EFFECTIVE SPATIAL LOCATION PATTERNS OF PGI MESSAGE BOARD IN STREET NETWORK

Yasuo ASAKURA
Professor
Transport Studies Unit
Dept. of Civil and Environ. Eng.
Ehime University, Matsuyama, 790-8577, JAPAN
FAX.+81 (0) 89-927-9843,
E-mail. asakura@en1.ehime-u.ac.jp

Eiji HATO
Research Associate
Transport Studies Unit
Dept. of Civil and Environ. Eng.
Ehime University, Matsuyama, 790-8577, JAPAN
FAX.+81 (0) 89-927-9843,
E-mail. hato@en2.ehime-u.ac

Masuo KASHIWADANI
Professor
Dept of Civil and Environ. Eng.
Ehime University, Matsuyama, 790-8577, JAPAN
FAX.+81 (0) 89-927-9843,
E-mail. kashiwa1@en1.ehime-u.ac.jp

Abstract: Parking Guidance and Information (PGI) systems are expected to guide car drivers to appropriate car parks by providing locational, directional and availability information of car parks. The information is usually provided on the road side message boards using signs and characters. This paper aims to show a microscopic network simulation model with car parks and PGI systems, and to evaluate the effects of providing availability information of car parks to drivers. The present location pattern of VMS board in the street network of the city of Matsuyama is examined using the simulation model.

1. INTRODUCTION

Parking Guidance and Information(PGI) systems are expected to guide unfamiliar car drivers to appropriate car parks by providing locational, directional and availability information of car parks. PGI systems were first implemented in German cities over twenty years ago. Now a considerable number of the systems are in operation throughout the world. Thompson and Bonsall (1994) shows the evidence of driver's response to dynamic parking guidance and information systems. However, there is little comprehensive before and after study of the effectiveness of PGI systems and the general conclusion on the effects of the PGI systems has not yet been obtained. This was first pointed out by Polak et.

al(1990).

The effects of the PGI systems have been studied by two approaches. One is the behavioural approach studying actual driver's response to PGI systems. Allen(1993) studied the impact of PGI systems on behaviour at a disaggregate level, using an attitudal questionnaire and Stated Preference(SP) exercise administrated in Kingston-upon-Thames. It was found that the impact of occupancy information was shown to have a significant effect on car park choice probabilities. Asakura et al. (1995) examined the PGI system in Matsuyama and found that more than 80% of drivers are aware of the PGI system, while less than 20% of them actually utilize the information. Those figures are consistent with the survey results in Frankfurt by Polak and Axhausen (1994). Asakura and Morikawa (1993) presented a theoretical model evaluating the effects of information, which was a random utility model combined with Bayesian up-dating process.

The other is the network modelling based approach. Static network traffic assignment models with car parks was first applied to discuss parking strategies. For example, Cascetta et al.(1991) showed Stochastic User Equilibrium model could be used for the evaluation of parking policy. However, those static models may not be sufficient for evaluating dynamic aspects of the effects of PGI systems since dynamic parking information could not be explicitly included in static traffic assignment models.

Asakura(1996) studied the pilot model of a dynamic network and car park simulation which describes a car driver's route and car park choice behaviour. The model is available for evaluating the effects of providing parking information on system performance and to compare how the types of information and the situation of the system cause different results. However, the model must be improved for the application in actual situations. For example, the PGI systems usually provide information on the road side message boards using signs and characters. It seems important to determine the spatial location pattern of those PGI message board in a road network. This paper aims to show an improved microscopic network simulation model with car parks and PGI systems, and to compare spatial location patterns of the PGI message boards in the street network of Matsuyama city.

2. MODEL STRUCTURE

2.1 Model Framework

In order to evaluate the effects of the dynamic parking information provided through the PGI system, it is necessary to develop a dynamic network traffic simulation model with car parks. The model is also required to describe driver's car par and route choice behaviour with/without parking information. A simulation model consists of demand, performance and information service sub-models as shown in Figure 1. The structure of the model is similar to a dynamic traffic assignment simulation model incorporating a route choice sub-model and a traffic flow sub-model. In addition to those sub-models, the proposed model involves an information service sub-model.

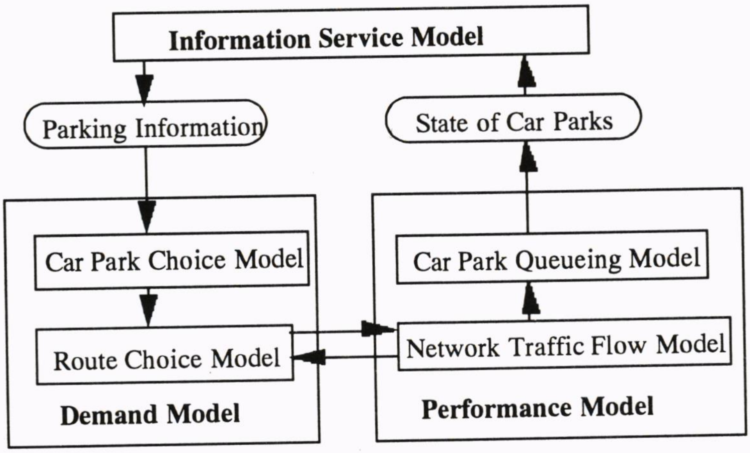


Figure 1 Simulation Model Framework

2.2 Demand Sub-model

Demand sub-model is prepared to describe a driver's route choice and car park choice behaviour. We assume a sequential choice process in which a driver first determines a car park and next chooses the route to the car park. This means that the chosen route is hold until the driver does not change his/her car park choice.

