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Little's Formula and Parking Space Policy Viewed from Consumers' Parking Behaviors at City Center Retail Environment

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Abstract Many local cities in Japan now are facing the critical problem of managing car parking to alleviate traffic congestion occurred chronically at weekends in their city center commercial area. The crucial point, we believe, to make matters worse for solving the problem is that planners at local cities seem to have no means to assess whether or not parking lots are insufficient and if so, how many parking lots they actually need. Taking up the actual instance of city center retail environment of Fukuoka and conducting the interview survey of parking behaviors of consumers who visit there by automobile, the purpose of this paper is to address the problem to show a simple method to determine how much capacity the parking space must need at the city center by using Little's formula with taking into account the distinctive feature of consumers' parking behaviors at city center retail district.

Keywords: Little's formula; Parking space; City center retail district; Consumer behavior

1. Purpose

Many local cities in Japan now are facing the critical problem of managing car parking to alleviate traffic congestion occurred chronically at weekends in their city center commercial area. The crucial point, we believe, to make matters worse for solving the problem is that planners at local cities seem to have no means to assess whether or not parking lots are insufficient and if so, how many parking lots they actually need.

The basic idea behind this paper is that while we have been conducting the on-site survey of consumer shop-around (Kaiyu) behavior at the city center retail environment of Fukuoka city every year since 1996, we have just noticed that if we utilize respondents' responses in this survey about their arrival time at and scheduled departure time from the city center, a simple application of Little's formula can get around the above problem. (Cf. [6]) However, since our on-site

survey are designed to sample the respondents from visitors who are on the way of their shop-around, that is, have yet to finish their shop-around trip, their responses about the departure time are their self-estimated time they roughly plan to leave from the city center. Thus to implement our idea we have carried out another on-site interview survey of parking behavior of consumers who visit the city center by automobile to get their accurate departure time. We have selected several parking lots. The survey was designed to sample the respondents from the visitors who parked at these parking lots and just were going to leave from there so that the samples for this survey can be considered to have finished their shop-around trips.

On the other hand, we think there are distinctive features in parking behavior of consumers who visit city center retail facilities. For example, in Fukuoka, the retail establishments are located at the middle of the city center area and the accesses to the middle by car can be divided into four directions: from north, south, east and west. Note that we have no circular roads surrounding the middle of city center area. If there are no circular roads, the access direction to the middle greatly matters. The destination facilities are located only at the middle so that it becomes the most congested area. Hence if you are accessing the middle from some direction and would like to change the direction to another one, you must pass through the middle, the most congested area. Thus the visitors by car who are accessing to the middle from some direction would not change the direction and like to find the parking space on the way of the direction to the middle. We must take into account these peculiar characteristics of drivers' incentives to avoid the congestion to enhance their trip utility.

While many previous studies on chronic traffic congestion at city center area (Cf. [1]) suggest that main factor and the large part of the congestion are due to driver's cruising behavior for searching the vacancy of parking lots, there have been few empirical studies to firmly support this suggestion. Moreover, there have been no previous studies taking into account the above features of driver's behavior.

With these in mind, taking up the actual instance of city center retail environment of Fukuoka and conducting the interview survey of parking behavior of consumers who visit there by automobile, the purpose of this paper is to show a simple method to determine how much capacity the parking space must need at the city center by using Little's formula while taking into account the distinctive feature of consumers' parking behavior at city center retail district.

The remaining parts of this paper are composed of as follows. Next we review Little's formula and data used. In Chapter 3 we use Little's formula to analyze the needed capacity of parking space dealing with the city center as one area. Chapter 4 discusses distinctive features of parking behavior of consumers. Chapter 5 makes the parking capacity analysis by access directions. Chapter 6 ends with conclusion.

