A STUDY ON THE RELATIONSHIP BETWEEN TRAFFIC FLOW CHARACTERISTICS AND ROADSIDE PARKING THROUGH THE TRAFFIC SIMULATION MODEL

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abstract: There are many cases of illegal roadside parking on arterial roads in Japan. It is a serious problem for the road users because such cases can bring about traffic jams or, in some cases, traffic accidents. The mechanism of the occurrence of traffic accidents on arterial roads with illegally parked vehicles on the roadside should be studied and clarified. Such information can help traffic management authorities in establishing rules on how to prioritize the removal of illegally parked cars. In this study, a traffic simulation model was developed to understand the relationship between traffic flow characteristics and illegal roadside parking on the arterial road.

1. INTRODUCTION

There are numerous and rampant cases of illegal roadside parking on arterial roads in Japan. It is a serious problem for the road users because such cases can bring about traffic jams or, in some cases, traffic accidents. These illegally parked cars should be removed. However, traffic management authorities are experiencing difficulty in removing a lot of these vehicles because of their limited manpower and resources. Understanding the mechanism of traffic congestion and accident occurrence on arterial roads having illegally parked cars on the roadside can help in establishing a priority system which will help authorities identify which roads, depending on prevailing traffic conditions, should be rid of such illegally parked vehicles first.

There are many researches that record the traffic flow by video camera in order to understand the drivers' characteristics and how they behave in situations where illegal roadside parking exist on the arterial road. In these researches, the mechanism of occurrence of traffic congestion is fully understood but that of traffic accidents is not. This is because traffic accidents occur rarely compared to traffic jams. Furthermore, it is hard to generalize the findings for other road types in terms of evaluating traffic safety.

In this study, a traffic simulation model was developed to understand the relationship between traffic flow characteristics and illegal roadside parking on the arterial road. The use of a simulation model was chosen because it can reproduce the traffic flow and the analyses can be easily modified and extended to the other road types. The aim of this study is to establish the priority system of removing the illegally parked vehicles on the roadside.

2. MODEL DEVELOPMENT

2.1 Geometric Condition

In order to develop the simulation model, the basic geometric and traffic conditions of the road should be identified. In this study, the basic conditions of the road considered are as follows:

- 2 lanes (3.2m width each lane)
- straight and no slope (at-grade)
- without intersection, traffic signals, and pedestrian crossings
- one car is parked on the left side and will remain stationary
- car size (parked and running) is constant
- acceleration and deceleration is constant for all moving cars
- duration of each interval is 1 second

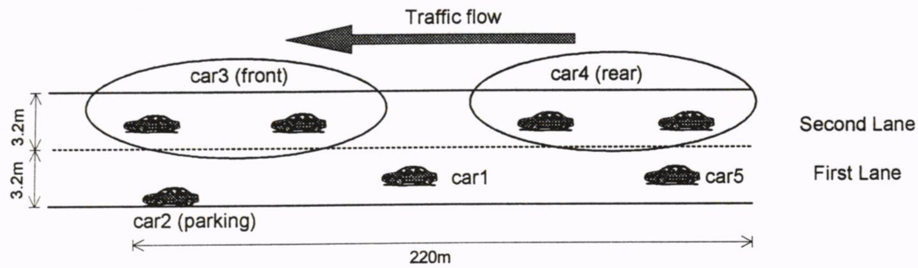

Figure-1 Outlook of this Simulation

Within each interval, the driver can check the possibility of lane changing, change their speed, and move to another position. During each interval, all cars move simultaneously in this simulation model. Initial and maximum speed of each car was set at the starting point.

2.2 Flow Chart of the Simulation Model

Figure 2 shows the flow chart of the simulation model. In this model, car1 (car approaching the parked vehicle) initially checks the possibility of lane change upon detection of the parked vehicle. Then car1, car5 (following car in the first lane), car3 (front car on the second lane) and car4 (rear car on the second lane) adjust their speed utilizing calculated new speed values. With the resulting configuration, the possibility of generating a new car can then be determined.