In order to evaluate the effects of providing availability information of car parks, drivers are classified into different two groups. One is the informed driver group and the other is non-informed driver group. We assume that all drivers have prior knowledge of some attributes of car parks except for availability. This means that a driver knows the location, the direction, and the walking distance to the final destination and the parking fee. A non-informed driver chooses car park using those prior knowledge. In addition to the prior knowledge, an informed driver uses the availability information provided from the PGI system. The percentage of the informed driver is unknown and we use the percentage as one of the control parameters in calculating simulation model.

The multinominal logit (MNL) model is applied to the car park choice process. The choice probability for a car park i of a non-informed driver is written as;

$$P_i = \exp(V_i) / \sum_{j \in J} \exp(V_j), \tag{1}$$

where V_i denotes the deterministic part of the utility function for car park $i \in J$. J is the set of all car parks. V_i is written as the linear function of the attributes of the car park.

$$V_i = \sum_{k \in K} \beta_k X_{ik} \tag{2}$$

here X_{ik} presents the k-th attribute of car park i, and the β_k denotes the parameter. For example, X_{i1} denotes the walking distance from car park i to the final destinationand X_{i2} denotes the one-hour parking fee of car park i.

Each driver is assumed to determine one of the car parks at his/her origin node. Then the driver chooses the shortest route to the car park, which is calculated in the street network at each time interval using the result of the performance model. When the driver is classified into non-informed drivers, he/she does not change the decision in the network until arriving at the chosen car park. However, a driver may search for another car park if he/she arrives at the car park and finds it full. A probability of switching is introduced and a driver makes the second choice of a car park and a route to the car park. This switching behaviour in front of the occupied car park is called as "terminal switching" and assumed common to both non-informed and informed drivers. The choice probability function of the terminal switching is written using NML model as,

$$P_i = \exp(V_i) / \sum_{j \in J^*} \exp(V_j), \tag{3}$$

where J^* denotes the set of car parks excluding the first chosen car park, which has been occupied before arrival.

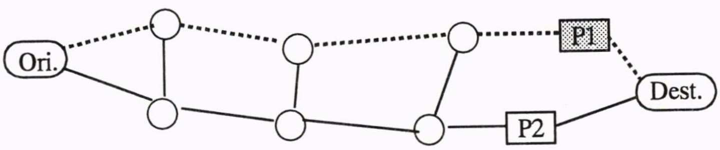
The usual PGI system provides information with the roadside VMS board. We describe the en-route car park choice of a informed driver using the availability information of car parks. As mentioned above, an informed driver also determines the first choice at his/her origin node and enters the network. When the informed driver finds a message on a VMS board in the network, he/she may change the decision using the information. Applying the MNL model, the car park choice probability is represented as the same functional form shown in Eq.(1). The variable reflecting the availability information is incorporated in the utility function. That is written as;

$$V_i = \sum_{k \in K} \beta_k X_{ik} + \gamma Y_i \tag{4}$$

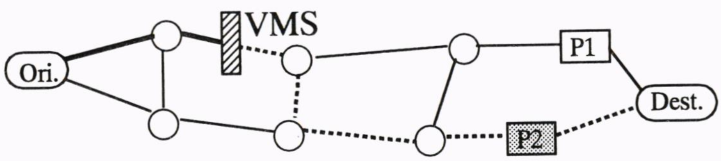
here Y_i denotes the availability information of car park i, and γ is the corresponding parameter. For example, $Y_i = 1$ when the message of "FULL" is given, or $Y_i = 0$ for the message of "SPACES". If a driver finds the message on the VMS board and changes his/her choice, this is called as "en-route switching".

Here we describe an example of choice behaviour of an informed driver in a network. The choice process is shown in Figure 2. An origin and destination pair is given to a driver. The driver chooses the car park at the origin node using Eq.(1). The car park information is not available at this stage. The driver runs along the shortest route to the chosen car park. When the driver finds an availability message on the route, his/her utility function is up-dated using Eq.(4). The driver may change the first choice and switch to an another car park. This is the en-route switching. The shortest route to the chosen car park is again calculated. When the driver recognizes the queue at the approaching link to the car park chosen, he/she may make the terminal switching and drive to the alternative car park.

