

2. SUPPORT SYSTEM FOR ANALYSIS OF A PARKING LOT WITH A SIMULATION MODEL

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[Abstract] There exists difficulty to analyze the movement of vehicles running within the parking lot, because such movement of vehicles is very complex. In this paper, for the purpose of making traffic flows safe and smooth within the parking lot, the support system for planning of the parking lot is developed. The system can take account of the scale of the parking lot, the area of storage space within the parking lot and the locate of the devices at entrances and exits of parking lot.

This system consists of a micro traffic simulation model which can track the movement of individual vehicles. By combining the road and the parking stall within the parking lot as elementary blocks, it is possible to compose an arbitrary scale and form of parking lot. Experimental results with actual investigated data suggest that the developed system is useful for supporting planning of the parking lot.

[Keywords] parking lot, simulation, micro simulation, support system, car following model

1. INTRODUCTION

The road traffic is one of the most important functions to support the activities of economy, the society and the culture in the city. Especially, high mobility is required according as the industrial structure and a life-style are changing in the present day, and the rate of dependence on road traffic with higher mobility has more increased.

Although the parking lot is an important facility with function of stopping vehicles which supports the life and the activity in the city, the construction of parking lots has lagged behind compared with the progress of motorization. The number of vehicles which were able to be stopped in parking lots was only about 100,000 vehicles at the beginning of 1965, and after 15 years it became about 900,000 vehicles in 1980. Moreover, in 1993 it has been increased to about 2,100,000 vehicles which were about 21 times as many as that in 1965^{1),2)}. However, according to rapid progress of the road traffic in recent years, the construction of parking lots in the city becomes indispensable. Furthermore, the expansion and the improvement of parking lots in the city will become more important.

It is extremely difficult to construct the parking lots which can hold all demand of parking in the city. In order to ease the parking problem and to obtain a smooth traffic flow in the city, it is effective to promote measures such as the optimum arrangement and the optimum use of the parking lots among a lot of measures^{3),4)}.

A fundamental theory of the design of the off-street parking lots has been researched before about 30 years and many articles about this have been presented^{5),6)}. Moreover, many articles concerning the equilibrium problem of the parking lots where the queue theory was applied were also presented⁷⁾⁻⁹⁾. However, in these researches there exists difficulty to evaluate and examine a basic condition of the parking lot such as a scale of the parking lot, an area of storage space within the parking lot and the arrangement of various devices in the parking lot in consideration of the complex movements of vehicles in the parking lot.

Since the idea in which the simulation technique with a computer is applied to traffic flow was proposed at the beginning of 1949 and the simulation technique with an analog computer was executed in 1955. Then a lot of simulation models of

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traffic flow have been developed¹⁰⁾⁻¹⁶⁾. However, in these models, simulation models which can be applied to the support system for the parking lot are extremely few, namely two or three models are only seemed to be applicable.

Muromachi, Hyodo and Harata combined the choice model of the parking lot and the simulation model, and tried to represent the state of the use of parking lots¹³⁾. Tsukaguchi and Nishiumi proposed the choice model of parking location for the parking management and simulated the behavior of parking choice by the use of the model which made choice model detailed^{12),16)}. Moreover, the state of use of parking lots was dynamically expressed and preferable parking management system was discussed. However, these are parking management systems based on the modeling the parking choice behavior and are not researches based on the movements of the vehicles in a single parking lot.

In this study, for the purpose of making traffic flows within the parking lot safe and smooth, the support system for planning of the parking lot with a microscopic traffic simulation model is developed. The developed system based on the movement of individual vehicles can take account of the scale of the parking lot, the area of storage space within the parking lot, the parking fee and the arrangement of the devices at entrances and exits of the parking lot and can evaluate an appropriate parking management measures.

FORTRAN-77 is used in consideration of the generality of the program. This simulation model uses 32 arrays including 6 arrays having maximum three dimensions. 7 arrays are used to input the data of the road and the traffic conditions, 16 arrays are used to input the data of vehicle information on the operation and other arrays are used to input the calculation results. This program is composed of a main program and 7 subprograms. A main program consists of about 920 statements and subprograms consist of 10-40 statements severally, where 169

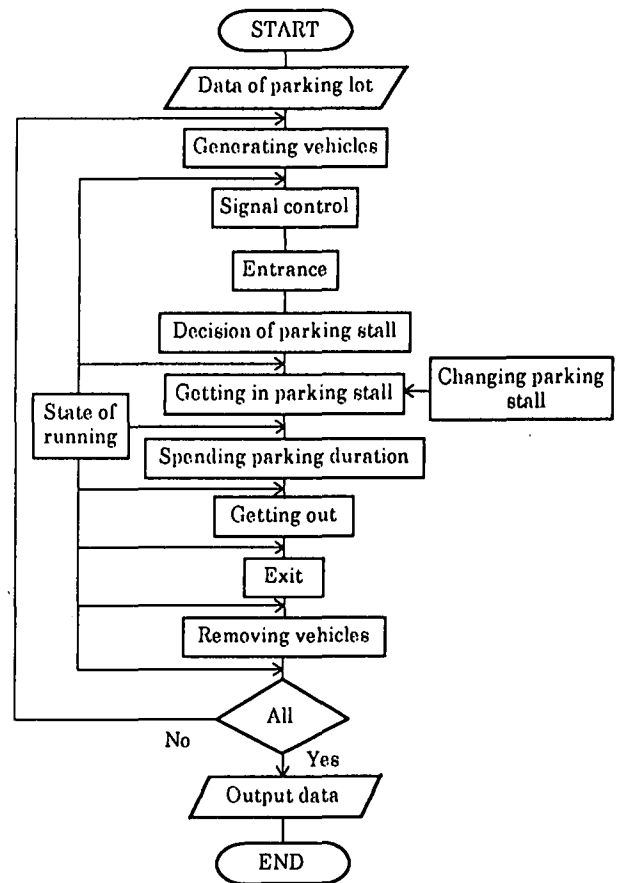


Figure-1 Flow chart for the simulation

statements are written in total.

