SIMULATION MODEL OF PARKING LOT CHOICE BEHAVIOR AND PARKING LOT STRATEGIES IN CBD

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Abstract: The purposes of this study are grasping of parking lot choice behavior and examination of parking lot strategies. The first step is classification of drivers starting points, then a subject area entry point choice model is constructed. Also, based on statistics of drivers' actual parking utilization, parking zones are set up. Then the parking zone choice model and the parking lot choice model at each parking zone are constructed. When doing so, weights calculated from analytic hierarchy process, including human sensatory consciousness as well, are introduced as the explanatory variables for driving elements and walking elements. Next, parking process simulation by adopting each constructed choice model is carried out. Based on this simulation, parking lot strategies in central business district are examined.

1. INTRODUCTION

With the increased need for organized parking spaces in recent years, many cities have taken measures to establish parking lots in their centers. In addition, research in the field has been advanced from various angles. The research that deals with parking lot issues is based on construction of parking lot choice models. Walking distance to a destination (time), parking fees, and parking lot entry waiting time are adopted as main explanatory variables. In other words, in order to analyze a driver's behavior when parking a car, almost all the existing research has been conducted using models that consider only elements related to the parking lot and the distance between it and the destination. Professor Iida and others have conducted research which takes into account driving elements[1]. The driving elements utilized in that research are the distance between an entry point to an area subject to analysis and a parking lot, and the number of turns before getting to the parking lot. However, it can not be said that drivers are really exactly aware of the location of the entry point. Therefore, some questions still remain when using the distance as an explanatory variable. Moreover, besides these explanatory variables, there are some other things that need to be considered, such as road traffic.

Almost all the existing research in drivers' parking lot selection process is based on an assumption that all parking lots in the subject area are available choices. However, if the area is rather large, it is difficult to consider all the parking lots in the area to be options.

Figure 1. Assumption of the Drivers' Parking Process

In other words, it can be assumed that the drivers limit parking lot selection to a certain area (parking zones) considering the destination and the entry point to the subject area, then select a parking lot from among the choices.

Thus, based on the assumption of the drivers' parking process shown in Figure 1, this research endeavors to construct a mid-town parking lot choice model. In other words, the first step is classification of drivers starting points, then construct a subject area entry point choice model. Also, based on statistics of drivers' actual parking utilization, parking zones will be set up. Then the parking zone choice model and the parking lot choice model at each parking zone are to be constructed. When doing so, weight calculated from analytic hierarchy process as a general parameter, including human sensatory consciousness as well, are introduced as the explanatory variables for driving elements and walking elements.

2. OBJECTIVE AREAS OF ANALYSIS AND OUTLINE OF SURVEY

In this research, the survey was taken at eight main parking lots that have a capacity of more than one hundred cars in the Tenjin area of Fukuoka, which is the subject area as shown on Figure 2. Also, the twelve main commercial facilities were designated as destinations. Then, a 600 meter-circle was drawn with Tenjin station as its center. The area within this circle was considered to be the mid-town area. Eleven points were considered to be mid-town entry points that intersect eleven main trunk lines around the circle. The locations of these mid-town entry points matched the locations of map-style parking lot information signs that are supposed to be the first eye-catching signs for drivers coming into the Tenjin area.

The survey was taken on Sundays between the end of July and the beginning of September of Year Heisei 3 and 4. The time the survey was taken was from 10:00 to 19:00. The weather on those Sundays was always fair. Both an observation survey and a questionnaire survey were held. The observation survey was conducted by keeping a time record of all cars' arrival times, in and out of the garages at the entrance and exit of each parking lot. On the other hand, the questionnaire survey was conducted by handing out the questionnaire papers at the entrance gate of each parking lot, keeping a record of the car license plate numbers, and collecting the papers at the exit gate. The content of the questionnaire included questions related to individual information, the starting-point (the address), route, destination and so on. The number of questionnaires distributed to drivers was 4824 and number of the paper returned was 4318.

3. GROUPING TOGETHER SIMILAR STARTING POINTS AND CONSTRUCTION OF A MID-TOWN ENTRY POINT CHOICE MODEL

As for the starting points, a survey was taken to allow people to write down their respective addresses so that if used as is, the zone data would be quite detailed. Actually, information was collected from 43 different wards, cities, and districts in the prefecture, various prefectures in Kyushu, and other areas. Then, cluster analysis was conducted, based on the composition of each ward's ratio of entry point to the city center acquired as a result of the survey. The results were divided into four different groups: Higashi-ward type, Minami-ward type, Hakata-ward type, and Chuo and Nishi-ward type.

As for the choice of an entry point, it is difficult to contemplate a driver considering all entry points as real options. In reality, it is considered that a driver decides an entry point after limiting available choices, based on the entry direction to mid-town and the road conditions. Then, choices are limited to available options by each Origin-Destination pair (hereafter called OD pair) of the starting point and the destination point. In other words, a cross statistic analysis is performed of the destination and the entry point using the same starting point group. From the result, those pairs for which the number of samples is few and the congruence low are excluded. Only those choices conceivable as possible options are determined.

As for explanatory variables when constructing the mid-town entry point choice model, they have to be ones that show the characteristics of the entry point. Conceivable explanatory variables include: the direction of entry point, the route-characteristic congestion level, the number of lanes, and the possibility of utilizing urban highways.

As for the direction, it is difficult to evaluate according to a fixed volume. Even if conducted, it has to be shown how the location of the starting point, the entry point, and the destination point are related, utilizing elements such as coordinates. This makes matters cumbersome and human sensation cannot be taken into account when using fixed volume evaluation. Therefore, for the direction, pair comparison was conducted between the entry points at every OD pairs considered accessibility. Based on the results, the weight calculated from analytic hierarchy process was used as explanatory variables.

As for the number of lanes, the actual numbers were used. Also, as for the level of congestion, it greatly depends on human sense, so the weight calculated from analytic hierarchy process was used in this case. Moreover, as for the possibility of whether or not to utilize the urban highway, the case of highway availability is 1, and the case of unavailability is 0, according to the relation between the starting point and the entry point.