(1) *Initial choice:* A car park is chosen using MNL model and the shortest route is calculated..



(2) *En-route switching* : When a PGI board is located on the route, a driver may switch the car park using the availability information .



(3) *Terminal switching:* When a driver arrives at a car park and the car park is occupied , he/she may change car park again .

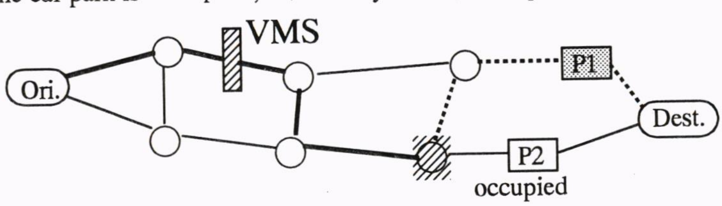


Figure 2 An Example of Choice Behaviour in a Network

2.2 Performance Sub-model

The performance model presents the interaction between the degree of congestion and level of service in a car park and that of the road network. It has the same function as the traffic flow model in a dynamic assignment simulation model. The model traces the movement of vehicles with given route and car park. For convenience, the performance model is separated into a network flow model and a car park model.

The network flow model corresponds to a traffic flow simulation model in a network. Microscopic simulation models previously developed could be used for the network flow model. In this paper, the model is designed as simply as possible. A directed link has a single lane and the first-in-first-out principle is applied for the movement of vehicles. The difficulty of right turn or left turn is not considered. A vehicle is moved from a link to the next on the predetermined route. The link travel time consists of the running time on that link and the queuing time at the exit of the link. The running time of a vehicle is calculated using the function of the number of vehicles on that link when the vehicle enters the link. If the preceding link is saturated, the vehicle has to wait in the present link. The queuing time is determined by the degree of congestion in a preceding link. The calculated link travel time is used in the demand model as one of the explanatory variables of driver's route choice.

In the car park model, two variables are used to describe the states of car parks. NQ_i and NS_i denote the number of queuing vehicles and the number of parked vehicles in car park i, respectively. The model consists of several different branches.
(1) When a vehicle arrives at car park i during time period $t \sim (t + \Delta t)$, the vehicle has to follow the queue ($NQ_i = NQ_i + 1$) if the car park is full. Otherwise, the vehicle can enter the car park ($NS_i = NS_i + 1$), and the time that the vehicle leaves the car park is calculated. The exponential distribution is assumed to represent the parking service time distribution.
(2) If a vehicle finishes the service during time period $t \sim (t + \Delta t)$, such a vehicle leaves the parking facility ($NS_i = NS_i - 1$). If there is a queue at the car park, the first vehicle of the queue can enter the car park ($NQ_i = NQ_i - 1$, $NS_i = NS_i + 1$) and the time that the vehicle leaves the service is calculated. When another vehicle finishes its service in the same time period, this process is iterated again.
(3) If no car finishes parking service, the state at time t continues at next time interval.

2.3 Information Service Sub-model

The information model monitors the condition of the network and car parks and provides availability information to car drivers using the message boards that are located on some links in the network. The outputs of the car park performance model are transferred to the availability information such as FULL or SPACES.

The actual PGI system shows FULL message even if not all of the parking spaces are occupied. Therefore, we determined that the FULL message is displayed on VMS board when the ratio of vacant spaces becomes lower than a certain level. The ratio is defined as $(C_i - NS_i)/C_i$ for car park I, where C_i denotes the capacity of car park i. Otherwise, the message SPACES is displayed. Other information such as queuing time and number of vacant spaces are also produced as well using the output of the performance model. Those variables are used as the inputs for the demand model mentioned above.

3. MODEL APPLICATION TO MATSUYAMA NETWORK

The PGI system was installed in the city of Matsuyama in 1995. According to our survey made in 1997, it was shown that more than 80% of drivers knew the system. The percentage of the drivers who used the PGI system was about 20%. They confirmed the congestion of the popular car parks using the FULL/SPACES message. A small percentage of drivers switched to the alternative car park. We will show the results of the model application to the network of Matsuyama. The model performance is examined and the effects of providing parking information is evaluated.

3.1 Input Conditions

Figure 3 shows the simulation network with car parks. We assume that parking demand is generated from four external nodes of the network. Four destination nodes (D1~D4) are allocated in the centre of the network. Six car parks in the street network are connected with those destinations using walking links. Table 1 shows the attributes of car parks. Both the time interval of trip generation from an origin and the service time in a car park distribute due to the exponential function. 4000 vehicles are generated from origin nodes in total and each destination is chosen equally. The message boards are located at some links of the network. The location pattern is almost the same as the actual PGI system at the present. When the vacant space ratio is greater than 0.1, the message of FULL is presented.