The flow chart for this simulation program is shown in Figure-1.

First of all, the vehicle which enters the parking lot receives the parking ticket at the entrance and decides the parking stall in the scene. Next, the vehicle moves to the parking stall decided at the entrance and gets in this parking stall. Then, the vehicle gets out from the parking stall when the designated time is passed and the parking duration ends, and moves to the toll booth. Furthermore, after the exit service is carried out, the vehicle leaves the parking lot. The information which is necessary for the above period can be output by the proposed program.

2. SIMULATION MODEL FOR PARKING LOTS

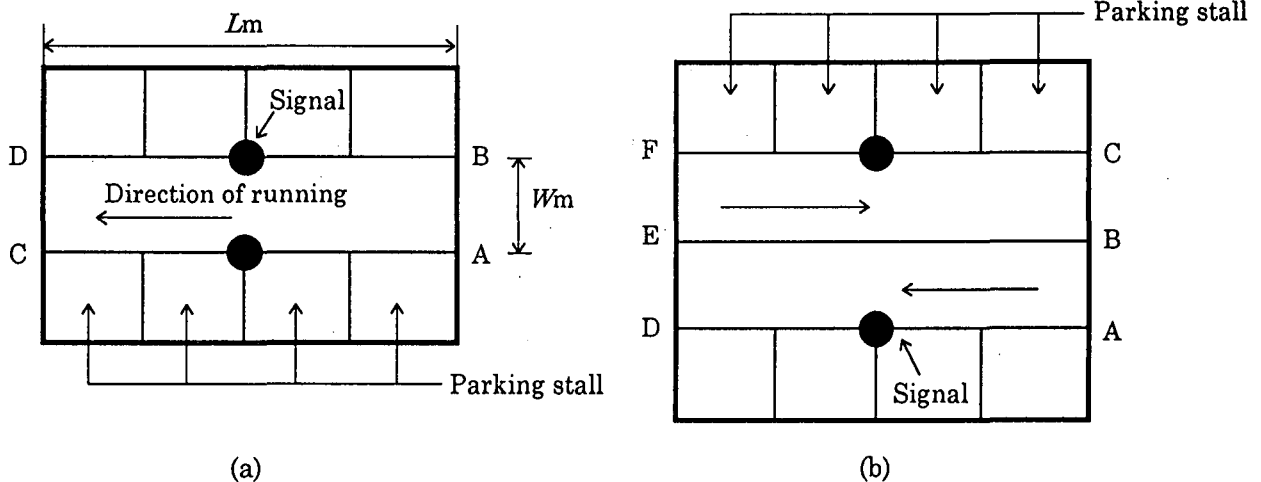


Figure-2 Elementary block

The movement of the vehicle running in the parking lot is extremely complex and has a lot of nonlinear factors. Furthermore, because a definite factor is included in such movement simultaneously in addition with a probabilistic factor, it is very difficult to grasp the movement of the vehicle with an analytical method. The simulation is the effective technique to evaluate the movement in the parking lot and the optimum management measure of the parking system. The simulation can reproduce such complex movement easily and can analyze the phenomenon which contains a probabilistic factor by making a similar model of the parking system.

In this paper, the system module composed of a road and the parking stalls is treated and the parking lot in an arbitrary form can be constructed by combining these system modules appropriately.

2-1 Elementary block

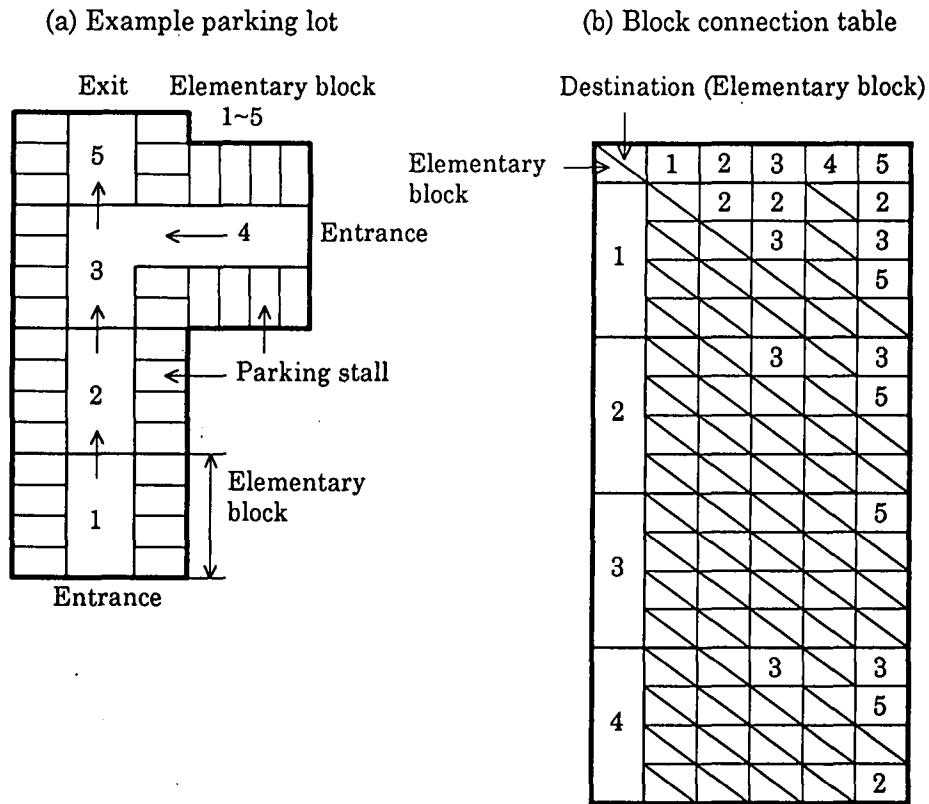
The system module of the proposed simulation model is composed of a elementary block shown in Figure-2(a). This elementary block is a single road in which the lane width is W_m and lane length is L_m . Four parking stalls are located on both sides of the road respectively. Moreover, the signal is put on the center of the roadside. The constructed parking lot can be fitted to the road and traffic condition and the form of the parking stall at the selected area by combining elementary blocks appropriately. The road and traffic condition are almost similar in a