Table 1. Estimated Result of the Parameter (Mid-town Entry Point Choice Model)

Explanatory Variable	Model 1	
	Parameter	t-Value
A.S.D.V. (Entry Point 1)	-0.3058	-1.568
A.S.D.V. (Entry Point 2)	-0.5087	-2.014
A.S.D.V. (Entry Point 3)	0.4867	1.904
A.S.D.V. (Entry Point 4)	0.2433	1.426
A.S.D.V. (Entry Point 5)	-0.0445	-0.188
A.S.D.V. (Entry Point 6)	0.0921	0.659
A.S.D.V. (Entry Point 7)	0.0550	0.427
A.S.D.V. (Entry Point 8)	-0.2358	-1.367
A.S.D.V. (Entry Point 9)	-0.0688	-0.427
A.S.D.V. (Entry Point 10)	-0.0082	-0.053
Direction	3.4602	16.690
Possibility of Utilizing the Urban Highways	0.2020	1.242
Number of Samples	1396	
Likelihood Ratio	0.55	
Hit Ratio (%)	43.9	

A.S.D.V. : Alternative Specific Dummy Variable

As a result of constructing a mid-town entry point choice model based on disaggregate login using explanatory variables, the chosen explanatory variables were the direction and the possibility of utilizing the urban highways. The estimated result of the parameter is shown on Table 1. The likelihood ratio is 0.55, which is very good. The parameter mark is also an appropriate result; however, the hit ratio is a low value of 43.9%. This can be understood when a driver selects an entry point, though doesn't choose the same route all the time even if the conditions are the same. Also, some drivers select a different route just because they know the road well. Based on these facts, for the mid-town entry point choice model, each driver's choice is not considered as a determining element, but rather should be thought of as a probability element.

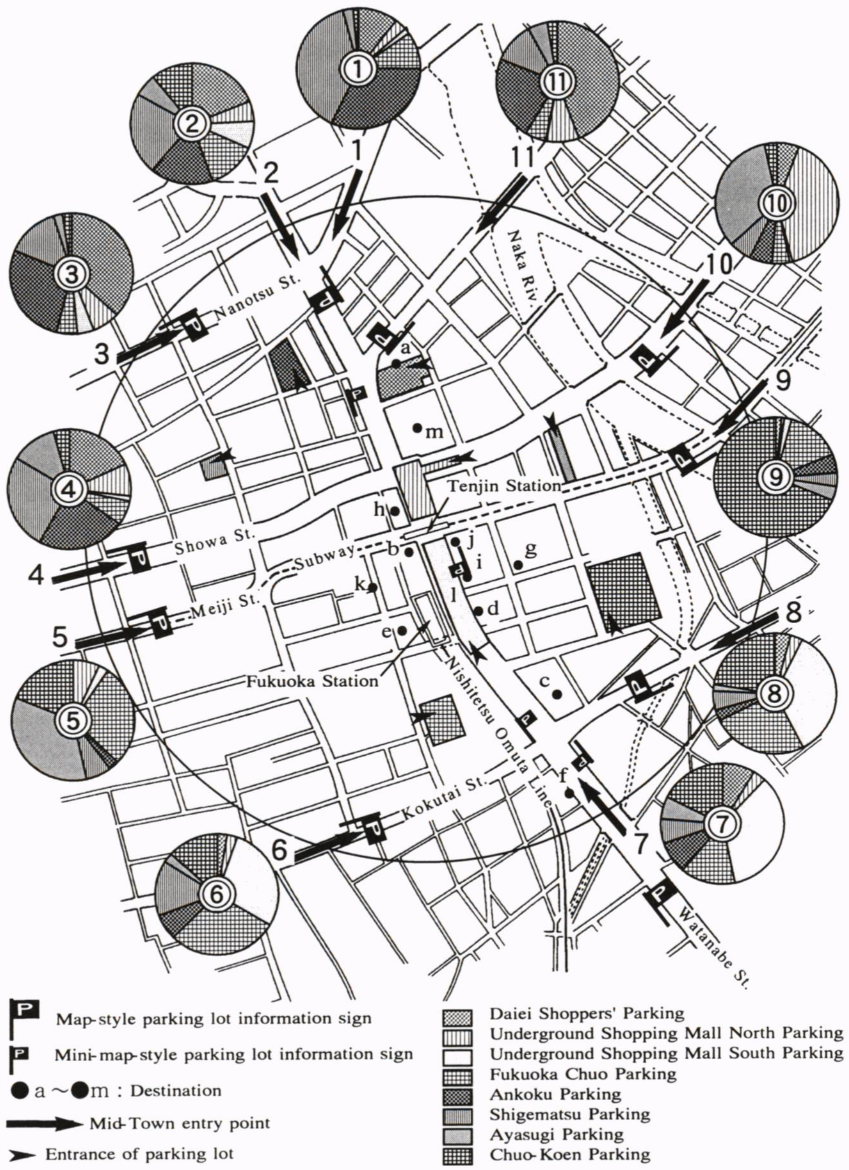

Figure 2. Ratio of Parking Lot Selection to each Mid-town Entry Point

4. RELATIONSHIP BETWEEN THE MID-TOWN ENTRY POINT AND PARKING LOT SELECTION

Figure 2 is showing the ratio of parking lot selection to each mid-town entry point by pie charts. In order to eliminate the effect of elements besides driving hindrances, a selection ratio of mid-town entry point to each parking lot is calculated. Based on that value, each parking lot ratio to each mid-town entry point is calculated.

According to the figure, the proportion of users at Daiei Shoppers' parking lot located in the northern part of Tenjin area is high at the north entry point. One can see from this that drivers tend to choose a parking lot to avoid the center of the city, where there is heavy traffic, and select one cross to the entry point.

From this, it can be seen that drivers' parking lot selection is strongly affected by the elements of driving hindrances, making it necessary to consider these facts when constructing a parking lot choice model.