2. Little's Formula and Data Used

2.1. Little's formula

As is well known, Little's formula, $L = \lambda W$ prescribes the relationship between L, the length of the queue or waiting line, λ, the arrival rate, and W, the waiting

time. (Cf. [2], [3])

Here we explain how to interpret and apply Little's formula to the parking capacity analysis. The Little's formula is concerned with the queuing theory. Suppose some system provides some service for customers. As a concrete example, suppose a ticketing device at railway station where travelers line to get tickets. The length of waiting line L is the number of travelers to wait in front of the ticketing device. The arrival rate λ is the number of travelers to come to the ticketing device per unit of time. The waiting time W is the length of time from starting to join the waiting line to leaving the line after getting the ticket. Here we interpret a whole city center retail environment as a system, which provides shopping services for consumers who visit the city center by car.

Look at Figure 2-1. The vertical axis indicates the number of cars and the horizontal axis is the time. In the figure the dark curve expresses the cumulative number of car arrivals and the light line the cumulative number of car departures. Let S be the area surrounded by two curves, let N be the total number of car arrivals (departures) and let T be the total time length from the beginning to the end.

Notice that the vertical difference between the two curves means the number of parking cars, which corresponds to the length of waiting line, and that the horizontal difference between the two means the staying time, which corresponds to the waiting time. It also should be noticed that the unit of the area S must be the multiplication of time and the number of cars.

The average waiting time can be expressed by $W = S/N$ and the average length of waiting line can be represented by $L = S/T$. Noting that the average arrival rate can be formulated by $\lambda = N/T$, Little's formula is derived as follows. (Cf. [4])

$$L = \frac{S}{T} = \left(\frac{N}{T}\right)\frac{S}{N} = \lambda W$$

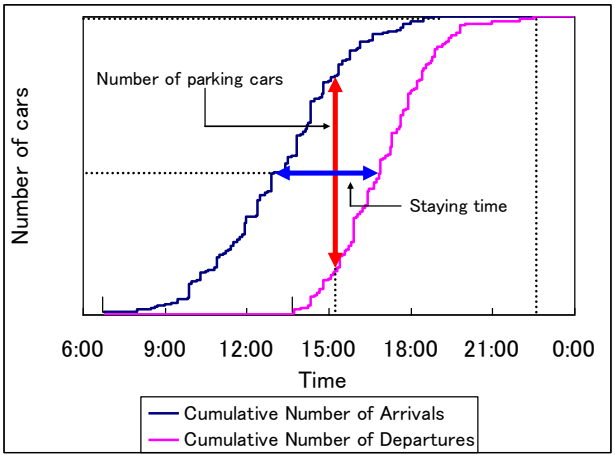

Figure 2-1 Exposition of Little's formula

2.2. Data used

In this paper we use the data obtained from the following two surveys. The first

one is the 12th survey of consumer shop-around behavior at city center of Fukuoka and the second is the first survey of consumer parking behavior at city center of Fukuoka. Table 2-1 gives the outline of the 12th Survey of Consumer Shop-around Behavior at City Center of Fukuoka.

Table 2-1 Outline of 12th survey of consumer shop-around behavior

Name of Survey	The 12th Survey of Consumer Shop-around Behavior at City Center of Fukuoka
Date of Survey	2007.06.30 (Sat), 2007.07.01(Sun)
Survey Time	12:00 - 18:00
Sampling Places	8 shopping facilities SOLARIA PLAZA , JR HAKATA STATION, CANAL CITY HAKATA, SHOPPERS DAIEI, IWATAYA, DAIMARU, MITSUKOSHI, HAKATA RIVERAIN
Number of Samples	686 samples
Survey Method	1. Samples drawn at random from visitors at the city center of Fukuoka 2. Interview with questionanaire for 15 to 20 minutes
Main Questionnaire Items	1. Personal profiles (Residence, Age, Sex, Occupation, etc.) 2. Shop-around History (Places visited, purposes done there, and expenditure there if any) 3. Travel time to the city center of Fukuoka 4. Transport means to the city center of Fukuoka 5. Frequency of visits to the city center of Fukuoka 6. Frequency of visits to various shops at the city center of Fukuoka

Similarly, Table 2-2 gives the outline of the 1st Survey of Consumer Parking Behavior at City Center of Fukuoka. In this survey, we picked up 11 parking facilities as sampling sites. We conducted on-site sampling in which the respondents were sampled at random from visitors who parked their cars at these parking facilities and were going to leave from there. We implemented our on-site interview survey for the consumers who can be thought to have finished their shop-around trip. As shown in Table 2-2, in this survey we asked the respondents from which direction they entered the city center area of Fukuoka, how many minutes they had cruised before they found the vacancy of the parking space and how many minute they spent from starting to join the waiting line for the parking lots to finally parking their car and leaving there for starting their shop-around trip.