elementary block and 30m or less is preferable for the length of a elementary block because of the following reasons. Namely, the several parking stalls should be included in one elementary block and running state of the vehicle can be judged in this block. According to the investigation of the parking lot, the proper length of a elementary block was 24-32m.

Although the vehicle enters and/or leaves the block through edge AB and edge CD in principle, it is possible to pass edge AC and BD when the vehicle gets in/out from the parking stall. The edge AB is an entrance for the vehicles running the whole road of other elementary blocks or for the vehicles generated, and the edge CD is an exit for the vehicles running the whole road in this elementary block. The each signal put on both sides of the road lights red when parking stalls located one side of the road are all occupied and lights green when parking stalls are not all occupied. With this signal, the vacant parking stalls can be indicated. If such signals are not put in the actual parking lot, the signals are always assumed to be extinguished.

When the road in the parking lot has two lanes, the form shown in Figure-2(b) is applied. This block is composed by combination of two parallel blocks where the parking stalls on the edge BD of the elementary block shown in Figure-2(a) are detached. Although the vehicles are prohibited from turning around in this block, it is possible that the

Table-1 Block connection table



vehicles running left get in the parking stall through the edge CF and that the vehicles get out through the edge CF.

2-2 Block connection table

When the roads and parking stalls in the selected parking lot are constructed with required elementary blocks, the block connection table shows the relation of connection and the order of connection of such elementary blocks. The block connection table is the matrix where any particular element gives the block number. The vehicles running whole road of each elementary block must enter the block indicated by such matrix in order to reach the destination of parking stall. From this table, it can be seen whether there is a merging lane in the elementary block. It is also possible to construct the vertical parking lot by the use of such block connection table, to say nothing of the horizontal parking lot.

In the block connection table, elementary block numbers other than the blocks for leaving, which exists in a selected parking lot, are indicated on the

most left column. Moreover, destination numbers are indicated on the top row. Each element of this table shows the elementary block number which vehicles must enter to reach destination. The block connection table of an example parking lot drawn in Table-1(a) is shown in Table-1(b). This block connection table includes 4 elementary blocks and 5 destinations (elementary blocks). Each elementary block has four lines respectively. The top line number of each section shows the block number which the vehicle enters first. The block number which vehicle enters next after running the whole road of first block is shown in the second line. In this block connection table, only three elementary block numbers can be indicated in the direction of movement. If there is the merging lane at the end of the elementary block, the merging block number is denoted in the last line of the section. The slash is marked in the element where the vehicle cannot move from the elementary block.

From the block connection table shown Table-1(b), it can be seen that the vehicle which moves

from elementary block 4 to destination 5 passes elementary block 3 from elementary block 4 and reaches elementary block 5. Moreover, the number 2 is marked at the last line. It means that the vehicle is allowed to enter the elementary block 3 only when there is not influence of the vehicle in elementary block 2.

2-3 Vehicle information

In order to accumulate information on the vehicle, each vehicle is run in the system with 16 information as follows. Vehicle information are the time when the vehicle enters the study area, the type of the vehicle, the location of entrance and exit, the desired speed, the running speed, the position, the elementary block where vehicle is running, the state of running, the time required to enter the parking lot (t_1), the service time at entrance (t_2), the time when the vehicle gets in the parking stall (t_3), the storage time in the parking stall (t_5), the time required to get out from the parking stall (t_6), the time when the vehicle gets out from the parking (t_7), the service time at exit (t_8) and the parking stall number.

Information given as a initial value among these values are four information from the time when the vehicle enters the study area to the desired speed and then information other than such four information are changeable information calculated on each cycle time of the operation. Among information on the vehicle in the parking lot, the vehicle has information shown in Figure-3. The signs in this figure are mentioned above. However t_4 is the time to begin parking and t_9 is the time when vehicle leaves the parking lot. These values are calculated on each cycle time.