Table 1 Conditions for Car Parks

Car Park	Capacity (vehicles)	Fare (yen/hour)	Walking Distance (meters)			
			D1	D2	D3	D4
1	100	250	100	300	300	500
2	200	250	400	200	500	400
3	200	250	200	300	200	500
4	100	250	200	200	200	400
5	200	250	400	500	100	200
6	100	250	600	400	500	100

Using the 1500 samples of the Stated Preference (SP) survey asking an individual's preference on parking behaviour and the response to the PGI system in Matsuyama, the utility functions of the MNL model for car park choice was estimated. The utility functions of the car park i of a non-informed driver and an informed driver are written as;

$$V_i = -0.01857WD_i - 0.02104PC_i \qquad \text{(for a non-informed driver)}$$
$$\quad (-18.99) \qquad (-21.75)$$

$$V_i = -0.01857WD_i - 0.02104PC_i + 5.52917FS_i \qquad \text{(for an informed driver)}$$
$$\quad (-18.99) \qquad (-21.75) \qquad (17.93)$$

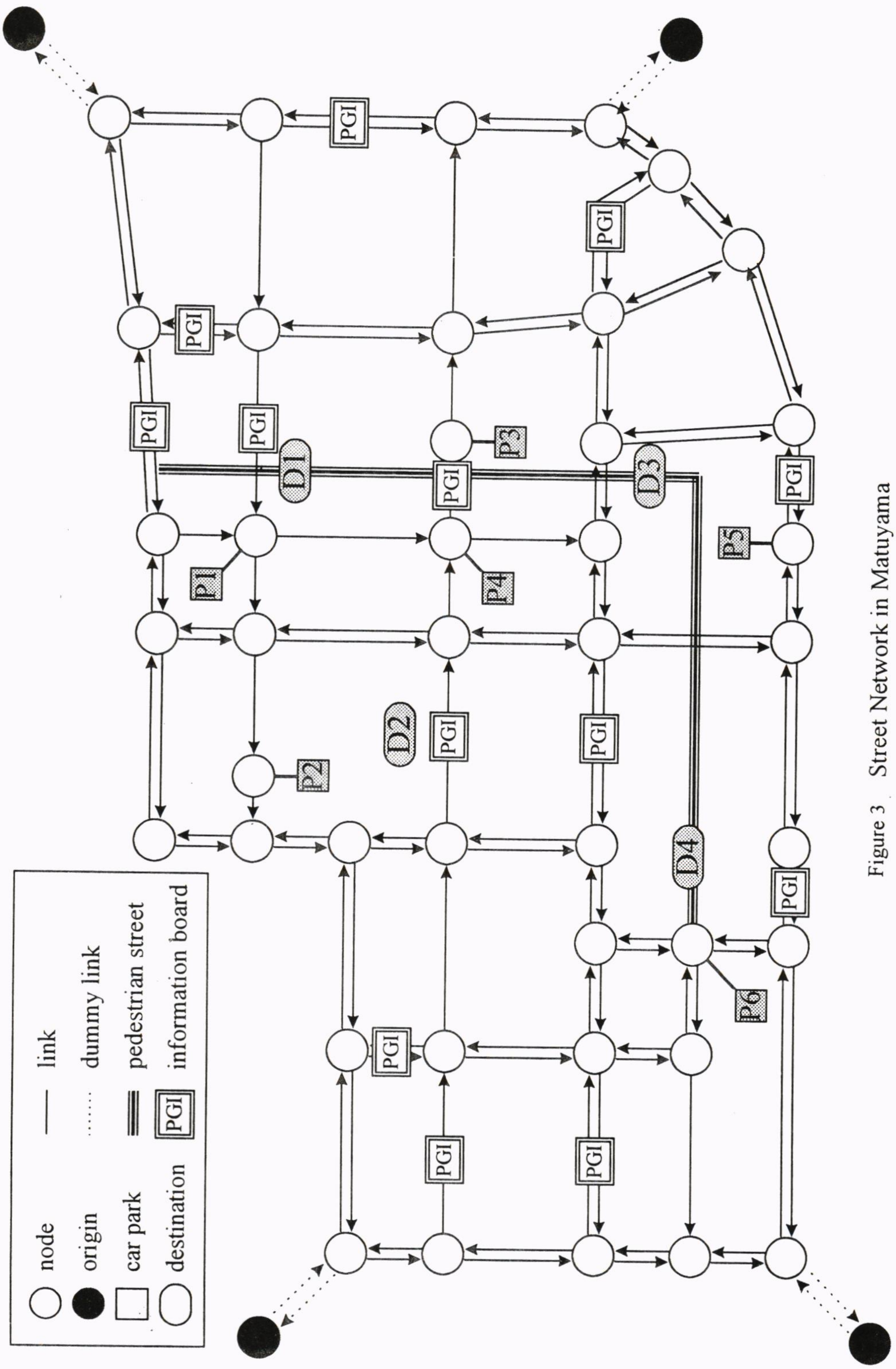


Figure 3 Street Network in Matuyama

where WD_i,PC_i and FS_i denote walking distance (meters), car park charge (yen/hour), full and space information (FS_i =1if the message of "car park i has spaces" is given), respectively. Figures in the parenthesis shows t-statistics of the parameters. The signs of the estimated parameters are consistent and the values of t-statistics are sufficient. The values of χ^2 and ρ^2 were 1,835 and 0.560, respectively. The percentage of estimated values which corresponded with actual responses was 79.5%.