2.3 Car Movement

There are three patterns of car movement in the model. These are a) movement in the free flow speed, b) movement in the car-following speed, and c) movement of lane change. Categories a) and b) are distinguished by the headway. In this simulation model, the

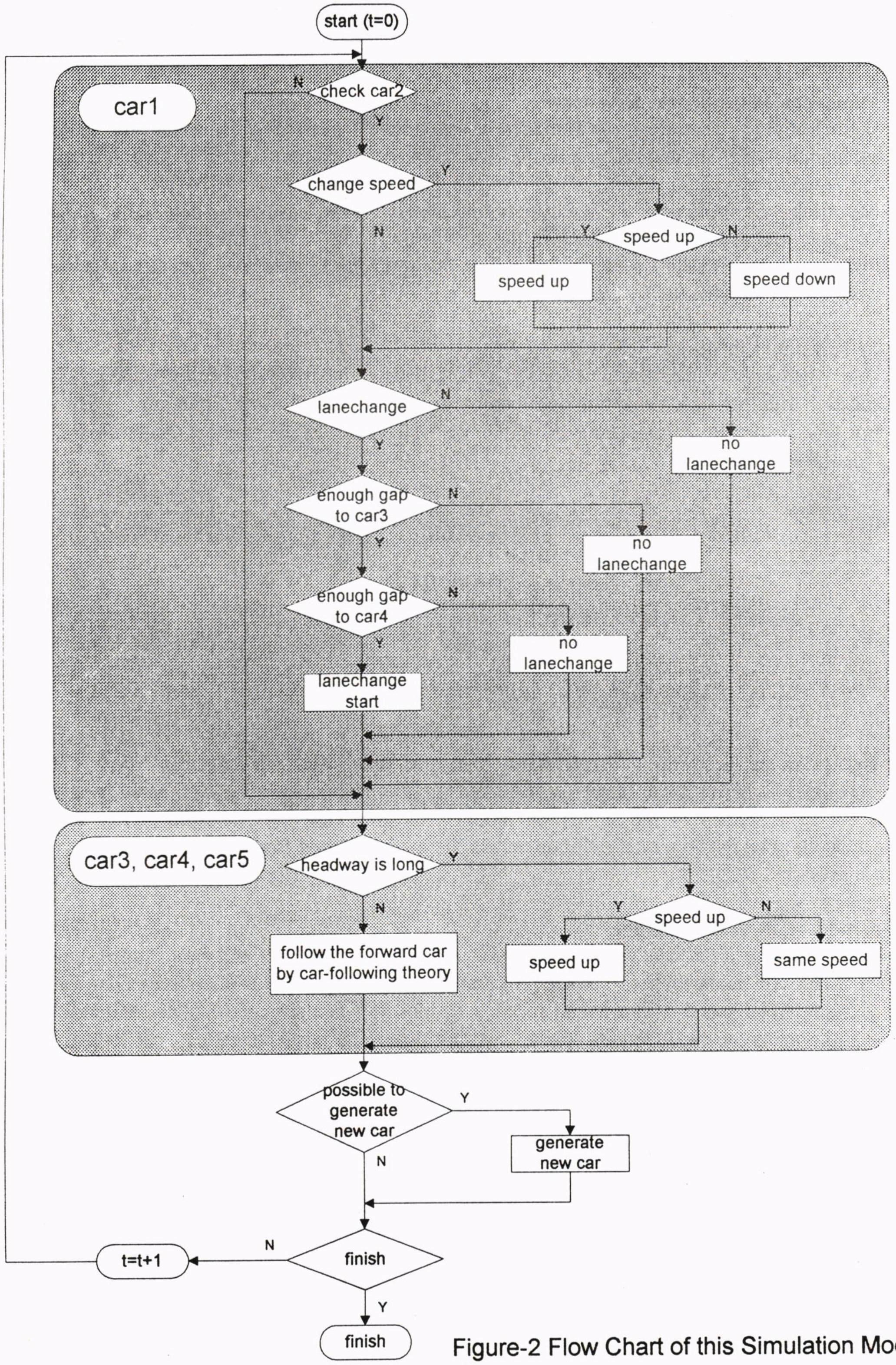

Figure-2 Flow Chart of this Simulation Model boundary headway was fixed. If the gap exceeds this boundary headway, the car can run in the free flow speed, otherwise car must run in the car-following speed.

a) movement in the free flow speed

In the free flow, drivers can run at maximum speed that is given initially in each car. In this simulation model, if the running speed is lower than the maximum speed, the driver increases the speed to maximum. When the running speed is equal to the maximum, the driver does not change the speed until the headway with the front car becomes lower than the boundary headway that is determined initially in this simulation model. When the headway becomes lower than the boundary headway, the driver changes speed based on the speed calculated from the car-flowing theory (category b).

b) movement in the car-following speed

When the headway shortens, new speed will be calculated based on the headway and relative speed. The rate of acceleration/deceleration can be calculated using Equation (1) below. For this simulation, parameters l, m, and λ were calibrated using empirical values from the video observation.