The position of the vehicle is expressed as the distance (m) from the end of the elementary block. Therefore, when the position of the vehicle becomes zero, it means that the vehicle runs the whole road of the elementary block. The position of the vehicle

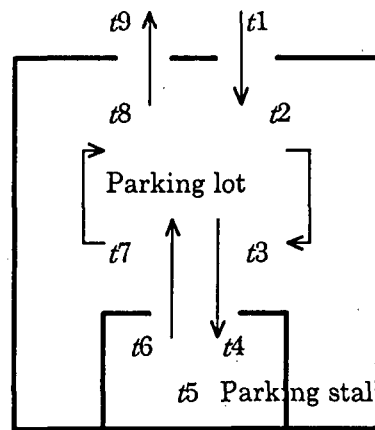


Figure-3 Vehicle information

is calculated on each cycle time from the mileage per the unit time which is calculated with the formula corresponding to the state of running. (The unit time can be arbitrarily selected. Since the unit time was assumed to be 0.2sec in this study, the 1.2m or less movement of the vehicle running in the maximum speed was disregarded. Such state of running was extremely few in the parking lot.)

2-4 Running state of the vehicles

When considering the movement of the vehicle, it is necessary to divide into the movement in a elementary block and the movement when running the whole road of a elementary block.

From the investigated value of the running vehicle in the parking lot, the maximum speed is set as 22 km/h (6.0m/sec) and the minimum speed is set as 8 km/h (2.2m/sec).

(1) Running state in a elementary block

- (a) Free flow state: Vehicle can run at desired speed.
- (b) Following state: Vehicle has not been reached at desired speed yet and runs at speed of precedent vehicle.
- (c) Acceleration state: Vehicle has not been reached at desired speed yet and there are enough headway. Therefore, the vehicle is able to accelerate.

- (d) Deceleration state: Because headway becomes short, vehicle does not run at present speed and needs to decelerate.
- (e) Stop state: Because of too short headway, vehicle needs to stop. In this state, the waiting time is occurred.
- (f) Forcible deceleration state: Vehicle is decelerating in order to get in the parking stall.

Let $L_{0.2}$ denote the position of the vehicle after a cycle time, L denote the present position, $V_{0.2}$ denote the running speed after a cycle time, V denote the present speed, V_{k+1} denote the running speed of precedent vehicle, V denote the running speed of the base vehicle, Acc denote the acceleration, Dcc denote the deceleration and t (0.2sec) denote the cycle time.

Here, the following formulas are obtained.

Free flow state (Sign of state 1)

$$L_{0.2} = L - V \cdot t, V_{0.2} = V$$

Following state (Sign of state 2)

$$L_{0.2} = L - V_{k-1} \cdot t, V_{0.2} = V_{k-1}$$

Acceleration state (Sign of state 3)

$$L_{0.2} = L - V \cdot t - 0.5 \cdot Acc \cdot t^2, V_{0.2} = V + Acc \cdot t$$

Deceleration state (Sign of state 4)

$$L_{0.2} = L - V \cdot t + 0.5 \cdot Dcc \cdot t^2, V_{0.2} = V - Dcc \cdot t$$

Stop state (Sign of state 5)

$$L_{0.2} = 0, V_{0.2} = 0$$

Forcible deceleration state (Sign of state 6)

$$Dcc = V^2 / L$$

where L denotes a distance between the base vehicle and the destination of parking stall.

Dcc calculated from such value L is substituted for the formula about deceleration state and then the value of $L_{0.2}$ and $V_{0.2}$ are obtained. The running speed and the running position of each vehicle are decided from these formulas.

The running state of the vehicle entering the parking lot is the free flow state and other state can be decided from the running states of the precedent vehicle and the running speed of base vehicle (Table-2). The present speed and present position of the vehicle are calculated from the formula corresponding to such running state.

Table-2 Relation between running state of precedent vehicle and headway

Free = 1					Following = 2				
	20	15	10	5m		20	15	10	5m
1			FR	FR				FR	FR
2	FR		AC	FL		FR		AC	FL
3								FL	
4	AC					AC			
5			DE	ST				DE	ST

Acceleration = 3					Deceleration = 4				
	20	15	10	5m		20	15	10	5m
1			FR					FR	
2	FR		AC			FR		AC	
3			FL					FL	
4	AC					AC			
5			DE	ST				DE	ST

Stop = 5				
	20	15	10	5m
1				
2				
3			AC	ST
4				
5				

IB: Running state
VSP: Speed

Precedent Vehicle Base Vehicle

D: Headway

IC: Running state
VSQ: Speed
VSR: Desired speed

Numbers of left column denote the running state of precedent vehicle
 Numbers of top row denote the headway (m)
 1: Free flow state (FR) 2: Following state (FL)
 3: Acceleration state (AC) 4: Deceleration state (DE)
 5: Stop state (ST)

The running state of the base vehicle is indicated on the upper part of the table, the running state of the precedent vehicle is indicated at the most left column of the table and the headway between the base vehicle and the precedent vehicle is indicated at the top line of the table. An average headway was 5m for the vehicles stopping and a minimum headway was 20m for the vehicle running at the maximum speed in the free flow state¹⁷⁾. In the case that headway was contained within 5-10m sections, the base vehicle ran in the free flow state or the following state and the precedent vehicle ran in the free flow state, the following state or the

acceleration state, it was hardly seen that the base vehicle ran in the acceleration state. Moreover, in the case that headway was contained within 10-20m sections, the base vehicle ran in the free flow state, the following state or the acceleration state and the precedent vehicle was decelerating, it was relatively few that the base vehicle was decelerating. Therefore, headway was divided equally between 5-20m. Since running state is judged at each elementary block, the length of the elementary block as a system module is needed to be larger than that of the maximum of headway.