3.2 Effects of Providing Information

Taking the percentage of informed driver as a parameter, the effects of providing availability information to drivers are examined. Ten rounds of simulations were calculated for a case and then averaged. This is because each simulation has a fluctuation due to random variables. Figure 4.a shows the averaged waiting time(A), the averaged running time in the network(B), and the averaged total travel time(A+B). Trip generation rate is fixed at 0.15 vehicles per unit time interval.

When the availability information is not provided, the averaged waiting time is about 5 minutes and the averaged running time is about 20 minutes. When 50% of drivers are informed, the averaged waiting time becomes half of the case without information. It becomes smaller in proportion to the percentage of the informed drivesr. However, the averaged running time will not be so reduced when large amount of drivers are informed. Consequently, the reduction of total travel time is mainly caused by the reduction of the waiting time.

Figure 4.b depicts the same figure for the congested case. The trip generation rate is set 0.20 vehicles per unit time interval, and the density in the network becomes higher than the previous case. The waiting time decreases constantly in proportion to the percentage of the informed drivers. It is found that the reduction of the runnnig time becomes larger, and it contributes for saving total travel time. These two figures imply that the providing parking information will be effective for reducing both the waiting time at car parks and the running time in the network. The degree of effects will be different from the congestion level of the network. The actual percentage of the car drivers who use the parking information will be 20%. Thus, we can expect that the parking information saves 10~20% of the total travel time in the street network.

Figure 5 depicts the number of parked vehicles of each car park for the different proportion of informed drivers. Car parks 1 and 6 attract many customers when the percentages of informed drivers are smaller. This is because these two car parks are close to the popular department stores in the city. As the number of informed drivers becomes larger, the demand of those car parks disperses to both car parks 3 and 5. The demand of car park 1 shifts to car park 4, and the demand of car park 6 moves to car park 5. The amount of the

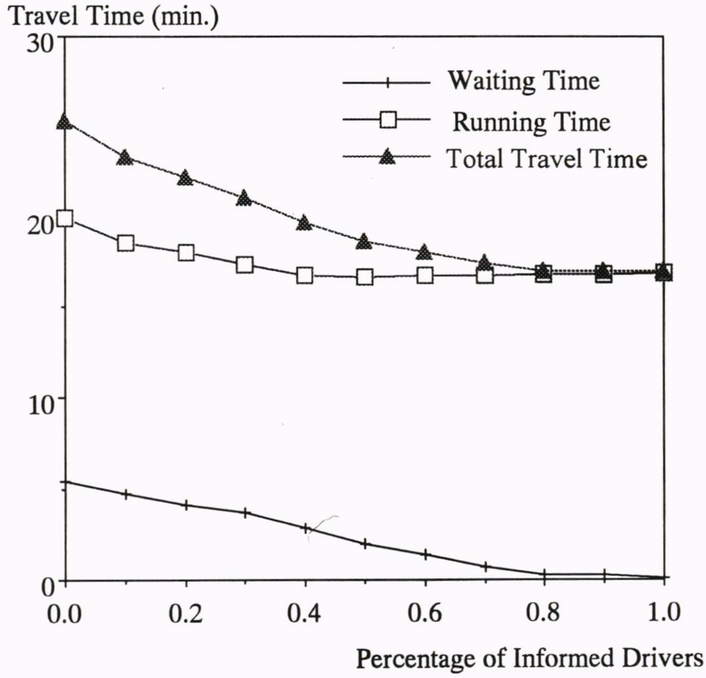


Figure 4.a Total Travel Time Reduction with Parking Information (Less Congested Case)

