised in Table 1. Whether respondents use a reservation or regular car park is asked on the given conditions. Three factors, parking fee, walking time to destination and average waiting time for entering a regular car park are considered. To design questions, an experimental design technique is applied. Three levels are prepared for each factor, and consequently, nine questions are designed. It is preferable to reduce a number of cases to answer. Therefore, a block item is applied to spread nine questions over three questionnaire sheets. Eventually, three questions are asked to each respondent.

**Table 1 Values of the Factors**

| Level | Parking fee (Yen/hour) | Walking time to a destination | | | Average waiting time for entering a regular car park |
|---|---|---|---|---|---|
| | | Reservation car park | Regular car park | Difference | |
| 1 | 250 | 3 min. | 6 min. | - 3 min. | 10 min. |
| 2 | 300 | 3 min. | 3 min. | 0 min. | 20 min. |
| 3 | 350 | 6 min. | 3min. | + 3 min. | 30 min. |

### Car Park Choice Model

Table 2 indicates the estimation results of car park choice model. This model has 4 degrees of freedom. $\chi^2$ test statistic with 4 degrees of freedom for the null hypothesis that all parameters are zero is 203.106. As $\chi^2_{4,0.05}$ is 11.14, this hypothesis can be rejected with high confidence. Therefore, it is worth discussing a driver behaviour based on this result. The *t* test statistics of all parameters are found to be significant at 5% confidence level. Estimated parameters of parking fee and waiting time indicate that 100 yen/hour is equivalent to 9 minutes waiting time for entering a car park. From estimated parameters of walking and waiting time, the weight of walking time is 1.37 larger than that of waiting time. Another analysis conducted by the authors (Kurauchi et al, 1997) enhances the validity of this model because the comparative weight of these values at the past survey is similar (1.51). The estimate of the intercept of the reservation car park is compared with other individual variables. The estimated parameter is negative, and drivers tend to use regular car parks. 7.5 minutes of walking time and 10 minutes of waiting time for entering a regular car park are equivalent to the estimated intercept. This implies that if drivers have to walk 10 more minutes more, or wait for 7.5 minutes more when they use a regular car park, disutility of the reservation car parks is

indifferent to the regular one.

**Table 2 Estimation Results of Car Park Choice Model**

| Individual variables | Parameter | *t* statistic |
|---|---|---|
| Intercept (Reservation Car Park) | -0.951 | - 4.259 |
| Parking Fee (Yen/Hour) | -0.010 | - 6.560 |
| Walking Time (Min.) | -0.127 | - 4.941 |
| Expected Waiting Time (Min.) | -0.093 | -11.033 |
| Number of samples | 1158 | |
| -2 ($L(0)$-$L(\theta)$) | 203.106 | |
| Hit Ratio | 0.630 | |
| Adjusted Likelihood Ratio | 0.125 | |

## Dynamic Traffic Simulation Model

### Overview of the simulation

Behavioural model shown at the previous chapter are installed into our existing dynamic traffic simulation model (Kurauchi, et. al, 1998). Nowadays, many traffic simulation models are available in a market. However, as it is really hard to customise the simulation like changing a structure of decision making behaviours, we utilised the simulation of our own. Our simulation model is originally created in order to evaluate the effect of installing PGI system. One of the specific characteristics of our simulation is that it considers the learning behaviours of drivers. In another words, our simulation is 'double dynamic' in a sense that it simulates day-to-day dynamics as well as within-day dynamics.