The sign in the table shows the running state of the base vehicle at next cycle time. For instance, if the base vehicle runs in the free flow state, the headway from precedent vehicle is 15m and the running state of the precedent vehicle is 3 (acceleration state), the running state of the base vehicle becomes either the free flow state, the acceleration state or the following state. The details of such running state can not be judged from only this table. However, when the running speed of the base vehicle is equal to the desired speed, the free flow state is selected. Moreover, when the running speed is higher than the desired speed, the following state is selected, and when the running speed is lower than the desired speed, the acceleration state is selected.

(2) Running state among elementary blocks

When the vehicle finishes running on a elementary block, it is necessary to move all information on the vehicle to the following block. When the distance from the end of the elementary block becomes zero or negative, the vehicle is moved to the following block.

First, the following elementary block where the vehicle intended to leave the present block next enters is identified from the block connection table. Next, the number of vehicles which exist in the following elementary block is calculated and then it is examined whether such number is less than the capacity of such elementary block. Furthermore, the vehicle is moved to the following block when the

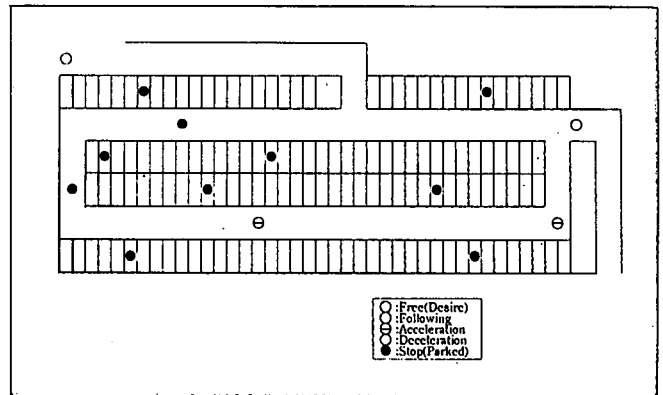


Figure-4 Graphic information on parking lot

existing number of vehicles is less than the capacity or the vehicle is stopped in the present elementary block when the existing number is equally to the capacity.

The vehicle intended to enter the following is moved after the last vehicle in the following elementary block and all information is transferred. Next, one vehicle is subtracted from the number of the vehicles in the present elementary block and one vehicle is added to the number of the vehicles in the following elementary block. Furthermore, the order of the vehicles in the present elementary block is updated, because one vehicle is disappeared.

2-5 Output information on simulation program

In the developed program, arbitrary information on the running vehicle can be output. However, information in the three forms as follows is usually output.

Information (a) is information on the vehicle which exists in each elementary block and each parking stall every arbitrary cycle time.

Information (b) is total information divided into three parts. The first is the entering flow, the leaving flow, the service time distribution at the entrance and the exit, the storage time distribution at the parking stall every 10 minutes. The second is the occupancy of the parking stall and the occupied proportion of the parking stall every 5 minutes. The third is the parking behavior (1-19) of the vehicle in the parking lot every 5 minutes.

Information (c) is graphic information which

Table-3 Service time distribution at the entrance

City	Name of parking lot	Time of service at entrances (sec)												Average number of parking (vehicles)	Average time of service (sec)		
		0 ~ 2	2 ~ 4	4 ~ 6	6 ~ 8	8 ~ 10	10 ~ 12	12 ~ 14	14 ~ 16	16 ~ 18	18 ~ 20	20 ~ 22	22 ~ 24			24 ~ 26	
Toyohashi	Daiichi	148	88	25	6	1	0	1	0	0	0	0	0	0	0	269	2.23
	Daini	115	109	28	10	2	0	0	0	0	0	0	0	0	0	264	2.54
Toyota	Nishimachi	137	90	27	5	1	0	0	0	0	0	1	0	0	261	2.33	
	Motoshiro	168	102	30	10	5	0	0	0	0	0	1	0	0	316	2.41	
Okazaki	Kita-Koen	120	75	25	7	3	1	0	1	0	0	0	0	0	232	2.47	
	Kagota-Koen	102	87	19	5	3	0	0	2	0	0	0	0	0	218	2.52	

shows the movement in the parking lot at arbitrary time. Figure-4 shows the movement of the vehicle running in the parking lot. In this figure, the vehicles in the free flow state are displayed with red ○, the vehicles in the following state are displayed with pink ○, the vehicles in the acceleration state are displayed with ⊖, the vehicles in the deceleration and forcible deceleration state are displayed with green ○ and stopping vehicle are displayed with black ○.

3. VERIFICATION OF SIMULATION MODEL FOR THE PARKING LOT

In order to use the proposed simulation model as the support system for analysis of the parking lot, it is necessary to verify the accuracy of the reproducibility of the movement of the vehicle running in the parking lot. Therefore, the movement of the vehicle in some parking lots were actually investigated and these investigated data were used to verify the accuracy of the developed simulation model.

The investigated parking lots were as follows. Toyohashi City Daiichi parking lot and Toyohashi City Daini parking lot were investigated on Sunday of 11 September 1994, Toyota City Nishimachi parking lot and Toyota City Motoshiro parking lot were investigated on Sunday of 4 September 1994 and Okazaki City Kita-Koen parking lot and Okazaki City Kagota-Koen parking lot were investigated on Sunday of 18 September 1994.

3-1 Service time distribution at entrance/exit of parking lot

The service time distribution at the entrance/exit of the parking lot changes largely depending on the location of the parking lot, the form at the entrance/exit and the situation of the road connected with the parking lot. Therefore, the parking lots which were almost same form of the entrance/exit were chosen in this investigation.