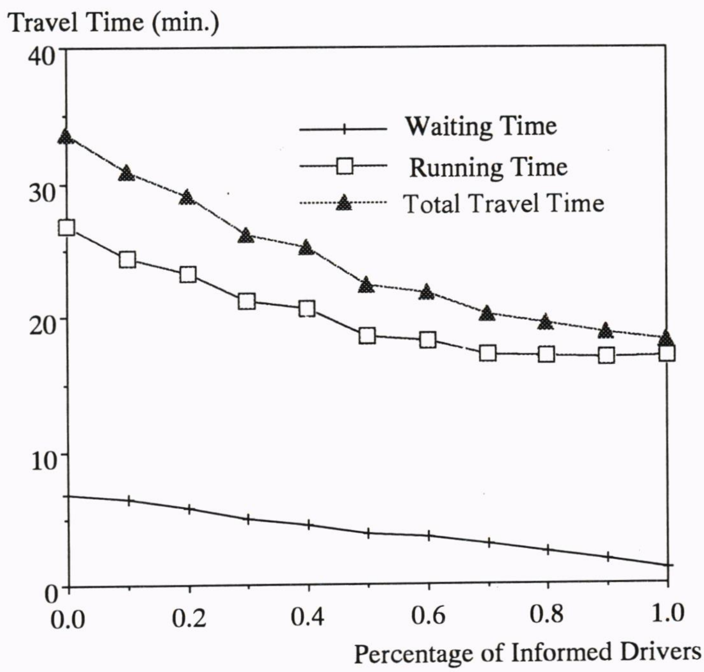


Figure 4.b Total Travel Time Reduction with Parking Information (Congested Case)

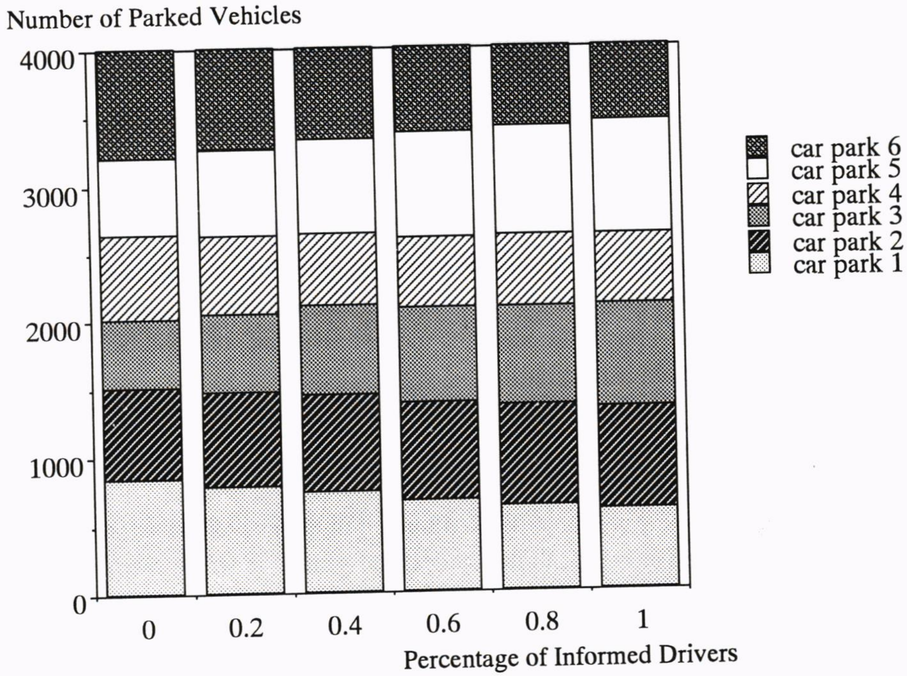


Figure 5 Spatial Distribution of Parking Demand

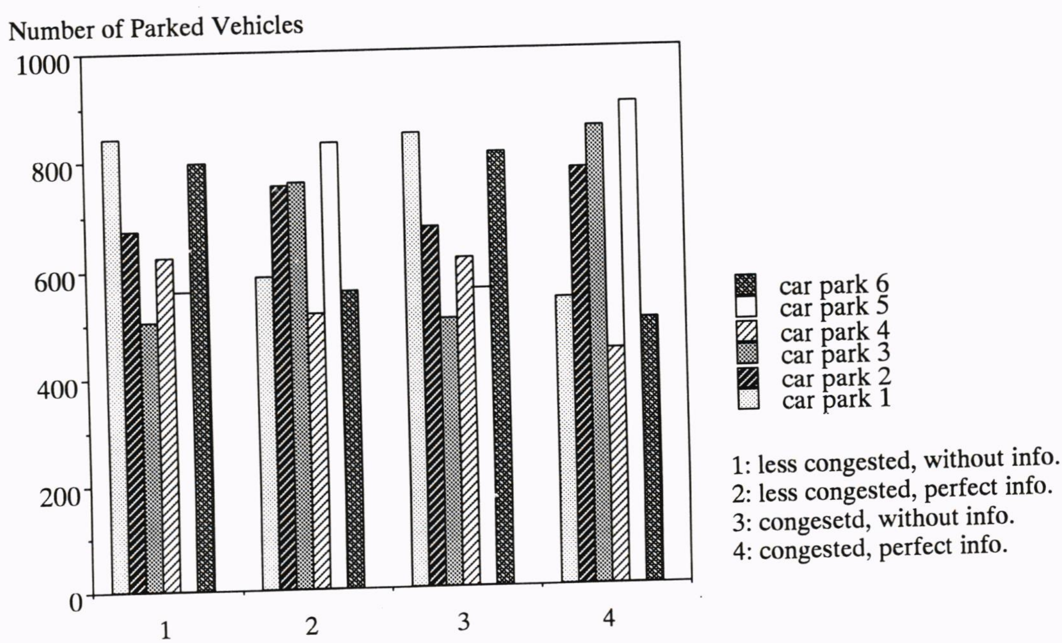


Figure 6 Comparison of Spatial Distribution of Parking Demand

demand moved to the alternative car parks are about 30% of the initial demand. This shows the effects of information on the spatial redistribution of parking demand.