Table 2-2 Outline of the 1st survey of consumer parking behavior

Name of Survey	The 1st survey of consumer parking behavior
Date of Survey	2008.5.24 (Sat) 15:00-20:00; 2008.5.25 (Sun) 14:00-19:00
Sampling Places	11 parking facilities Takedou Parking, Ankoku Parking, F-Parking Kitatenjin, N-Parking Tenjin, Tenjin Chuoukouen Parking, Ayasugi Parking,
Number of Samples	204 samples
Survey Method	1. Samples drawn at random from visitors to each parking of survey point 2. Interview with questionanaire for 10 to 15 minutes
Questionnaire Items	1. Personal plofiles (Residence, Age, Sex, Occupation, etc.) 2. Shop-around History (places visited, purposes done there, and expenditure there if any) 3. Travel time to the city center of Fukuoka 4. Frequency of visits to the city center of Fukuoka 5. Access direction from which they entered the city center area of Fukuoka 6. How many minutes they had cruised before they found the vacancy of the parking space

2.3. Dividing the city center retail district by access directions

The city center retail district of Fukuoka City is called Tenjin. To characterize consumers' parking behavior by accessing directions, we divide the Tenjin area into five blocks as shown in Figure 2-2. The five blocks are the north, the south, the east,

the west, and the middle blocks. We distinguish the access directions of consumers to the middle by checking what block they entered first among the four blocks: north, south, east, and west.

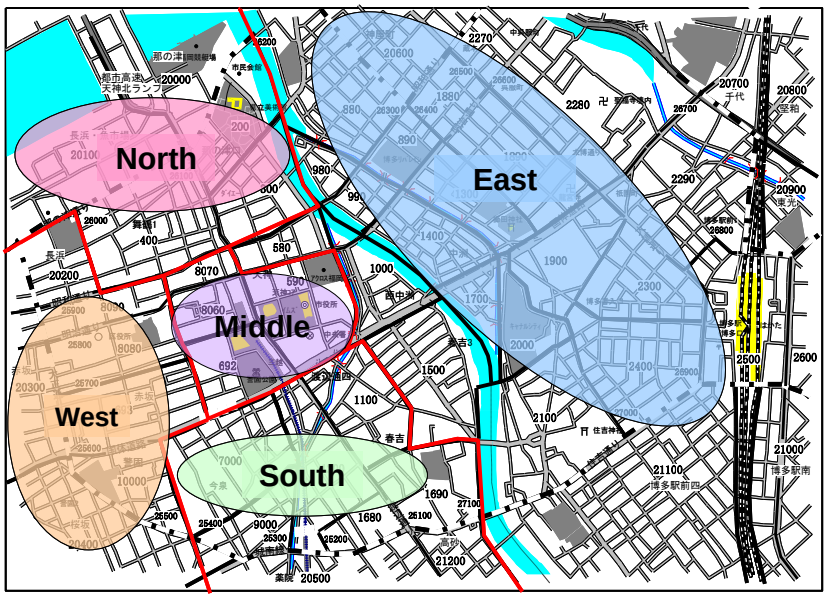

Figure 2-2 Division of City Center Retail District, Tenjin

2.4. Total number of visitors who visit the city center by car

For the parking capacity analysis, we need the number of actual incoming visitors at the city center of Fukuoka. From our previous study, the number of incoming visitors at the city center of Fukuoka for the purposes of shopping, leisure and eating out was estimated to be 150,000 persons per day in average over the year as of 2000. (Cf. [5]) According to the 12th Survey of Consumer Shop-around Behavior at City Center of Fukuoka in 2007, the percentage of the visitors who visit the city center by car turns out to be 14.1%.