The 8mm video camera was set up at the entrance/exit of the parking lot and the vehicles entering and leaving the parking lot were recorded on videotapes from 9:00 to 17:00. Then the movement of the vehicle was later analyzed with a video deck.

(1) Service time distribution at entrance

The service at the entrance of each parking lot is mechanically operated. These investigated results are shown in Table-3. The ratio of the service time at entrance which is 6.0sec or less is 95 percent. The average service time of each parking lot is between 2.23sec and 2.54sec and the average service time of all parking lots is 2.42sec. Besides, it can be seen that left-hand-drive vehicles needed comparatively long service time at entrance to enter the parking lot.

(2) Service time distribution at exit

The service at the exit of Kagota-Koen parking lot is mechanically operated and the others are manually operated. The investigation results are shown in Table-4. In Kagota-Koen parking lot the ratio of the service time at exit which is 16sec or less is 16.5 percent, while in other parking lots the ratio shows 71 percent or more. This means that the difference between the service times of the

Table-4 Service time distribution at the exit

City	Name of parking lot	Time of service at exits (sec)																				Average number of parking (vehicles)	Average time of service (sec)			
		0~2	2~4	4~6	6~8	8~10	10~12	12~14	14~16	16~18	18~20	20~22	22~24	24~26	26~28	28~30	30~32	32~34	34~36	36~38	38~40			40~50	50~60	60~70
Toyohashi	Daiichi	4	25	25	47	30	32	22	17	19	14	9	4	5	4	4	1	3	2	0	1	2	0	0	270	16.99
	Daini	1	10	26	33	22	33	31	17	19	13	12	10	8	4	7	1	1	4	1	3	4	5	0	266	14.98
Toyota	Nishimachi	2	23	26	45	35	30	20	20	15	14	8	5	4	3	2	0	3	2	0	2	2	1	0	262	11.57
	Motoshiro	1	20	32	72	35	30	22	18	20	15	10	9	9	4	5	2	4	5	0	2	4	4	0	302	14.21
Okazaki	Kita-Koen	2	10	24	35	25	19	18	22	13	13	10	13	10	11	2	2	2	0	3	2	0	0	0	235	14.00
	Kagota-Koen	0	0	1	3	6	8	4	5	7	6	7	16	17	11	14	13	12	9	8	7	26	13	5	6	206

Table-5 Distribution of parking duration at Daiichi parking lot

11 Nov. 1994	Distribution of parking duration								total
Parking duration (min)	0~30	30~60	60~90	90~120	120~150	150~180	180~210	over 210	
Frequency	10	25	47	12	25	21	20	8	168
Percentage	6.0	14.9	28.0	7.1	14.9	12.5	11.9	4.8	100

Table-6 Occupancy of parking lot

Elementary block number	2	3	4	5	6	7	8	9	10	11
Occupancy of parking (percent)	4.3	13.7	0.5	11.6	0.1	1.4	0.5	0.2	4.7	0.3
Elementary block number	12	13	14	15	16	17	18	19	20	total
Occupancy of parking (percent)	11.2	17.4	9.1	0.5	0.2	10.3	0.4	12.6	1.0	100

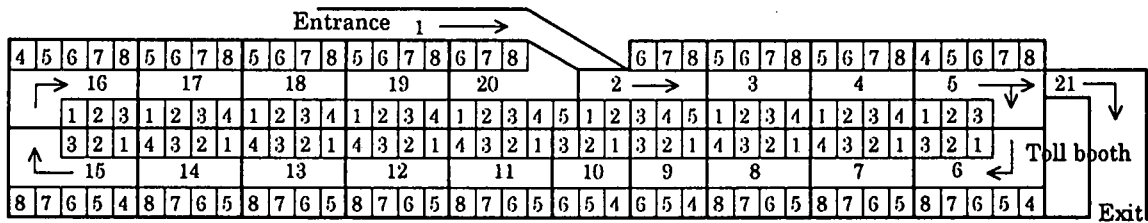


Figure-5 Plan of Toyohashi City Daiichi parking lot

mechanical and the manual operations is large. An average service time at exit operated mechanically is 31.6sec, while the average time operated manually is between 12sec and 14sec. Namely, manual service time is small and is as 0.39-0.45 times as mechanical service time.

3-2 Distribution of parking duration and decision of parking stall

The distribution of parking duration of the vehicle parked in Toyohashi City Daiichi parking lot was analyzed (Table-5). Such distribution was able to be obtained from parking tickets on 11 September 1994, from which the required time

when the vehicles get in the parking stall and then get out from the parking stall is calculated. Therefore, transit time in the parking lot in addition to the storage time is included in such distribution of parking duration. The ratio of parking duration which is 120min or less is 55.1 percent and the parking duration between 60min and 90min is the most. The storage time over 2 hours is considerably a lot as 16.7 percent.

Moreover, the presence of the vehicles in the parking stalls was investigated by recording the blinking of the light of "Parking stall model type" set up in the parking lot to decide the parking stall

Table-7 Specification of each elementary block in Daiichi parking lot

Elementary block number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
Elementary block length	80	20	16	16	24	24	16	16	12	12	16	16	16	16	24	24	16	16	16	20	40	456m
Capacity of parking	16	4	3	3	5	5	3	3	2	2	3	3	3	3	5	5	3	3	3	4	8	89
Number of Parking stall	Enter	8	8	8	8	8	8	8	6	6	8	8	8	8	8	8	8	8	8	8	Exit	148

in 8mm videotape every 15 minutes and analyzing this tape. The light turns on when there is a parked vehicle. The ratio of the each number of parking stalls in each elementary block to the number of all parking stalls is calculated as parking lot occupancy (percent). These are indicated in Table-6. Figure-5 is a plan of Toyohashi City Daiichi parking lot.