### Behavioural model

Discussions in the previous chapter only handle the car park choice behaviours. In reality, drivers have wide range of choice options including whether to go out, where to go, what time to go, which mode to use, which route to use, and so on. In our existing simulation model, only the car park choice is considered because the main purpose of the study was to disperse travel demand spatially by installing PGI system. As we address PR system as a scheme to disperse the demand temporally as well as spatially, a departure choice behaviour should be considered. In this study, we adopted a joint choice model with car park and departure time. Without PR system, by repeating a use of car parks, drivers accumulate their knowledge of travel time from their origin to each car park together with expected waiting time to enter them. By considering the negative utilities of driving time from an origin to a car park, departure time is determined together with car park. With PR system, an additional consideration is required. Our previous analysis encourages that these trips with time constraint encourages to the use of reserved car parks (Kurauchi, et al, 2001). Therefore, we assume that a certain amount of drivers have to reach at their destination at a specific time. On the other hand, they can not shift their time of activity because they have a time constraint. So we assume that departure time shift is assumed to occur only when a driver does not have a time constraint. If a driver has a time constraint and reserved car park is not available during his activity, its utility is set to be negative infinite, and drivers will choose any one of regular car parks. If a driver does not have a time constraint and reserved car park is not available, then time shift needed to finish his/her activity is calculated. The utility of the reserved car parks is reduced according to this shift time, and they will choose any of regular/reserved car parks. For example, if he/she has 90 minutes of activity at the destination which is 5 minutes on foot from a reserved car park and his planned arrival time is 12:00, then the system would check the availability of the reserved car park from 11:55 to 12:35. If no parking space is available during this time interval, the system will look for a slot later than11:55 that continual 100 minutes of parking are available. Let us assume that from 12:25, it is available. Then, the utility of 30 minutes for shifting a departure time is subtracted from the utility of this reserved car park. Unfortunately we do not have enough data to analyse the value of parameters for shifting a departure time. However, the value of them should be relatively low because a driver can spend this time by doing other behaviours at their origin. Expediently in this study, the parameter for this shifting time is set to be one tenth of driving time from their origin to a

car park. Apparently, the further analysis to identify this parameter is recommended. Together with our existing knowledge we have got from our analysis (Kajifusa, 2001), a car park choice model used in our simulation is shown as Table 3. Additionally, there is no evidence that all drivers will consider about using reserved car parks. As we do not have a good model to explain this behaviour, we set it as a parameter called *ratio of drivers accessing to PR system*. The effect of this parameter will be analysed in our case studies.

**Table 3 Car park choice model in the simulation**

| Explanatory Variable | Parameter | Explanatory Variable | Parameter |
|---|---|---|---|
| Walking time (min.) | -0.553 | Intercepts for reserved car parks | -1.383 |
| Average waiting time to enter car park (min.) | -0.277 | Time constraint X Reserved car park | 2.828 |
| Driving time from an origin to a car park (min.) | -0.189 | | |
| Parking fee (100yen) | -0.327 | Departure shift time (min.) | -0.019 |

## Case Studies

Case studies are conducted on the network shown in Figure 1. This network is created referring to Ibaraki City, Osaka, where we conducted the questionnaire survey. Simulation settings are summarised as Table 4. Two case studies are analysed here. One is to evaluate the impact of the locations of reserved car parks onto the effect of the system, and the other is to evaluate the ratio of the people accessing to the PR system. Furthermore, in-depth analysis about the effect of PR system is done by picking up some cases. The settings of scenarios are summarised as Table 5. Note that in this simulation, we do not consider on-road parking behaviours. Therefore, drivers have to choose any one of five car parks.