Hence the number of visitors who come to the city center by car is estimated to be 21,150 persons per day in average over the year.

2.5. Parking capacity for each block of Tenjin

Other information we need is the parking capacity of the city center retail environment. We have carried out the field survey of parking space at the city center retail district of Tenjin. First we checked the location of parking lots by using the city map and counted the number of parking lots by the visual check on site while visiting the spot. As for the parking space like high-storied parking facilities, whose number of parking lots cannot be counted by the visual check on site, we asked the management of the parking space how many cars it can accommodate.

From these field survey efforts, the numbers of parking capacity are obtained. They are shown in Table 2-3.

Table 2-3 Parking capacity by five blocks of Tenjin, 2008

	Parking capacity	parking lots
North	4,506	100
Middle	2,399	21
East	998	53
South	2,732	121
West	2,692	91
Total	13,327	386

3. Little's Formula and Parking Capacity Analysis

In this chapter we deal with the city center retail district as one area and analyze whether or not the capacity of parking space is sufficient by using Little's formula. We regard the length of waiting line in Little's formula as the demand for parking capacity. For the purpose, we need the arrival rate and the average waiting time.

3.1. Arrival rate

Figure 3-1 shows the distribution of arrival time of consumes who visit Tenjin by car. We see that the two third of the arrival time are between 10:00 to 15:00.

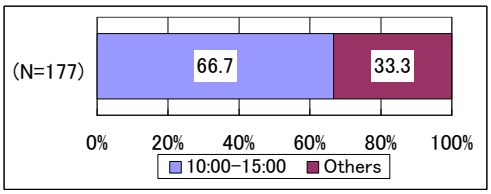

Figure 3-1 Distribution of arrival time

We have assumed that the total number of visitors who visit the city center by car is 21,150 persons per day in average over the whole year.

Thus the number of arrivals during the time period of 10:00 to 15:00 becomes 14,101 people per day. During other time period, the number of arrivals is 7,049 people per day. They are shown in Table 3-1.

Table 3-1 Number of arrivals by time zone

Time Zone	Total	Percentage	Number of Arrivals
10:00–15:00	21,150	66.7	14,101
other time	21,150	33.3	7,049

From these results, we can calculate the arrival rate as shown in Table 3-2.

Table 3-2 Arrival rate (unit: persons per minute)

Time Zone	Number of Arrivals	Time (Minutes)	Arrival Rate
10:00–15:00	14,101	300	47.00
All time	21,150	1080	19.58

3.2. Average staying time for visitors by car

According to the result of the 1st Survey of Consumer Parking Behavior, the

average length of staying time for visitors by car turns out 224.6 minutes.

3.3. Demand for parking lots calculated by Little's formula

Since we have the arrival rate and waiting time, we can estimate the demand for parking lots using Little's formula. The results are shown in Table 3-3.

Table 3-3 Demand for parking lots calculated by Little's formula

Time Zone	Arrival Rate (λ)	Average Waiting Time (W)	Demand for Parking Lots (Number of Cars)
10:00–15:00	47.00	224.6	10,557
All time	19.58	224.6	4,398

3.4. Parking capacity analysis.

Dealing with the city center retail district as one area, we can now compare the demand and supply of parking lots to make the parking capacity analysis. Table 3-4 gives the result. From the table we see that the number of parking lots turns out to be over-supplied. While the number of parking lots would be likely to be expected to be insufficient from the chronic congestion, the opposite becomes true.

It should be noticed that in this analysis we have excluded the demand for the parking lots by business use so that accurately speaking, we must estimate the size of demand by business use. We would like to save this issue for a further study.