$$\ddot{x}_{n+1}(t+T) = \lambda \frac{\{\dot{x}_{n+1}(t+T)\}^m}{\{x_n(t) - x_{n+1}(t)\}^l}[\dot{x}_n(t) - \dot{x}_{n+1}(t)] \qquad (1)$$

$\ddot{x}_{n+1}$: acceleration of (n+1)th car

$\dot{x}_{n+1}$: speed of (n+1)th car

x_{n+1} : position of (n+1)th car

T : delay time

l, m, λ : parameters

The rates of acceleration/deceleration calculated from the car-following theory are sometimes higher or lower than the acceptable range. This is because the minimum interval is set to 1 second in the simulation model. In such cases, the acceptable maximum acceleration or minimum deceleration values that is determined from the actual traffic flow are prevailed.

c) movement of lane change

If the combination of headway and relative speed of car1 with car3 and car4 is acceptable, the driver will change lanes. In such a situation, the driver moves to the second lane with constant lateral speed. This lateral speed is set initially when this car generates and has no relationship to the car-following speed. At this instant, car1 will have a new car-following speed. This speed is given by considering headway and relative speeds of car1 with car2 (parked car) and car3 (front car on the second lane), and driver take the lower speed.

2.4 Confirmation of Lane Change

In this simulation model, only car1 is allowed to change lanes from the first lane to the second lane. Confirmation of a lane change is decided by evaluating the headway and relative speed with car3 and car4. If the headway between car3 and car4 is greater than the boundary value that is calculated by Equations (2) and (3), a lane change is confirmed. This confirmation occurs in one interval of the simulation model.

Headway between car1 and car3: $x_3 - x_1 > (v_{x1} - v_{x3}) \times \frac{w}{v_{y1}}$ (2)

Headway between car1 and car3: $x_1 - x_4 > (v_{x4} - v_{x1}) \times \frac{w}{v_{y1}}$ (3)

v_{xi} : longitudinal speed of car i (m/s)
v_{yi} : lateral speed of car i (m/s)
x_i : position of car i (m)
w : width of the lane (m)

2.5 Generation of the New Car

New car in the first and second lane is set to generate so as to fit the actual pattern of traffic flow. However, if the calculated headway and relative speed for a new car is not acceptable (the position of new car is overlaid with generated car), then the new car will not be generated.

3. MODEL PARAMETERS

This section describes several parameters required in defining the simulation model. Such parameters include mean and standard deviation of vehicle speed, and the average number of generated cars in the lanes. There are several ways of setting the values for these parameters. Values can be quoted or lifted from other papers or books. However, it is not clear what values to adopt for the simulation model because values vary from source to source. Therefore, actual site observation using a video camera was conducted and empirical values were obtained and used. The site for the video observation was carefully selected so as to fit the basic road and traffic conditions defined in section 2.1 (Geometric Condition).

3.1 Selection of Observation Site

There were two general criteria in selecting the site for video observation. Firstly, the actual site conditions must satisfy all items enumerated in section 2.1 under "Geometric Conditions". Secondly, since this study aims to investigate the relationship between parked vehicles on arterial roads and the occurrence of traffic accidents, the road must have had history of traffic accidents related to illegal roadside parking.

The selection of the location was facilitated by the use of GIS. The GIS database can readily identify the specific areas where accidents had occurred due to roadside parking.

Photo-1 shows the selected site.

3.2 Video Observation

After further investigation, it was found out that the condition at the selected road site approximates that of the idealized condition for the simulation model during the period from 7 to 9 AM. With this information, it was decided to conduct the video observation on the

7th of January 1997, from 8 to 9 AM. The camera was positioned on a tall building so as to capture lane-changing maneuvers. During the observation, the normal state of lane-changing behavior was recorded because the traffic flow was calm.