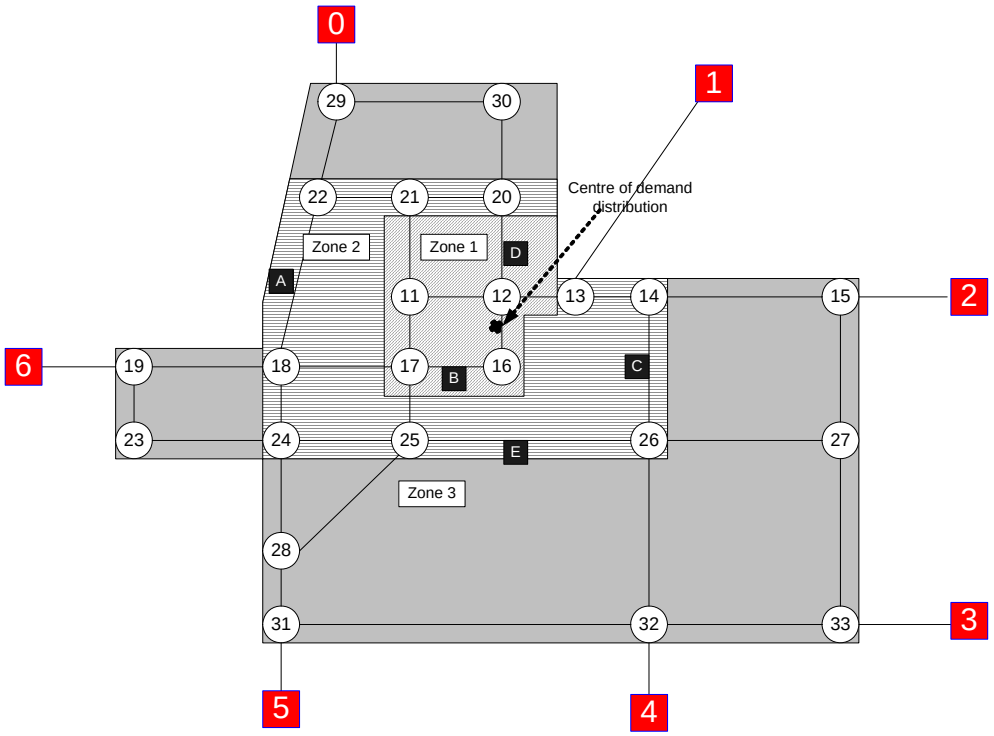



**Figure 1 Ibaraki Network**

**Table 4 Settings of the simulation**

| | |
|---|---|
| Overall | |
| Scanning time interval | 1 seconds |
| Time simulated within day | 6:00～21:00（54000seconds） |
| Days simulated | 30 days |
| Demand | 3,000 veh. / day (1,500 parking vehicles, 1,500 through traffic) |
| Demand distribution | Normally distributed with standard deviation of 400m for N-S and E-S directions |
| Parking | |
| Maximum number of queuing spaces for waiting to enter | 10veh. (for all car parks) |
| Parking fee for 30 minutes | ¥125 (Res.), ¥100(Reg.) |
| Vehicle | |
| Max. acceleration | $1m/s^2$ |
| Max. deceleration | $2m/s^2$ |
| Min. distance headway | 5m |
| Min. time headway | 1second |
| Velocity while searching alternative car park | 50% of regulated speed |

**Table 5 Study cases**

| Case Name | Reserved Car parks | | | | | Ratio of people accessing to PR system | Ratio (number) of reserved spaces comparing with total capacities |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | | |
| N | | | | | | - | 0.00（ 0） |
| A(0.5) | X | | | | | 0.5 | 0.36（180） |
| B(0.5) | | X | | | | 0.5 | 0.10（ 50） |
| BCD(0.5) | | X | X | X | | 0.5 | 0.40（200） |

**Locations of reserved car parks**

To evaluate the effect of PR system when the locations of reserved car parks are different, 4 simulations are executed. The traffic demand level of 3,000 means that all car parks are fully occupied in peak hours. Therefore, this is the case when dispersing the demand temporally is required. Figure 2 illustrates the average travel time of car park users from their origins to destinations. The time to destination is the sum of travelling time from the origin to the preferred car park, wandering time, waiting time to enter a car park and walking time to the destination. Wandering time is defined as (the time when a driver arrived at their preferred car park) – (the time when a driver got into the queue of any car parks). In this simulation, drivers will be in a queue if any spaces in queuing area are available, and they do not leave the queue for any reasons. Ratio of drivers accessing to PR system is set to be 50%. From the result of A(0.5) in Figure 2, total average of travel time to their destinations increased comparing with a basal case N. It can be said that setting car park A as reserved is not suitable. From Figure 1, car park A is rather less popular because it is located further from the centre of the demand. This implies that if we set a less popular car park as reserved, then the demands concentrate to other more popular car parks. If we set rather popular car parks as reserved, the system works well. From the comparison of the results of cases B and BCD, setting three popular car parks as reserved is preferable when a ratio of people accessing to PR system is 0.5. Also it is can be said that the travel time when a driver use reserved car parks is rather stable regardless to the cases.