5. SETTING UP PARKING ZONE

When setting up a parking zone, it is desirable to have a parking lot group that has similar proportions with regard to mid-town destinations and mid-town entry points. We created a cross map of the destination and the entry point to each parking lot. Then it was divided into groups by cluster analysis based on the correlation coefficient. The result is shown on Figure 3. Based on the figure, we decided to set up three parking zones: a Northern Parking Zone, a Middle Parking Zone, and a Southern Parking Zone. The Northern Parking Zone includes Daiei Shoppers' Parking, Ankoku Parking, and Shigematsu Parking. The Middle Parking Zone includes The Underground Shopping Mall North Parking and Ayasugi Parking. The Southern Parking Zone includes The Underground Shopping Mall South Parking, Fukuoka Chuo Parking, and Chuo-Koen

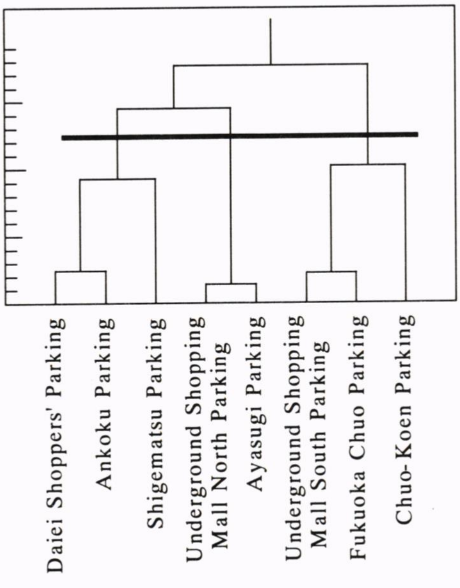

Figure 3. Result of Cluster Analysis

Parking.

6. CONSTRUCTION OF PARKING LOT CHOICE MODEL INSIDE THE PARKING ZONE

When constructing a parking lot choice model for each parking zone based on a disaggregate logit model, one can possibly make predictions of parameters for each parking zone. When doing so, even if the explanatory variables are the same, some discrepancy in the variables is possible depending on the parking zone. So we decided to make predictions of a parking lot choice model for each parking zone based on the same utility function.

As the explanatory variables for the model, the elements included were: driving hindrances from the mid-town entry point to the parking lot, walking hindrances from the parking lot to the destination, whether or not there is a parking fee discount system when shopping, and parking waiting time. As for driving and walking hindrances, in order to take into account drivers' awareness structure and include elements that could not be shown in numbers, weight calculated from analytic hierarchy process was used here. On the other hand, a parking fee was not introduced as an explanatory variable. This is because there was not much variation in parking fees at the time of survey. (The maximum difference

Table 2. Estimated Result of the Parameter (Parking Lot Choice Model)

( ) : t-Value < > : Number of Samples

	Explanatory Variable	Model 2	Model 3
	Alternative Specific Dummy Variable (Daiei Shoppers' Parking)	-0.96810 (-4.838)	
	Alternative Specific Dummy Variable (Underground Shopping Mall North Parking)	1.14921 (4.912)	
	Alternative Specific Dummy Variable (Fukuoka Chuo Parking)	0.46349 (4.343)	
	Driving Hindrances (A.H.P.)	7.48165 (12.004)	5.92022 (11.254)
	Walking Hindrances (A.H.P.)	6.75607 (11.442)	4.58967 (10.485)
	Parking Fee Discount System	1.95670 (7.526)	
	Parking Waiting Time	-0.04976 (-5.669)	-0.02587 (-4.553)
	Likelihood Ratio	0.27	0.20
Hit Ratio (%)	Daiei Shoppers' Parking <181>	73.9	70.6
	Ankoku Parking <111>	70.6	70.0
	Shigematsu Parking <18>	94.2	94.2
	Whole of the Northern Parking Zone <310>	79.6	78.3
	Underground Shopping Mall North Parking <147>	73.1	62.3
	Ayasugi Parking <65>	73.1	62.3
	Whole of the Middle Parking Zone <212>	73.1	62.3
	Underground Shopping Mall South Parking <247>	68.5	64.9
	Fukuoka Chuo Parking <171>	71.3	74.4
	Chuo-Koen Parking <157>	83.0	81.7
	Whole of the Southern Parking Zone <575>	74.3	73.8
	Whole <1097>	75.7	73.5

was 70 yen an hour). The result of parameter prediction was shown on Model 2 of Table 2. The likelihood ratio was 0.27. The overall hit ratio was 75.7%. For each parking zone, the hit ratios were as follows: The North zone was 79.6%, the Middle zone was 73.1%, and the South zone was 74.3%. When looking at t-values, while each of those explanatory variables was convincing enough, nevertheless, the values of driving and walking hindrances were high. One can consider elements of location as the main factors affecting drivers' selection of a parking lot. Also, the results for each parameter's marks were appropriate.

Model 2 can be utilized as a prediction of drivers' parking lot selection process for each zone when new demands occur. However, when organizing new parking lots, in other words, when the number of choices is increased, the demand can not be predicted just by utilizing Model 2 due to the mode' structure. In other words, a problem occurs when utility function values can not be considered for a newly added option because choice specific dummy variable and choice specific variable govern the relative relationships among existing choices.

Among the variables used in Model 2, if the model were reconstructed using only common variables, the results would be the same as Model 3 in the same table. The likelihood ratio is 0.20. The overall hit ratio is 73.5%. The hit ratio of each parking zone is as follows: The North zone is 78.3%, the Middle zone is 62.3%, and the South zone is 73.8%. For the t-value, all the explanatory variables are convincing enough. Also, the parameter's marks are appropriate.

As shown above, two models are constructed; however, we recommend that each model be used depending on the situation. For instance, when the number of choices is not increased, Model 2 is used for the demand prediction since the accuracy of Model 2 is superior. When examining needs associated with organization of new parking lots, Model 3 is used.

7. CONSTRUCTING PARKING ZONE CHOICE MODEL

The explanatory variables when constructing the parking zone choice model are as follows: driving hindrances between the entry point and the parking zone, walking hindrances between the parking zone and the destination, whether or not there is a parking lot in the parking zone that provides a discount for the parking fee when shopping, and the average parking waiting time in the parking zone. In addition to this, by taking into account log-sum variables calculated from the parking choice model for each parking zone in the previous paragraph, one can conceive of a model such as a nested logit model which can be constructed.