3-3 Verification of simulation model

Toyohashi City Daiichi parking lot shown in Figure-5 is an underground parking lot which is located in a central city near Toyohashi Station and is used by many visitors from a near business area. The number of parking stalls of this parking lot is 148 vehicles as a whole. The entrance is mechanically operated and the exit is manually operated. Each driver can freely select the parking stall to park the vehicle. Furthermore, the management method to restrict the entry by the signal at the entrance is operated when all parking lots become occupied.

This parking lot is composed of 21 elementary blocks where 19 blocks have parking stalls and all parking stalls are for 148 vehicles. The elementary block 21 has the merging section with elementary block 1 to enter this parking lot. The specification of these elementary blocks are shown in Table-7. The investigated data, namely entering flow, leaving flow, the service time distributions at entrance and exits, the distribution of parking duration and a way to get in and get out from the parking lot, were input to the simulation model of the parking lot and the pattern of the vehicle entering and leaving the parking lot was simulated.

The simulation was executed with HITAC M-640/20 of computer center in Faculty of Science and Technology, Meijo University. About 10 minutes CPU time was required to calculate for the period

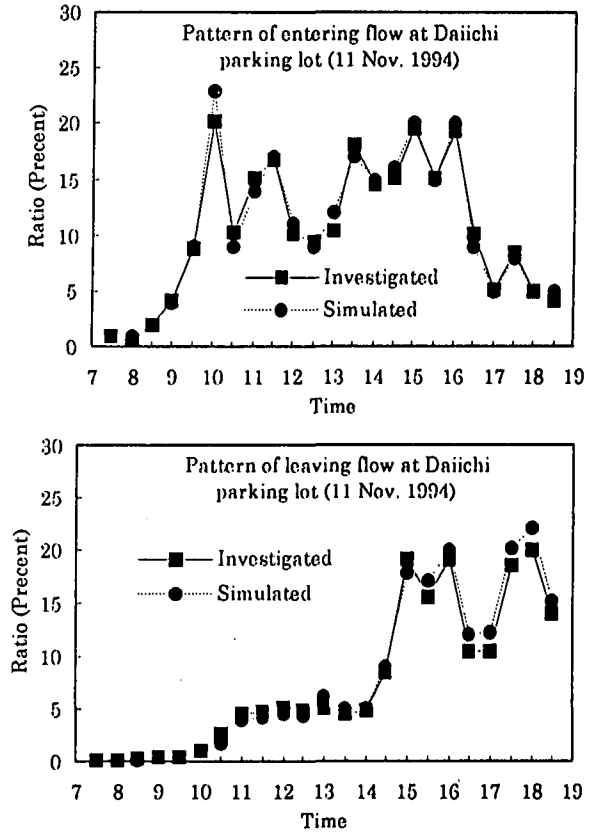


Figure-6 Pattern of entering/leaving flow

from 7:00 to 18:00. The relation between the simulation results and the investigated data are shown in Figure-6.

The vehicles enter the parking lot each 30sec according to the truncated exponential distribution. From the pattern of entering flow, the maximum difference between the investigated data and simulated data is 2.8 percent, namely about 4 vehicles, at about 10:00 and is comparatively small. On the other hand, since the pattern of leaving flow is the pattern as the result that vehicles leave the exit after spending the input time data mentioned above and repeating such movement, the differences between the investigated data and simulated data are seemed to be naturally large.

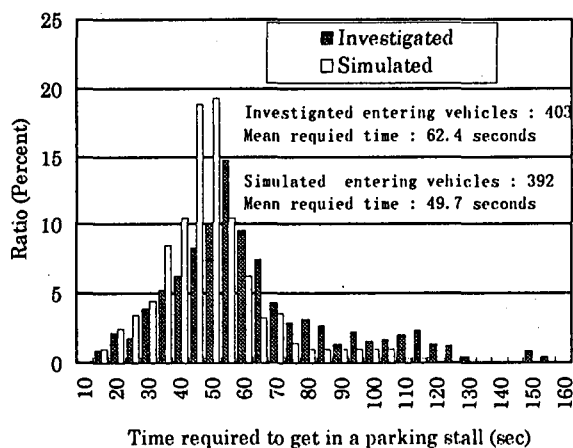


Figure-7 Movement with signal

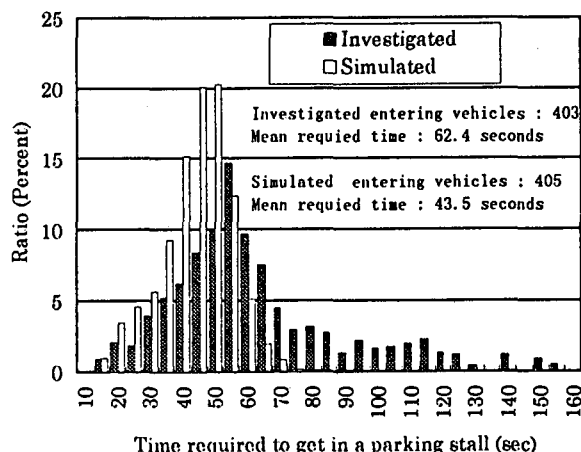


Figure-8 Movement with decided parking stall

Although there is a little difference between both data until about 14:30 and relatively large differences appear after 15:00. However, such differences as 0.5-2.0 percent are seemed to be comparatively small.