**Ratio of people accessing to PR system**

The ratio of drivers accessing to the system is an important factor that influences on the effect of PR system. Figure 3(a), (b) illustrates the relationship between ratio of accessing people and the total travel time to their destinations. Figure 3(a) represents the results for case B, and Figure 3(b) for case BCD. Note that zero of this ratio means none of drivers refer to PR system although some car

parks are set to be reserved. From both figures (a) and (b), total travel time increases if we set many car parks as reserved although the ratio of people referring to the system is small. Especially when we set three car parks as reserved, the travel time increase than the basal case even one forth of the drivers consider using reserved car parks. When ratio of people accessing to PR system is 0.25, case B is better than case BCD, and when the ratio is more than 0.5, case BCD is better. Obviously, if many people access to PR system and consider using reserved car parks, we should set many car parks as reserved.

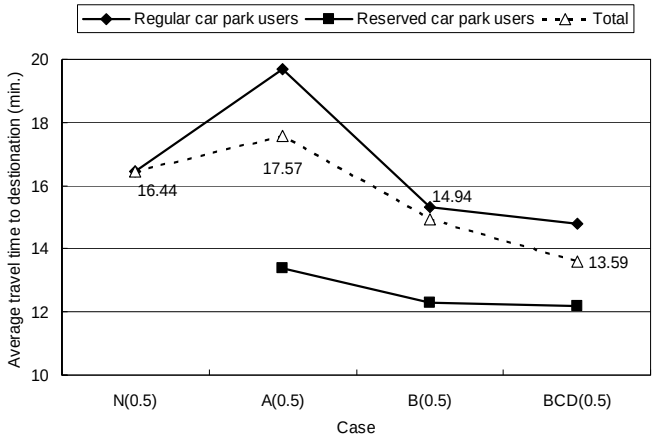
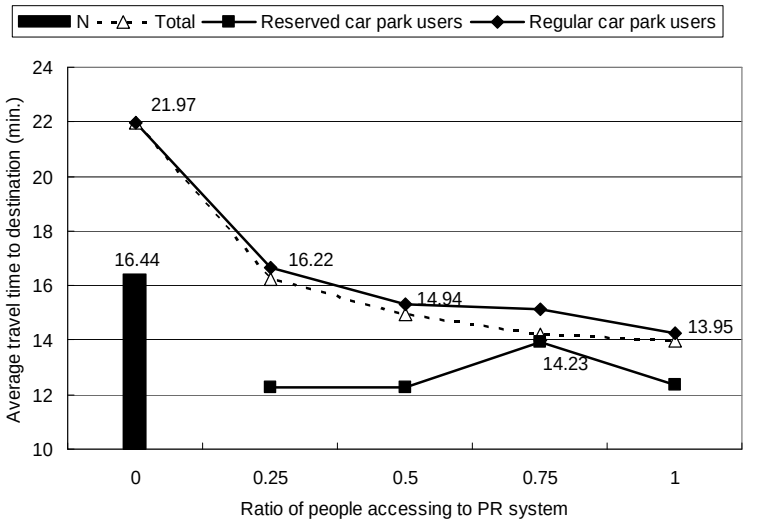