The result of predicting a parameter using these explanatory variables is shown in Model 4 of Table 3. This also uses weight calculated by analytic hierarchy process in terms of driving hindrances and walking hindrances. And the log-sum variables are calculated from Model 2. The likelihood ratio is 0.70. The hit ratio is 92.7%. It can be said that the model's duplication possibility is very high. The result of all the parameter's marks are also appropriate for all the explanatory variables. Yet, with regard to t-values, they are highly convincing for parking zone selection because the values of driving and walking hindrances are high enough, but can not be considered convincing enough in terms of whether or not there is a parking fee discount system and parking waiting time. Then, when looking at λ, the value is 0.190, which is between 0 and 1. Although this is a conceivable result, however, this value is small since the t-value is 0.896. Therefore, this result is dismissed within a 5% standard deviation. From all this, it can be understood that parking zone selection and parking lot selection are mutually independent.

Table 3. Estimated Result of the Parameter (Parking Zone Choice Model)

( ) : t-Value < > : Number of Samples

	Explanatory Variable	Model 4	Model 5
	Alternative Specific Dummy Variable (Northern Parking Zone)	0.36057 (1.288)	0.34582 (1.850)
	Alternative Specific Dummy Variable (Middle Parking Zone)	0.32621 (1.171)	
	Driving Hindrances (A.H.P.)	4.30357 (10.456)	4.75265 (15.178)
	Walking Hindrances (A.H.P.)	3.97371 (5.353)	4.61291 (21.767)
	Parking Fee Discount System	0.15552 (0.380)	
	Average of Parking Waiting Time	-0.03826 (-1.191)	-0.03841 (-2.112)
	λ	0.19037 (0.896)	
	Likelihood Ratio	0.70	0.70
Hit Ratio (%)	Northern Parking Zone <310>	92.6	92.9
	Middle Parking Zone <212>	91.5	91.3
	Southern Parking Zone <575>	94.0	93.9
	Whole <1097>	92.7	92.7

If the model is reconstructed by conducting variable selection, the result is the same as shown in Model 5 in the same table. The likelihood ratio is 0.70. The hit ratio is 92.7%, which is the same accuracy when compared to Model 4. The results of the parameter's marks are also appropriate. It can be said that this is a good model since the t-value is high enough. The choice specific dummy variable is shown only in the North Parking zone. This is because the t-value of the choice specific dummy variable in the Middle Parking zone has become smaller than 1 when using driving hindrances, walking hindrances, and the average of parking waiting time as explanatory elements.

8. EXAMINING PARKING MEASURES THROUGH PARKING PROCESS SIMULATION

In this section, we will first examine a significant application of each choice model proposed in this research. For the proposed parking zone choice model and parking lot choice model inside the parking zone in this research, the parking waiting time is used as an explanatory variable. However, this variable always changes depending on the circumstances of the parking lot. Then as a way to test the model, parking process simulation was carried out for all the arriving cars as objects. The flow chart of the simulation is shown on Figure 4. The data for the arrival time of each car, the range of parking time periods, starting points, and destination points was acquired from conducting the observation and questionnaire survey. For cars for which the destination and the starting points were not identified, predictions were made using random numbers based on a range of actual measurement.

The results of the simulation were shown on Figures 5 to 7. For the mid-town entry point