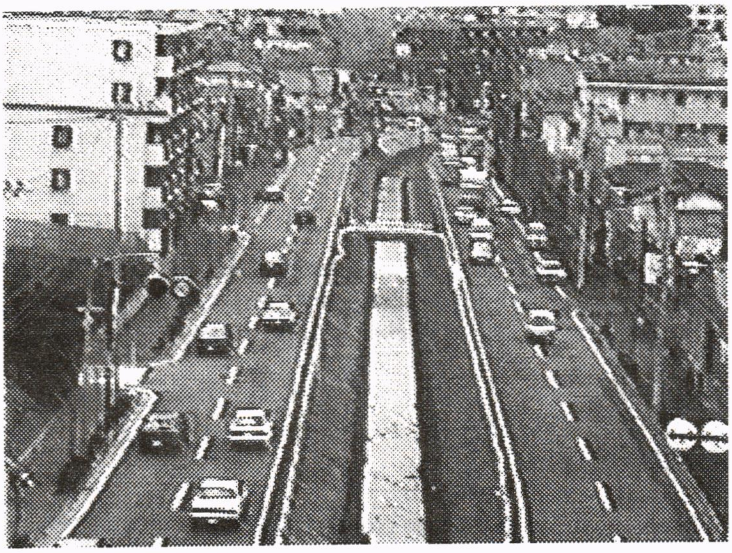

Photo-1 Video Observation Area

3.3 Model Parameters

a) Traffic Volume Per Lane

Vehicles were counted in each lane at 5-second intervals. In order to reflect undisturbed traffic flow, the counting was done only during green period. Figures 3 and 4 show the traffic in each lane. It is evident that vehicle arrivals on the first lane satisfy the Normal Distribution while arrivals on the second lane satisfy the Poisson Distribution. From the figures, the average number of traffic flow per 5-second period is 0.56 (=λ) and 2.16 (=μ) for the first and second lanes, respectively.

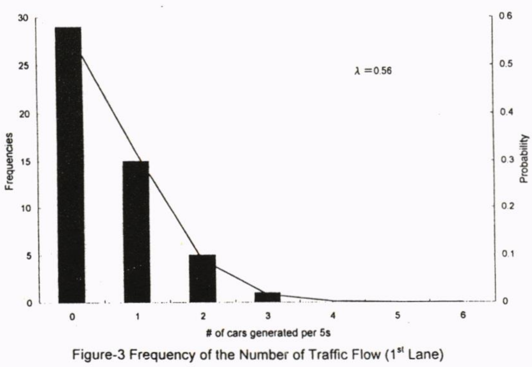

Figure-3 Frequency of the Number of Traffic Flow (1st Lane)

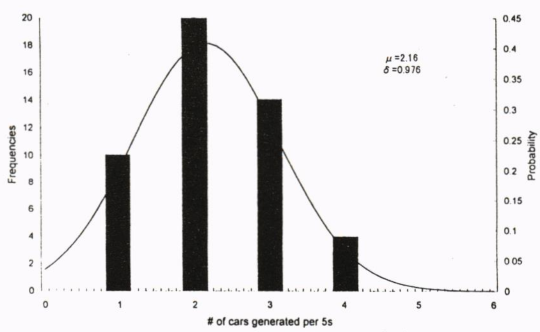

Figure-4 Frequency of the Number of Traffic Flow (2nd Lane)

b) Average Speed Per Lane

From the video observation, it was understood that the average speeds on both lanes are normally distributed. Average speed and standard deviations are as follows:

	average speed (m/s)	Standard deviation (m/s)
first lane	16.83	3.06
Second lane	16.40	2.69

c) Determination of Car-following Theory Parameters

When the headway shortens, the change in speed will be calculated based on the headway and relative speed (Equation-1). In this study, delay time (T) is assumed as 1 second, and, parameters l, m, and λ are determined by next procedure.

I. Figure-5 shows the relationship between the time and distance of 2 cars that rear car changes its speed by car-following theory.

II. From this figure, average speed $v_n(t)$ and acceleration $a_n(t)$ is calculated by following equation where x and t shows its distance from the start point and time period.

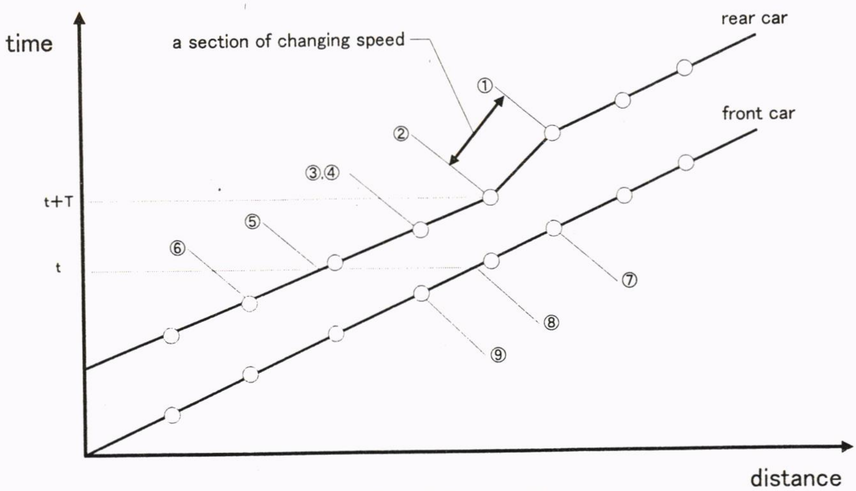

Figure-5 Car-Following Theory

$$x_n(t) = x_{⑧}, \quad v_n(t) = \frac{x_{⑦} - x_{⑨}}{t_{⑦} - t_{⑨}}$$

$$x_{n+1}(t) = x_{⑤}, \quad v_{n+1}(t) = \frac{x_{④} - x_{⑥}}{t_{④} - t_{⑥}}, \quad v_{n+1}(t+T) = \frac{x_{①} - x_{③}}{t_{①} - t_{③}}$$