**Figure 2 Effect of PR system when locations of car parks are different**

(a) Case B




(b) Case BCD

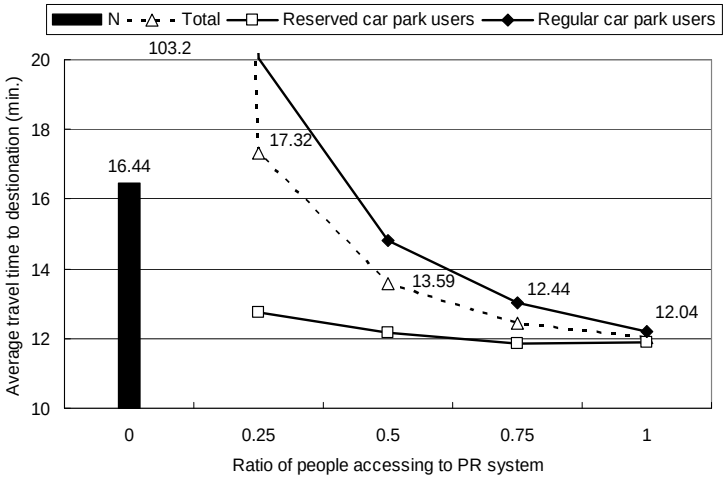



**Figure 3 Effect of PR system when ratio of drivers accessing to the system is different**

The important finding here is that, unlike information provision schemes, the effect of PR system increase as the ratio of users increase. It is generally said that if many people refer to information, the effect of information may decrease, or the traffic condition may get worse by providing information. In installing PR system, this may not happen. Moreover, it is interesting to say that the travel time of regular car park users also decrease enormously when we have larger amount of people accessing to PR system. This result indicates the social benefit of PR system.

**In-depth analysis on specific cases**

The evaluation of the system by total travel time to the destination is the evaluation from a users' point of view. As is summarised in the former chapter, there must have many social benefits in installing PR system, like relaxation of traffic congestion, etc. This section picks up two specific case studies, B(0.5) and BCD(1.0), to have more detailed analysis. B(0.5) would be a practical case to see the effect of PR system while case BCD(1.0) would be an extreme case to know the potential maximal performance of PR system. As a comparison, case N is also shown in the figures.

Firstly from the viewpoint of drivers, PR system is evaluated more in detail. Figure 4 explains the details of total travel time to the destinations. Without PR system (Case N), there are 3.14 minutes of waiting time in average to enter a car park, and 1.26 minutes of wandering time. As wandering time is expected to occur only in peak hours, drivers arrived around peak hours may have serious delays to get to their destination. By installing PR system, reserved car park users neither wait to enter a car park nor wander in the city to look for any available parking spaces. In another words, wandering time and waiting time of reserved car parks users are zero. Comparing the walking time and driving time of case N and reserved car park users of cases B and BCD, it can be said that main reason for reducing travel time is the extraction of wandering time and waiting time, which is the main effect of PR system. In case BCD(1.0), wandering time for regular car park users also decreased to 0.04, and waiting time decreased to 0.54. This means that regular car park users also have a benefit by installing PR system.