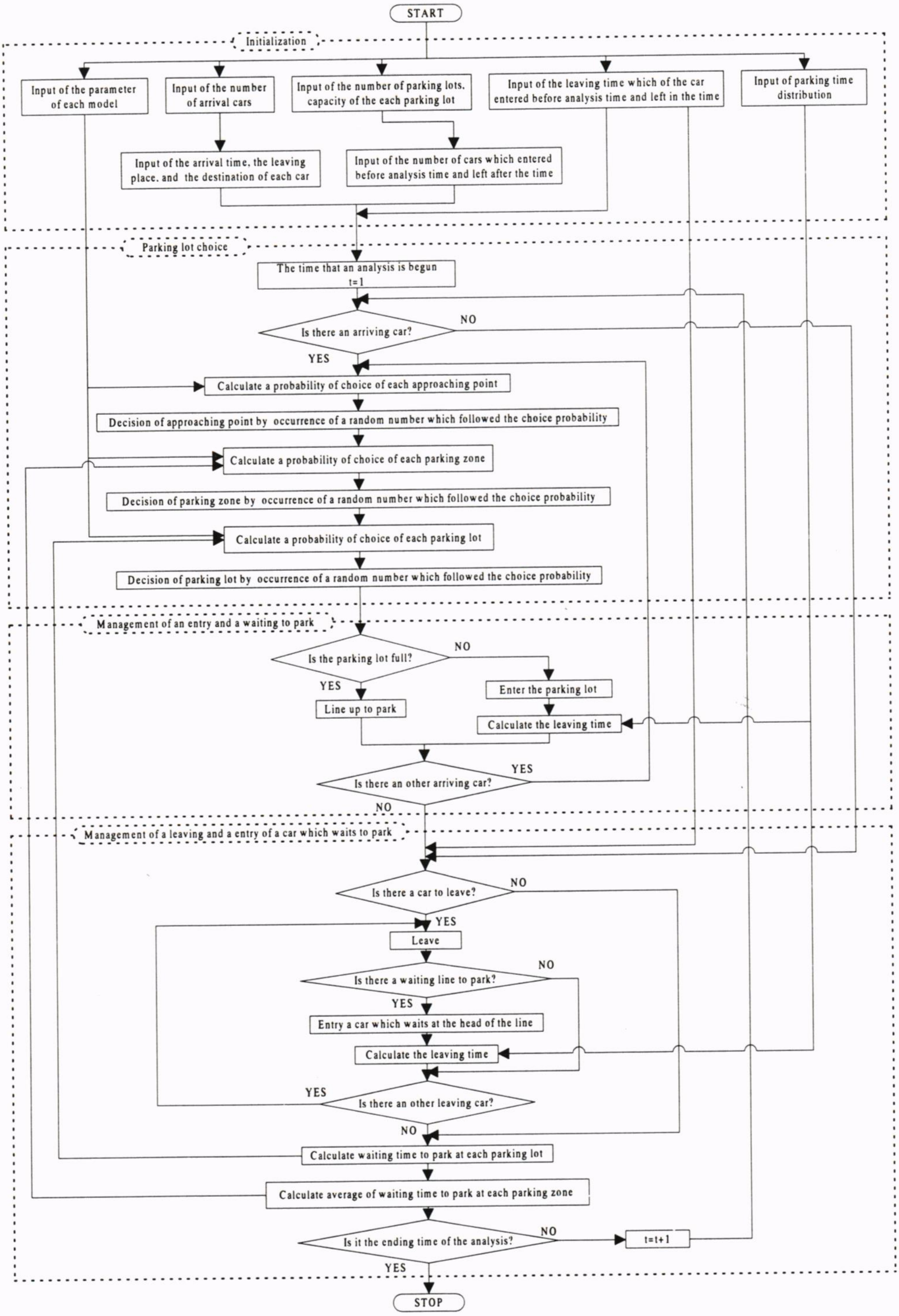

Figure 4. Flow Chart of the Simulation

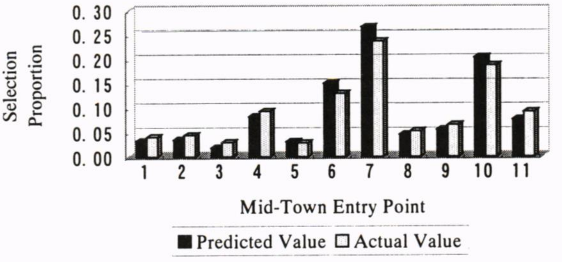

Figure 5. Result of Simulation (Mid-town Entry Point Selection)

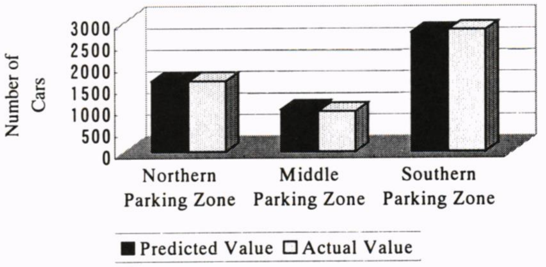

Figure 6. Result of Simulation (Parking Zone Selection)

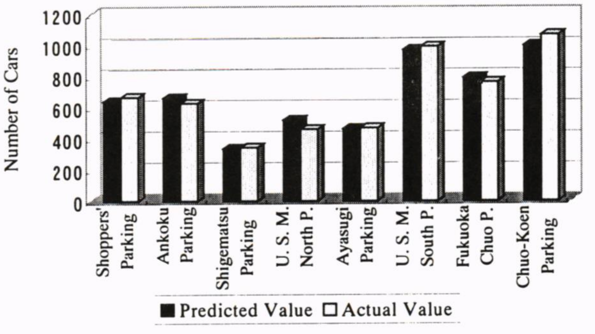

Figure 7. Result of Simulation (Parking Lot Selection)

choices, comparisons were made to the selection proportion because the actual measurement survey for all the cars doesn't exist. From these figures, mid-town entry point choices, parking zone choices, and parking lot choices of actual measurement value and predicted measurement value for each level are very well matched. This confirms that each choice model proposed in this research is significant.

As one parking measure, we tried to predict drivers' parking process and reduce the number of cars waiting in line on roads, by expanding one parking lot. In this research, we focussed on two parking lots in the South Parking zone which are most in demand in the Tenjin area of Fukuoka. One is the Underground Shopping Mall South Parking lot, which is located in the center of mid-town and is continuously full from the morning. Another is Chuo Park Parking lot, located in the outskirts of the mid-town area, which usually becomes full in the afternoon. The changing circumstances when measurements were taken to expand these lots in capacity will be analyzed here.

First, the case of the Underground Shopping Mall South Parking lot is examined when trying to increase capacity by 100 cars. As a result of carrying out the simulation, time