Table 3-4 Demand and supply of parking capacity

Time Zone	(a) Demand for Parking	(b) Supply of Parking	(a)–(b) Excess
10:00–15:00	10557	13327	**–2770**
All time	4398	13327	**–8929**

4. Analysis of Parking Behavior by Access Directions

Now we analyze data obtained from the 1st survey of consumer parking behavior to investigate from which access direction they have entered the city center, how long they have cruised to find the vacant parking lot, and at which parking block they have parked their cars.

4.1. Access directions by car to the city center

Look at Figure 4-1. The figure gives percentages of which access directions visitors by car have taken for entering the city center among the four access directions.

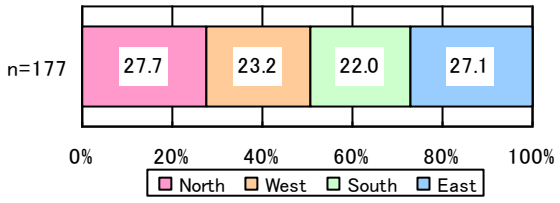

Figure 4-1 Access directions by car

Expanding these percentages by the number of total incoming visitors, 21,150, we have the numbers of actual incoming visitors by four accessing directions. They are given in Table 4-1 below.

Table 4-1 Numbers of incoming visitors by access directions

	North	West	South	East
the number of cars	5,854	4,898	4,659	5,736
%	27.68	23.16	22.03	27.12

4.2. Choices of Parking blocks

Table 4-2 shows the results of choices of parking blocks by access directions. As was mentioned before, the largest choice of parking block for each access direction becomes the parking block that coincides with that access direction.

Table 4-2 Choices of parking blocks by access direction

	to		Parking Blocks					all
	from		North	West	South	East	Middle	
Access Directions	North	frequency	35	9	0	1	4	49
		%	71.4	18.4	0.0	2.0	8.2	100.0
	West	frequency	11	10	2	7	11	41
		%	26.8	24.4	4.9	17.1	26.8	100.0
	South	frequency	5	7	14	4	9	39
		%	12.8	18.0	35.9	10.3	23.1	100.0
	East	frequency	8	6	5	16	13	48
		%	16.7	12.5	10.4	33.3	27.1	100.0
	all	frequency	59	32	21	28	37	177
		%	33.3	18.1	11.9	15.8	20.9	100.0

Similarly using the numbers of incoming visitors by access directions in Table 4-1, we can expand the choice probabilities of Table 4-2 into the actual number of cars parked at 5 parking blocks by access directions.

Table 4-3 Numbers of cars parked at parking blocks by access directions

	to		Parking Block					all
	from		North	West	South	East	Middle	
Access Direction	North	Number of people	4,182	1,075	0	119	478	5,854
		%	71.4	18.4	0.0	2.0	8.2	100.0
	West	Number of people	1,314	1,195	239	836	1,314	4,898
		%	26.8	24.4	4.9	17.1	26.8	100.0
	South	Number of people	597	836	1,673	478	1,075	4,659
		%	12.8	18.0	35.9	10.3	23.1	100.0
	East	Number of people	956	717	598	1,912	1,553	5,736
		%	16.7	12.5	10.4	33.3	27.1	100.0
	all	Number of people	7,049	3,823	2,509	3,345	4,420	21,150
		%	33.3	18.1	11.9	15.8	20.9	100.0

4.3. Cruising time to find parking lot by access directions

In Table 4-4, we provide the cruising time visitors spend to find the vacancy of parking lots from entering the city center for each parking block.

While it is natural that the middle block, the center of city center retail environment shows the longer time the visitors take to find the vacancy of parking lots, the east block attains the longest cruising time.

Table 4-4 Cruising time to find parking lots by parking blocks

	N	Average (unit :Minite)	SD	minimum value	maximum value
North	59	8.3	6.1	1	30
West	32	8.5	5.4	1	20
South	21	6.4	5.4	1.5	25
East	27	15.4	12.8	2	60
Middle	37	11.0	7.0	5	40
all	176	9.8	7.9	1	60

5. Parking capacity Analysis by Parking Blocks

5.1. Arrival rates for parking blocks

Now we will make parking capacity analysis by parking blocks. As in Chapter 3, we need the arrival rates and average staying time for five parking blocks.