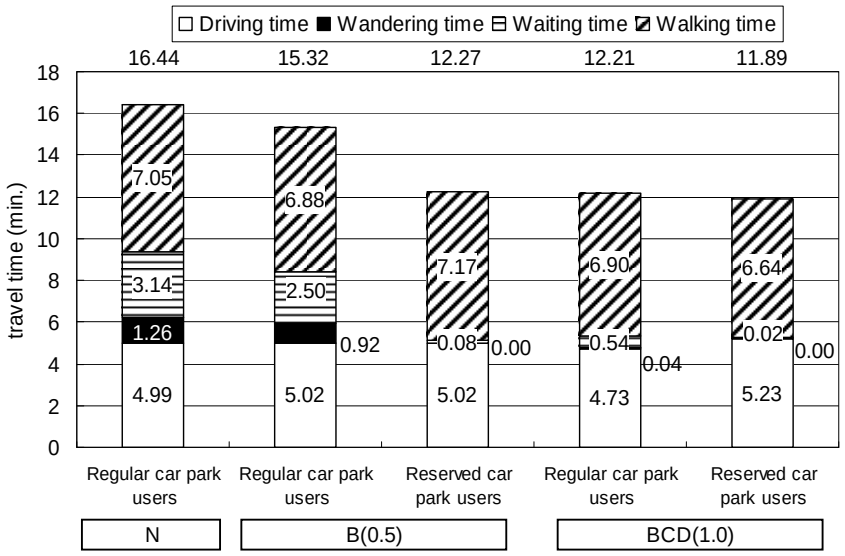
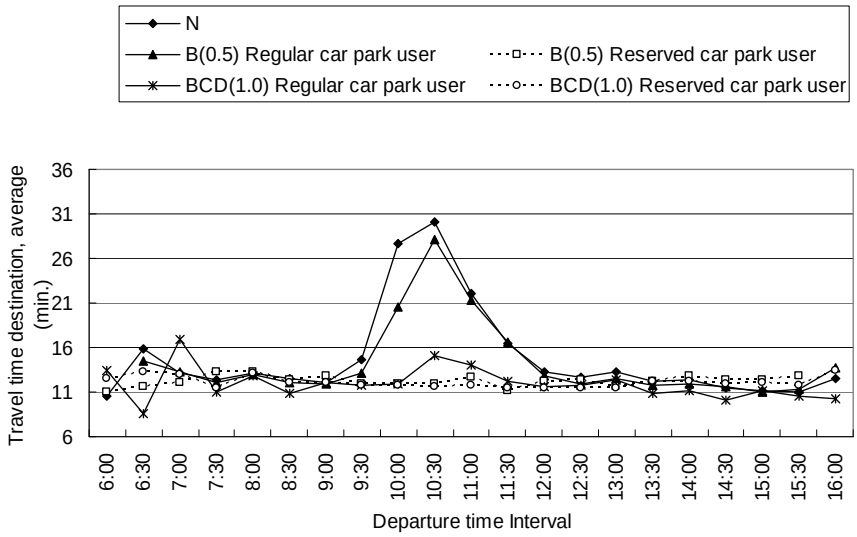



**Figure 4 Details in drivers total travel time**

One of the main effects of PR system is the reduction of uncertainty in travel time. Therefore, to check the variability of travel time, average and standard deviations of travel time to destinations is calculated for every 30 minutes of departure time interval. Figure 5(a) is the results of average travel time and Figure 5(b) is the results of standard deviations. When it is not congested, average and standard deviation of travel time are 12 minutes and 4 minutes, respectively. However, in case N, around 10 or 11 o'clock, the average travel time increased up to 30 minutes and standard deviation is about 15 minutes. In this situation, it is really hard to predict how much it takes to get to their destinations. Therefore, drivers who have to arrive at their destination on time need to depart their

origins early enough to ensure the arrival on time. With PR system, if the drivers can book their spaces at reserved car parks, the travel time and its deviation decreased enormously. In case B, even in peak hours, travel time is 12 minutes and its standard deviation is 4 minutes. This is almost the same as off-peak hours. Reserved car park users can reduce an uncertainty of travel time enormously. Also, regular car parks users may have similar benefits. Average and standard deviations of regular car park users in cases B(0.5) and BCD(1.0) decreased comparing with case N. Especially in case BCD(1.0), its average and standard deviation decreased to 15 and 7 minutes, respectively. Therefore, PR system may help to decrease the uncertainty of travel time of both reserved and regular car park users.