Figure 6 shows the comparison of the spatial distribution of parking demand for different levels of congestion. When the availability information is not provided, the spatial distributions of parking demand of both cases are not so different. However, the shift of parking demand from popular car parks to the less congested car parks becomes larger when the level of demand is higher. This means that the availability information is more effective in terms of distributing parking demand when the density in the network becomes higher and congested. However, this may depends on the type of the availability information and further investigation is required.

3.3 Effects of VMS Location Pattern

We compare two different location patterns of the VMS board in the network. The one is the present pattern shown in the Figure 3, and the other is the pattern of which the VMS boards are located at the nearest link of each car park. In the later case, drivers are informed just in front of car parks. For different percentage of the informed drivers, the simulation model is calculated.

Figure 7.a depicts the averaged waiting time at car parks. The waiting time of present location pattern is larger than that of the nearest location pattern. If a driver finds the FULL message at the approach , he/she can switch to the less congested car parks. The time difference of providing availability information may not occur in the location pattern near by car parks. The present location pattern is not so effective in terms of reducing the averaged waiting time at car parks.

Figure 7.b shows the comparison of the averaged running time in the network. When the percentage of the informed drivers are less than 0.3, the running time of the present pattern is larger than that of the near-by location pattern. However, the running time of the near-by location pattern increases gradually when the percentage of the informed drivers grows more than 0.4. The drivers who obtain the FULL message just in front of the car parks will switch to the another car parks. This causes the additional run to the next car park, and consequently results in the increase of the running time in the network.

Figure 7.c presents the averaged total travel time in the network; the waiting time plus the running time. The total travel time of the present location pattern is larger than that of the location pattern near by car parks when the percentage of the informed drivers are less than 0.7. However, the near by location pattern loses its advantage when higher percentage of drivers are informed. As above mentioned, this is due to the increase of the running time in the network of highly informed drivers. As a result, the improvement of the travel time saving is expected if it is possible to move some of the VMS boards at the present pattern.