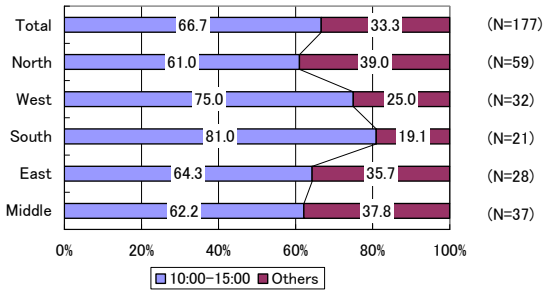

Figure 5-1 Distributions of arrival time by parking blocks

First, in Figure 5-1 we show the distributions of arrival time by parking blocks.

Table 5-1 Numbers of arrivals by parking block and time zone

	Time Zone	Total	Percentage	Number of Arrivals
North	10:00–15:00	7,049	61.0	4,301
	Other time	7,049	39.0	2,748
West	10:00–15:00	3,824	75.0	2,868
	Other time	3,824	25.0	956
South	10:00–15:00	2,508	81.0	2,030
	Other time	2,508	19.1	478
East	10:00–15:00	3,346	64.3	2,151
	Other time	3,346	35.7	1,195
Middle	10:00–15:00	4,420	62.2	2,747
	Other time	4,420	37.8	1,673

Next in Table 5-1 we give the actual numbers of arrivals by time zones and parking blocks. Here we used the actual number of incoming visitors by parking blocks shown in the bottom row of Table 4-3 and the distributions of arrival time by parking blocks shown in Figure 5-1.

Last, from Table 5-1 we calculate the arrival rates for five parking blocks as shown in Table 5-2.

Table 5-2 Arrival rate by parking block

	Time Zone	Number of Arrivals	Time (Minutes)	Arrival Rate
North	10:00–15:00	4,301	300	14.34
	All time	7,049	1080	6.53
West	10:00–15:00	2,868	300	9.56
	All time	3,824	1080	3.54
South	10:00–15:00	2,030	300	6.77
	All time	2,508	1080	2.32
East	10:00–15:00	2,151	300	7.17
	All time	3,346	1080	3.10
Middle	10:00–15:00	2,747	300	9.16
	All time	4,420	1080	4.09

5.2. Average staying time for visitors by car

We use the same data of average staying time (waiting time) for all parking blocks, Hence the staying time is 224.6 minutes as in Chapter 3.

5.3. Demand for parking lots for five parking blocks calculated by Little's formula

Now we can estimate the demand for parking lots fro each parking block using Little's formula. Table 5-3 gives these results.

Table 5-3 Parking lots demand for five parking blocks by Little's formula

	Time Zone	Arrival Rate (λ)	Average Waiting Time (W)	Demand for Parking Lots (Number of Cars) (L)
North	10:00–15:00	14.34	224.6	3,220
	All time	6.53	224.6	1,466
West	10:00–15:00	9.56	224.6	2,147
	All time	3.54	224.6	795
South	10:00–15:00	6.77	224.6	1,520
	All time	2.32	224.6	522
East	10:00–15:00	7.17	224.6	1,610
	All time	3.10	224.6	696
Middle	10:00–15:00	9.16	224.6	2,057
	All time	4.09	224.6	919

5.4. Parking capacity analysis for five parking blocks

Now we can carry out the parking capacity analysis for each parking block. Table 5-4 shows the result of the analysis.

From the table, contrary to our intuition, four parking blocks out of the five have enough parking capacity. All parking blocks except the east block are excess supplied by parking lots. The numbers of over supplied parking lots for each of five parking blocks seem to be roughly proportional to the cruising time for vacancy for each parking block given In Table 4-4.