(a) Average




(b) Standard deviation

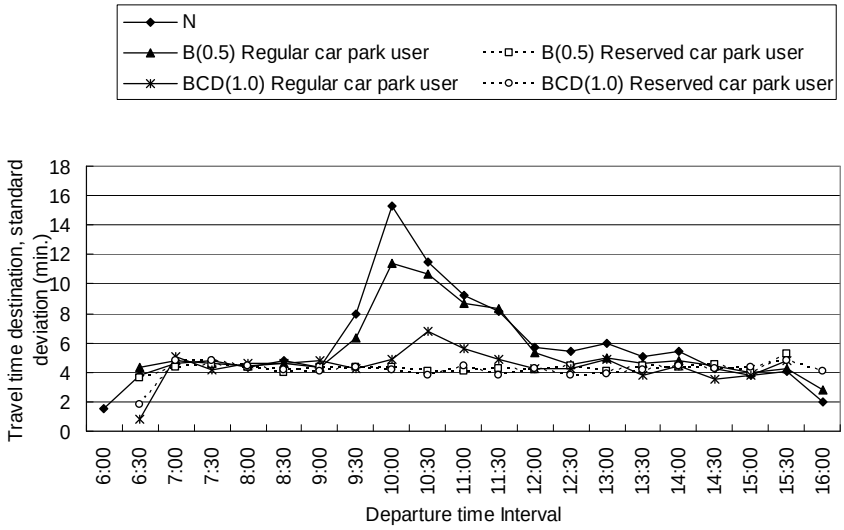



**Figure 5 Average and standard deviation of travel time to destinations**

So far we look at user side effects. From here, PR system is evaluated from the view point of public. Figure 6 shows the total occupied spaces and waiting queues of car parks. The reason why all spaces are not occupied in cases with PR system is that some parking spaces are reserved for unexpected behaviours of reserved car park users. The usage of car parks in case B(0.5) is almost the same as case N while total travel time of drivers decreased a lot. Also, when we look at the result of case BCD(1.0), the total length of waiting queues decreased to 10 vehicles. This contributes to the safety and efficiency of the road network. To evaluate the effect of PR system onto the flow of the traffic, daily link traffic volumes are calculated. Links are categorised into three zones as is shown in Figure 1. Figure 7 shows the calculation results. Link traffic volumes in zone 1 and 2

reduced by installing PR system. There would be two reasons for this. One major reason is that users of reserved car parks are guaranteed to use a car park and do not have to wander in the city to look for available car parks. The other reason is that, especially in case BCD(1.0), all car parks in zone 1 are reserved, and drivers knows that they can not use them without reservation. Therefore, the number of vehicles flowing into the downtown area decreased. From these findings, we can say that when we set all car parks in a downtown area as reserved, we can control the volume of the traffic spatially by installing PR system.