4. APPLICATION OF SIMULATION MODEL OF PARKING LOT

The movement of the vehicle running in the parking lot is analyzed with the simulation model of parking lot developed in this study. The model of the parking lot used in above chapter shown in Figure-5 is also used as the model of Toyohashi City Daiichi parking lot. The entering flow was assumed to be 403 vehicles. The service time distribution at entrance and exit, the distribution of parking duration, the occupancy of the parking stalls and a way to get in and get out from the parking stall obtained from investigated data were used for these application.

4-1 Movement of vehicles when the presence of parking stall are indicated

The signals at the center of the elementary block were turned on. Signals lighted blue when parking stalls more than one vehicle became empty and red when the all parking stalls became occupied. The maximum number of parking stalls in the elementary block was five and the minimum was three. In this simulation, the entering vehicle first decides the parking stall receiving the service at

entrance and such parking stall is selected with random numbers from investigated parking stalls. Next, the entering vehicle moves toward decided parking stall. However, the presence of the parking stall can be recognized beforehand because of the color of signals. In this study, it was assumed that vehicle was be able to recognize the presence of the parking stalls from 50m this side. Therefore, when the decided parking stalls were all occupied, the parking stall near decided parking stall as much as possible was selected with "Change in the parking stall" subroutine and the vehicle got in such parking stall.

The required time from the end of the service time at entrance (t_2) to the start of the time to get in the parking stall (t_3), namely time required to get in the parking stall, is shown in Figure-7.

From investigated data, a minimum value of the time required to get in the parking stall is 15sec, a maximum value is 155sec and a mode, which amounts to 14.7 percent of all, is 55sec. Furthermore, the required times between 45sec and 60sec amount to 42.2 percent of all. On the other hand, in simulated result in which the entering flow was 392 vehicles, a minimum value of the time required to get in the parking stall is 15sec, a maximum value is 115sec and a mode, which amounts to 19.3 percent of all, is 50sec. The required times between 40sec and 55sec amount to 59.7 percent of all.

While the average time required to get in the parking lot of investigated data is 62.4sec and the average time in simulated result is 49.7sec. The difference between both data becomes 12.7sec and shortening the required time by indicating the presence of the parking stalls is remarkable. In addition, the vehicle which required relatively large time when the presence of the parking stalls was indicated was affected by the precedent vehicles and consequently decelerated or stopped.

4-2 Movement of vehicles when parking stall is decided beforehand

In above section, the parking stall in which the vehicle gets is decided with random numbers at the entrance. On the other hand, the subroutine, in which a presence of the parking stalls is always observed and the parked parking stall is decided beforehand regardless of the intention of the driver of the vehicle arriving at entrance, is prepared in this simulation. Therefore, the vehicle can move directly to the specified parking stall and shortening the required time is expected. The distribution of the time required to get in the parking stall in this case is shown by Figure-8.

The entering flow was 405 vehicles. A minimum value of the time required to get in the parking stall is 15sec (1.0 percent), a maximum value is 115sec (1.0 percent) and a mode, which amounts to 20.3 percent of all, is 50sec. Moreover, the required times between 40sec and 55sec were relatively large such as the value amounting to 67.9 percent of all. The average time required to get in the parking stall is 43.5sec. As compared with the investigated data, 18.9sec is reduced, namely the required time is about 0.7 times as much as investigated data. Moreover, about 6.2sec is reduced in the comparison with the average value of the simulation of the above section. Namely, it can be seen that the required time is greatly reduced by the parking stall decision routine.

In addition, the method that such routine was used if the occupancy of parking stalls exceeded 50 percent was tried. However, such result was almost

similar to Figure-8.

5. CONCLUSION

It can be seen that the support system for analysis of a parking lot developed in this study faithfully reproduces the movement of the vehicle running in the parking lot and becomes an appropriate support system for the planning of the parking lot. This support system has some properties as follows.

- a. An arbitrary horizontal or vertical parking lot can be constructed by appropriately combining the system modules which consist of roads and parking stalls.
- b. The constructing of the model of the parking lot can be made easily by the use of the block connection table.
- c. The movement of the vehicle is expressed with the headway and the speed and the running state of the vehicle can be easily judged from Table-2.
- d. Because the required times of each vehicle running in the parking lot (1-19) are kept in the system, the movement of the vehicle can be easily reproduced. Furthermore, because much output information can be obtained, it is easy to analyze the movement of the vehicle.
- e. Because the output information needed can be graphically expressed, it is easy to explain for the person who is inexperienced in traffic engineering and evaluates the information.
- f. By the signal within the elementary block, the presence of the parking stalls is indicated and the information on the parking stalls can be informed to the drivers.
- g. It is possible that the group of parking lots can be simulated by combining some simulation systems for analysis of the parking lot described in this paper.
- h. This simulation system can be handled easier than a lot of general-purpose simulation model and can be used with no deep expertise about traffic engineering or computer engineering.

- i. The influence of traffic around the parking lot can be evaluated by using the support system for analysis of the parking lot developed in this study and "Support System for Traffic Flow Analysis on Urban Highway Maintenance Work with Lane Occupancy¹⁴⁾" developed by authors simultaneously.

Finally, a lot of data were used to reproduce the movement of the vehicle in the parking lot in this study. However, the investigation in a lot of parking lots will be needed to make this system higher accurate in the future.

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