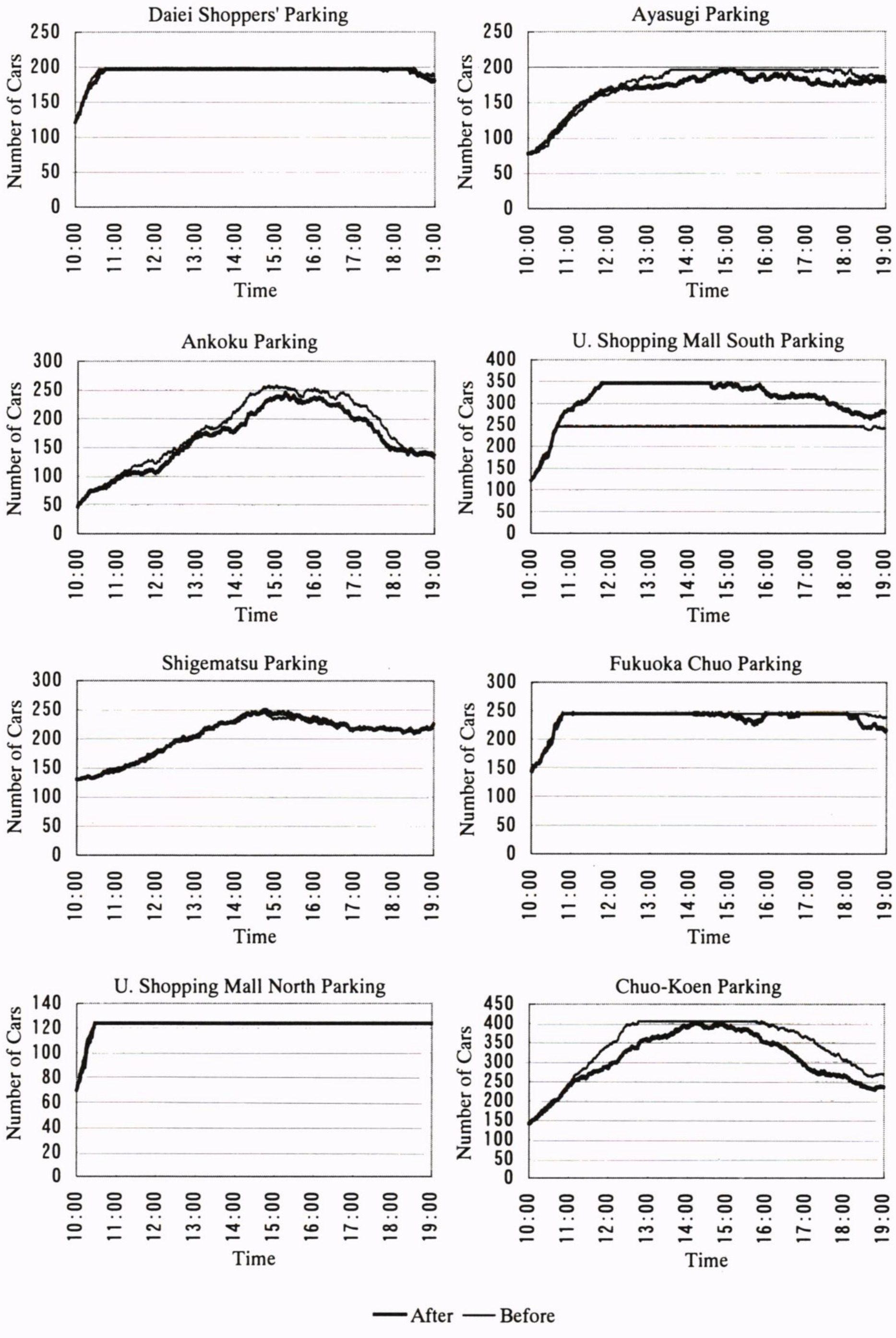

Figure 8. Time Changes of Occupied Spaces for each Parking Lot

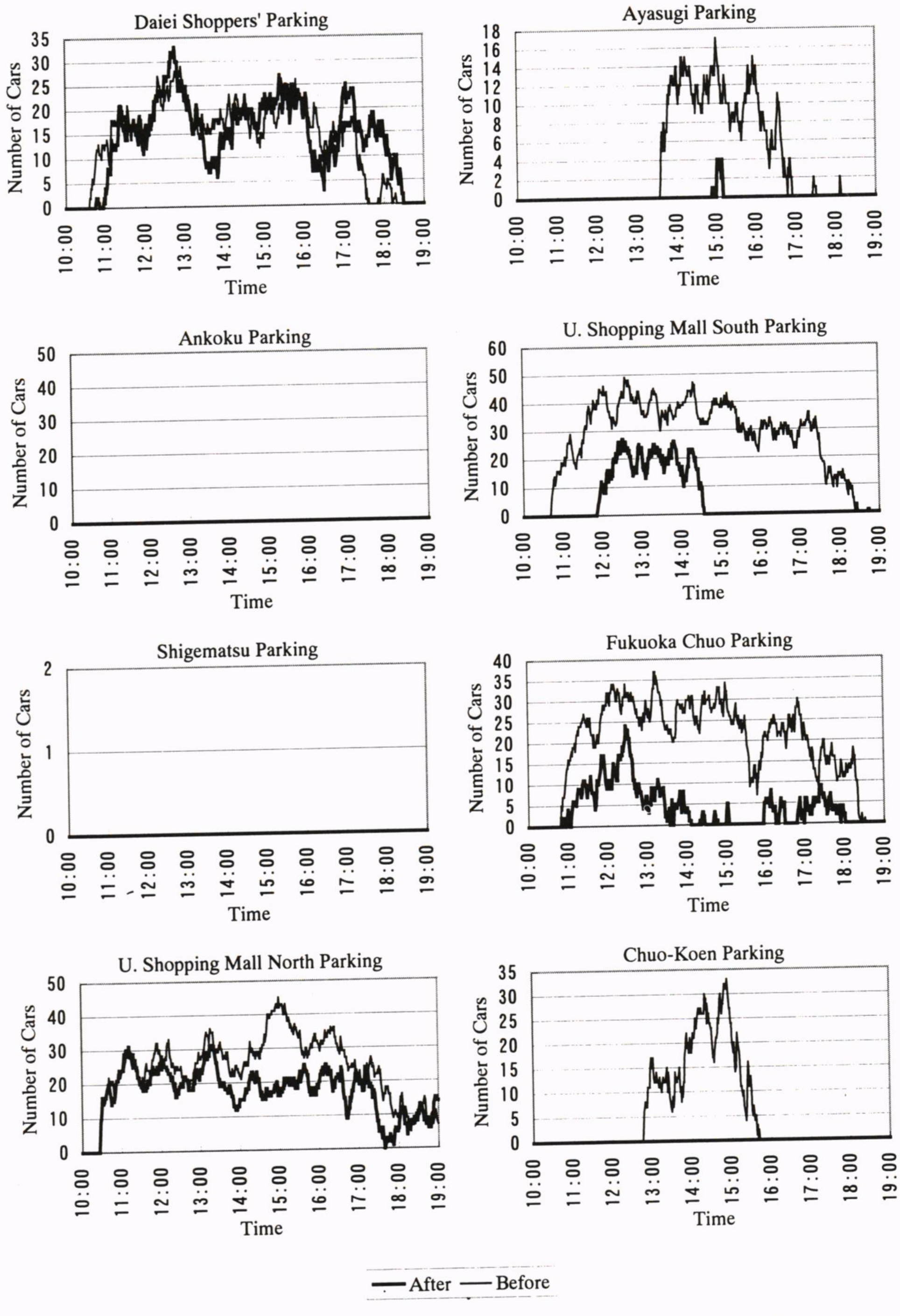

Figure 9. Time Changes of the Number of Cars Waiting for each Parking Lot

changes of occupied spaces for each parking lot were shown on Figure 8. From this figure, of course it can be understood that the Underground Shopping Mall South Parking lot's capacity was expanded by 100 cars. At the same time, it could be seen that the fully occupied time of the parking lot was shortened compared to the situation before this measurement. In other words, previously, the fully occupied time was from before 11:00 to around 18:30; but after this measurement it was from before 12:00 to around 14:30. When looking at other parking lots in the same parking zone, the fully occupied time at Fukuoka Chuo Parking lot was from before 11:00 to around 18:00 before this change; however, it was different after this measurement. The parking lot was once vacant between 15:00 to 16:00 and again, it was full after that. Moreover, after it became vacant at around 18:00, the number of parked cars decreased compared to the situation before this measurement. Looking at Chuo Park Parking lot, the number of parked cars decreased considerably. The previous fully occupied time was from around 13:00 to around 16:00, but it didn't become quite full after the measurement except for only a short time between 14:00 to 15:00. For other parking lots in the same parking zone, there were no changes for Daiei Shopper's Parking lot, Shigematsu Skypark Parking lot, and Underground Shopping Mall North Parking lot. For Ankoku Parking lot and Ayasugi Parking lot, the number of parked cars decreased slightly after the measurement.