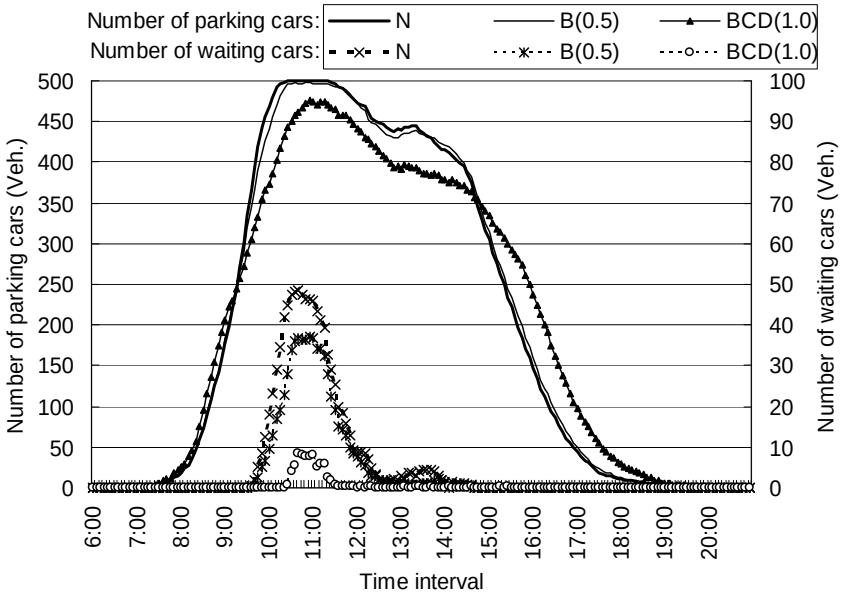



**Figure 6 Number of parking and waiting cars**

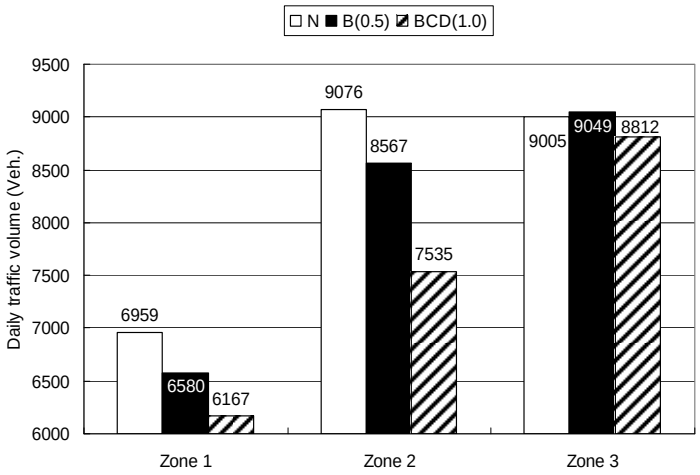



**Figure 7 Road traffic volumes for each zone**

## Summary

In this study, Parking Reservation system (PRs) is proposed to disperse parking demands temporally. Firstly, PR system is identified with some existing researches and expected effects and apprehensive problems are summarised. Although some analyses on PR system can be found, there are little researches concerning about the behavioural responses when PR system is installed. Therefore, we conducted the questionnaire survey to collect driver behaviours, and drivers parking choice behaviours under PR system are studied. The estimated car park choice model is installed into our existing traffic simulation model to evaluate the effect of PR system. Through some case studies, PR system is evaluated from both users and social points of views. Key findings of this

study can be summarised as follows.

1. The effect of PR system may vary when the locations of reserved car parks are different. Especially, when less popular car parks are set to be reserved, the drivers may not have any benefit by installing the system.
2. One of the interesting characteristics of PR system is that, unlike information provision schemes, the effect of installing the system may not decrease when large proportions of drivers consider to use reserved car parks.
3. From the first finding, when there is a mismatch between ratio of drivers accessing to PR system and reserved capacities, the system may not work well. However, by the second finding, when demand for reserved car parks are larger than supply, the system will work well. Therefore, it is preferable to set a small number of car park spaces in downtown as reserved at first, and then by looking at the balances between demands and supplies, we should consider increasing the number of reserved car parks.
4. PR system may help enormously to reduce the uncertainty of travel time. This effect not only limits to reserved car park users but also regular car park users. Therefore, the system would work well in central business areas.
5. It is possible by location reserved car parks strategically to control the traffic flow entering into the city. Therefore, PR system may work as one of the advanced traffic management schemes in the city.

Although we have many findings to support the success of PR system, some defects on this study should be noted. The major defect of this study is that parking demand is fixed. In general, public transport such as rail or underground is more reliable in a sense of travel time than private cars. Therefore, many people with time constraints will travel by rail in reality. Then, if PR system helps to reduce the uncertainty of travel time, the public transport users may as well think about using reserved car parks. This effect may reduce the effect of PR system, or the traffic condition may get worse by these additional demands. Further analysis about mode choice behaviour with PR system is needed to consider this effect. Second defect is that our simulation model does not consider the on-road parking behaviours. In Japan, unlike UK, we do not have many on-road parking spaces. However, many people parks on road illegally, and it is one of the major urban traffic problems in Japan. In this study, PR system works very well when we set all the car parks in downtown area as reserved. This finding may change when the number of illegal on-road parking cars increased by installing PR system.

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