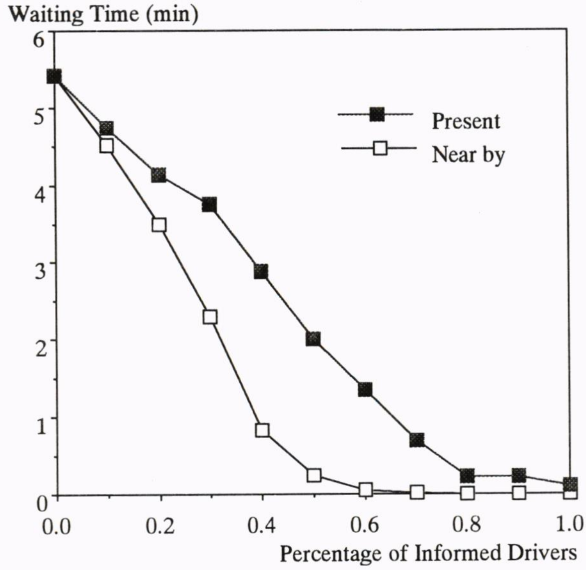


Figure 7.a Difference of Waiting Time Due to VMS Locatio Pattern

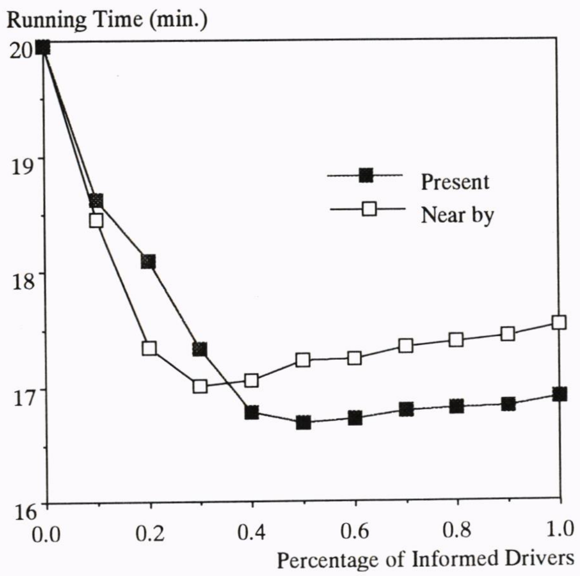


Figure 7.b Difference of Waiting Time Due to VMS Locatio Pattern

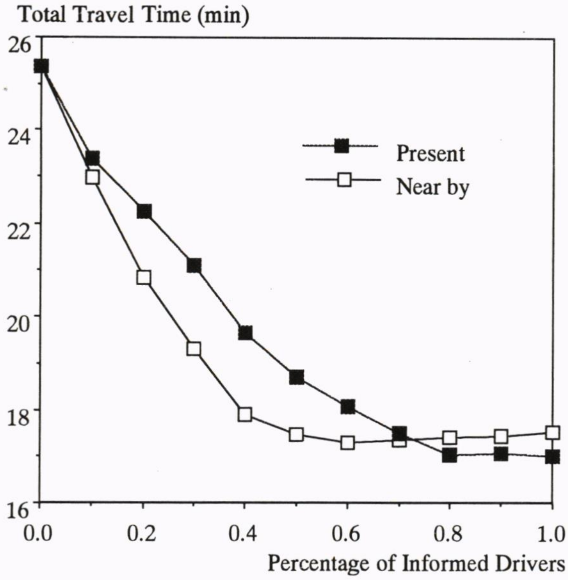


Figure 7.c Difference of Total Travel Time Due to VMS Locatio Pattern

They should be moved towards to the approach links when not so large percentage of drivers are informed.

4. CONCLUSION

In this paper, we have shown a microscopic network simulation model for evaluating the availability information service provided through the PGI system. We have used the street network in Matsuyama. The percentage of the informed drivers as a control parameter for the simulation. The spatial distribution of parking demand and the travel time reduction with availability information were examined. It is found that the availability information of car parks is effective to manage the parking demand from popular car parks to the alternative car parks. This contributes to reduce the avegaged waiting time at popular car parks and results in the total time savings.

The time saving effects among two location patterns of the message boards were compared. It is found that the message boards should be located close to the car parks when car drivers can find them easily after changing from congested car parks. It may be possible to design the PGI system so that the small numbers of the message boards located effectively can produce the same amount of the time saving effects as the large number of the boards in a network.

Of course, these findings are very limited to the given network and the OD pattern in the city of Matsuyama. Further studies are on going for improving the model to practical use. In particular, the pre-trip and en-route choice behaviour of car parks and routes are investigated and will be incorporated into the demand model. The effects of the different types of the availability information should be compared as well. The FULL/SPACES message may not be so effective if all of the car parks are nearly occupied. This can be discussed using the same framework proposed in this paper.

The author would like to express his gratitude to Mr. Katsu Sugino, Msc. Student of Ehime University, for his work in calculating numerical examples. This research was partly funded by the Grant in Aid for Scientific Research of the Japanese Ministry of Education (# 10650529).

REFERENCES

Allen, P.A. (1993) "Driver Response to Parking Guidance and Information Systems", Traffic Engineering & Control, Vol.34, No.3, pp.302-307.

Asakura. Y. and Morikawa T. (1993) "Evaluation of Parking Information Systems using Behavioral Choice Models", *Proc. 26th ISATA Conference in Aachen*, pp.218-226.

Asakura, Y. (1996). "A Parking Simulation Model for Evaluating Availability Information Service" in *Advanced Methods in Transportation Analysis*, Bianco, L. and Toth, P. (eds.), Springer, 1996, pp.457-480.

Asakura, Y., Kashiwadani, M., Nishii, K, and Furuya, H. (1995) "Driver's Response to Parking Information System: Empirical Study in Matsuyama City", Proc. 2nd ITS World Congress in Yokohama, pp.1813-1818.

Asakura, Y. (1997) "Comparison of Spatial Location Patterns of PGI Message Board: A Microscopic Network Simulation Model", Proc. 2nd Conference of HongKong Society for Transportation Studies, pp.9-14.

Cascetta E., Nuzzolo A. and Bifulco G.N.(1991) "Some Applications of a Stochastic Assignment Model for the Evaluation of Parking Policy", *Proc. of the 19th PTRC Summer Annual Meeting Seminar G*, 1991, pp.17-29.

Polak, J.W., Hilton, I.C., Axhausen,K.W. and Young, W. (1990)"Parking Guidance and Information Systems: Performance and Capability", *Traffic Engineering & Control*, Vol.31, No.10, pp.519-524.

Polak, J.W. and Axhausen (1994) "Parking Guidance and Information Systems: A Case Study of Frankfurt/Main", Proc. A3TM in Singapore, pp.343-350.

Thompson, R.G. and Bonsall, P.W. (1994) "Evidence of Driver's Response to Dynamic Parking Guidance and Information", TSWP 94/15, Department of Civil and Environmental Engineering, The University of Melbourne.

Young, W., Taylor, M.A.P., Thompson, R.G., Ker, I. and Foster, J. (1991) "CENCIMM, a Software Package for the Evaluation of Parking Systems in Central City Areas", *Traffic Engineering & Control*, Vol.32, No.4, pp.186-193.