Next, the change in the number of cars depending on the time before and after the measurement was examined. The result was shown on Figure 9. For the Underground Shopping Mall South Parking lot, it can be seen that the waiting time in line for a parking spot was shortened between before 12:00 and around 14:30, as mentioned above. The number of cars waiting during the peak time also decreased. For the Fukuoka Chuo Parking lot, the number of cars waiting decreased considerably compared to the situation before the measurement. As for the Chuo Park Parking lot, after taking this measurement, there wasn't a line of cars waiting to get in. Looking at other parking lots, it can be seen that there was no change at Daiei Shoppers' Parking lot, Ankoku Parking lot, or Shigematsu Parking lot. There was a slight decrease overall at the Underground Shopping Mall North Parking lot. At Ayasugi Parking lot, there was no line of cars waiting.

As mentioned above, it was possible to decrease the number of cars waiting in line by expanding the capacity of the Underground Shopping Mall South Parking lot. However, the effect of that did not generalize to the other parking lots, as the number of cars waiting in line only slightly decreased at the Underground Shopping Mall North Parking lot and at Ayasugi Parking lot.

In order to look at the level of improvement in a fixed volume according to this measurement, let's look at the average number of cars waiting in the whole area. The average number of cars waiting at each parking lot per minute at all parking lots during the designated analysis period defines the average number of waiting cars. The result showed that previously, the average number of cars waiting was 11.5 cars, but the number decreased to 5.0 cars after this measurement.

The next step examines the case of the capacity of Chuo Park Parking lot being expanded by 100 cars. The result of the simulation was shown on Figures 10 and 11, which indicate the change in the number of cars parked and cars waiting at each parking lot, depending on the time. As seen on Figure 10, compared to the situation before this measurement, though the number of parked cars during the peak period increased at Chuo Park Parking lot as the capacity of the parking lot grew, the volume of increase was very small. Looking at other parking lots, the situation was almost unchanged at Ankoku Parking lot during peak period and at Chuo Park Parking lot after 18:00, with the number of parked cars decreasing only slightly. When looking at Figure 11, although before this measurement a waiting line existed at Chuo Park Parking lot, the line did not occur after this measurement. For the other parking lots, it could be seen that the situation was