Table 5-4 Demand and supply of parking capacity by parking blocks

	Time Zone	(a) Demand for Parking Capacity (unit: Number of Cars)	(b) Supply of Parking Capacity (unit:Number of Cars)	(c)= (a)−(b)	(d)= (c)/(b)
North	10:00−15:00	3,220	4,506	−1286	−0.29
	Others	1,466	4,506	−3040	−0.67
West	10:00−15:00	2,147	2,692	−545	−0.20
	Others	795	2,692	−1897	−0.70
South	10:00−15:00	1,520	2,732	−1212	−0.44
	Others	522	2,732	−2210	−0.81
East	10:00−15:00	1,610	998	612	0.61
	Others	696	998	−302	−0.30
Middle	10:00−15:00	2,057	2,399	−342	−0.14
	Others	919	2,399	−1480	−0.62

There might be several reasons for this result. One is that as mentioned before, since we have ignored the demand for business use the demand for parking capacity calculated here might be underestimated. But our 1st survey of consumer parking behavior was conducted on Saturday and Sunday so that the effect of business use can be small. Other factors might be due to the choice of time period to calculate arrival rates and the number of total incoming visitors by car. It is apparent that if we choose the peak arrival rate the parking capacity needed would become large. Thus the issue of how to choose the time period for calculating arrival rates becomes important but we would like to leave it for a further study.

Table 5-5 Parking capacity analysis under another assumption

	Time Zone	(a) Demand for Parking Capacity (unit: Number of Cars)	(b) Supply of Parking Capacity (unit:Number of Cars)	(c)= (a)−(b)	(d)= (c)/(b)
North	10:00−15:00	5,635	4,506	1129	0.25
West	10:00−15:00	3,758	2,692	1066	0.40
South	10:00−15:00	2,660	2,732	−72	−0.03
East	10:00−15:00	2,818	998	1820	1.82
Middle	10:00−15:00	3,600	2,399	1201	0.50

Here we would like to elaborate on the latter issue of the number of incoming visitors by car. We have employed 21,150 as the number of visitors by car per day in average over the year. This estimated number is obtained by averaging the numbers of weekdays and weekends. Hence it does not represent the number of weekends.

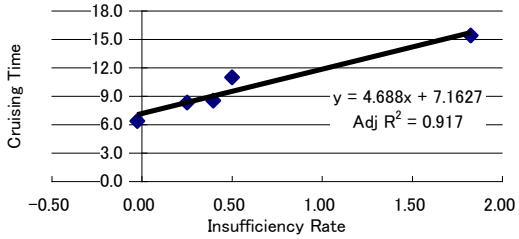

Figure 5-2 Relation of insufficiency rates and cruising time

Now assume that the numbers of Saturday's and Sunday's visitors are

respectively 1.5 times and 2 times as large as that of weekday's visitors. Thus let us assume that the average number of Saturday's and Sunday's visitors by car is 1.75 times 21,150, that is, 37,013 persons per day. Table 5-5 gives the result of parking capacity analysis under this assumption.

We see that all parking blocks except the south now are insufficient for parking lots. From Figure 5-2, we have known that those insufficiency rates for parking blocks are closely related to the cruising time for each parking block.

6. Conclusion

We have shown a simple method to investigate whether or not parking capacity is sufficient at the actual city center retail environment based on the survey of consumer parking behavior using Little's formula. By a concrete example of Fukuoka City, we have demonstrated that we can determine numerically how much parking capacity is needed at the actual city center retail district using Little's formula when we have the following information. 1) The total number of incoming visitors at city center by car, 2) The length of staying time of visitors who visit city center by car for shopping, 3) The arrival time distribution of visitors by car. Also we have indicated that as shown in the analysis of access directions, for the analysis of parking space policy the access structure to the city center of a specific city and the driver's behavioral mechanism such as avoiding congestion may greatly affect the effectiveness of the policy measures for the specific city.

We also have noted that sufficiency and insufficiency of parking capacity critically depends on the number of incoming visitors and the choice of time period for calculating arrival rates. Thus in addition to the parking capacity analysis for business demand further studies should be needed for exploring how we should decide to choose the time period of peak arrival rates and how we should deal with various variations of the numbers of incoming visitors such as seasonal, day to day, within-a-day, between weekdays and weekends, and so on.

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