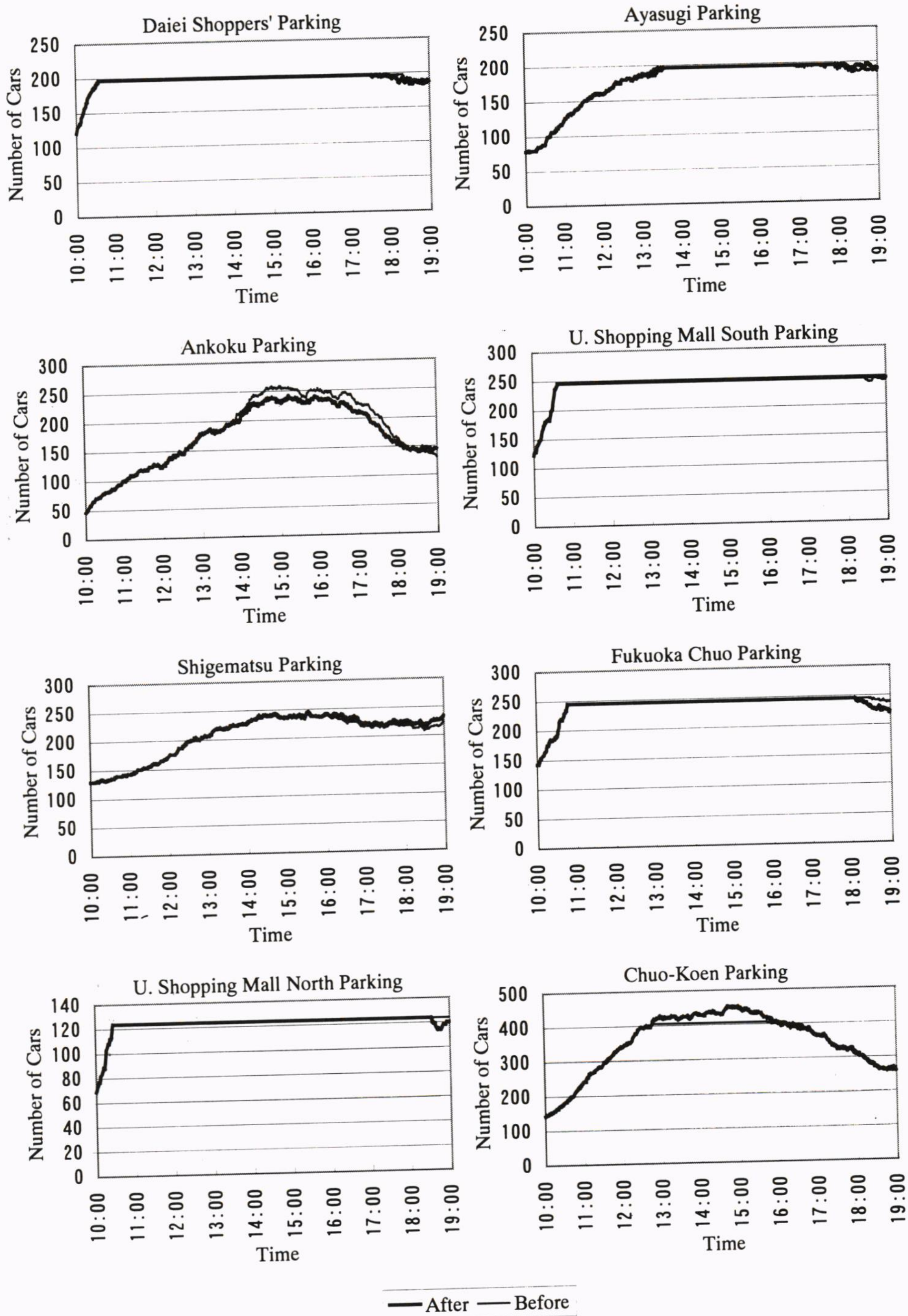

Figure 10. Time Changes of Occupied Spaces for each Parking Lot

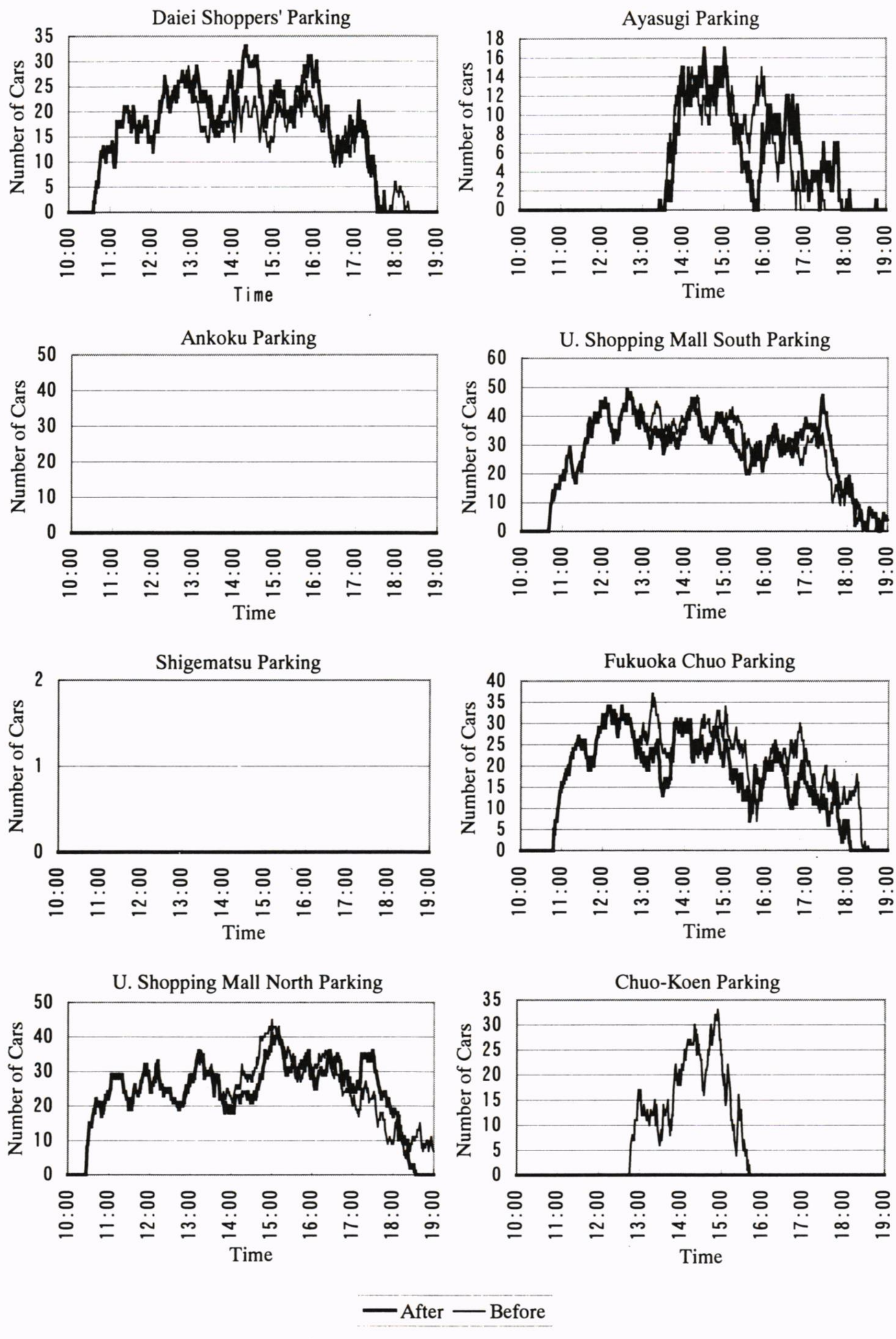

Figure 11. Time Changes of the Number of Cars Waiting for each Parking Lot

almost unchanged.

According to this, when the capacity of Chuo Park Parking lot was expanded, the overall parking situation in that area changed very little. The average number of waiting cars after this measurement was 10.7 cars; and since it was 11.5 cars before the measurement, it could be seen that there was no improvement made. The reason for that is, that the overall attractiveness for Chuo Park Parking lot is lower than the Underground Shopping Mall South Parking lot and Fukuoka Chuo Parking lot inside the South parking zone. Therefore, drivers strongly tend to choose those two parking lots even though waiting time is a little bit longer.

9. CONCLUSION

In this research, we constructed each choice model based on a disaggregate logit model on the assumption that the three steps of drivers' parking process are as follows: mid-town entry point selection, parking zone selection, and parking lot selection in a parking zone. According to this, we assumed that drivers select a parking zone before selecting a parking lot. However, in order to construct a disaggregate logit model, an important consideration is how choices for individuals are set up. From that point of view, the parking zone choice model can be seen as the parking lot choice group determination model.

As a result of carrying out parking process simulation by adopting each constructed choice model, the drivers' parking selection process was illustrated very accurately and the significance of the proposed models was confirmed. Moreover, by conducting simulation, we analyzed changes in drivers' parking lot selection process when expanding parking lots. As a result, it became clear that when a parking lot is expanded or a new parking lot is organized, elements of attractiveness such as location and so on of a subject parking lot are relatively lessened for drivers, and the effectiveness of such action is rather low. On the other hand, high effectiveness is achieved when relatively attractive parking lots such as the Underground Shopping Mall South Parking lot are expanded or when new parking lots that have the same kinds of elements are constructed. However, drivers tend to choose a parking lot that is attractive to them. So, when a parking lot is organized which is extraordinarily attractive, it tends to get too crowded, while the demand for those parking lots that are not as attractive decreases. As a result, it can be said that the efficiency of the overall parking lot utilization in that area deteriorates. It can be also be said that organizing a surplus of attractive parking lots brings heavier traffic to mid-town because those parking lots are usually located in the central area.

In conclusion, in this research, although models were constructed based on the assumption shown in Figure 1 in terms of drivers' parking process, it can be considered that the selection of the mid-town entry point might occur at the same time a parking lot choice is made or just afterwards. In future research this point needs to be examined as well.

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