$$a_{n+1}(t+T) = \frac{x_{①} - x_{②}}{t_{①} - t_{②}} - \frac{x_{②} - x_{③}}{t_{②} - t_{③}}$$

III Calculate other $v_n(t)$ and $a_n(t)$ from other couple of data.

IV Calculate following function and plot with $a_n(t)$ where the sets of (m, l) are assumed as (0,1) or (0,2) or (1,2) or (1,3).

$$\frac{\{v_{n+1}(t+T)\}^m}{\{x_n(t) - x_{n+1}(t)\}^l}\{v_n(t) - v_{n+1}(t)\}$$

V Most acceptable combination of (m, l) is adopted.
In this study, (l, m, λ) =(1, 0, 74.8)

d) Default Maximum and Minimum Acceleration/Deceleration Rates
Maximum acceleration and minimum deceleration rates were derived from the video observation. Rates were calculated by observing the passage of cars at 3 points and records elapsed times. The values obtained are as follows:

$$a_{max} = 7.58\ (m/s^2)$$
$$a_{min} = -9.63\ (m/s^2)$$

e) Perception Distance of the Parked Vehicle by the Approaching Driver
The distance of the driver from the parked car when driver starts noticing it vary from driver to driver. In this study, it was assumed that the instant of perception of the parked vehicle is the same as when the driver starts changing lanes. The distribution of the perception distance or position of the driver when he starts to see the parked vehicle is assumed to be Normally Distributed. The average length and standard deviation are defined accordingly.

4. MODEL ANALYSES

The findings in this section help to clarify the influence of on-street roadside parking on traffic capacity using sensitivity analyses on the simulation model.

In this chapter, two analyses are done to understand the degree of danger in the traffic flow. First analysis aims to evaluate the leeway time of car1 in the first lane to the car2, and second analysis aims to evaluate the leeway time in the whole traffic flow.

4.1 Evaluate the leeway time of front car in the first lane

The average traffic flow parameters λ and μ (for the first and second lanes, respectively) were assigned various combination of values. In this manner, sensitivity analyses on several variables can be done. Variables include (a) resulting traffic flows in each lane, (b) maximum queues formed in the first lane, and (c) percentage of leeway time below 5 seconds before hitting the parked vehicle.

Table-2 shows the traffic flow at the second lane without parking car in each traffic flow, and Table-3 to 6 and Figure-6 shows the result of traffic flow characteristics from the traffic simulation.

Table-2 Traffic Flow at the Second Lane without Parking Car (veh)

	μ=1.5	μ=2.0	μ=2.5
λ=0	982	1196	1301

Table-3 Traffic Flow at the First Lane (veh/hr)

	μ=1.5	μ=2.0	μ=2.5
λ=0.4	304	293	281
λ=0.6	451	432	378
λ=0.8	524	516	473

Table-4 Traffic Flow at the Second Lane (veh/hr)

	μ=1.5	μ=2.0	μ=2.5
λ=0.4	968	1153	1195
λ=0.6	958	1104	1159
λ=0.8	952	1065	1113

Table-5 Maximum Queue at the First Lane (veh)

	μ=1.5	μ=2.0	μ=2.5
λ=0.4	4	7	9
λ=0.6	10	19	16
λ=0.8	16	20	21

Table-6 Percentage of less than 5 Seconds Rest to Crash

	μ=1.5	μ=2.0	μ=2.5
λ=0.4	18.1%	30.0%	21.4%
λ=0.6	26.4%	33.5%	33.0%
λ=0.8	31.6%	28.9%	26.1%

NOTE: λ shows the average traffic flow in the 5s at first lane
μ shows the average traffic flow in the 5s at second lane

Important Findings:

1. Traffic volume in the second lane decreased when a vehicle is parked in the first lane (Compare Tables 2 and 4.) The percentage decrease in volume comparing "without" and "with" the parked vehicle is 7.7% ($\mu = 2.0$, $\lambda = 0.6$).

2. From Table 5, it can be seen that the number of cars in the queue that is formed increased as average traffic volume in both the first and second lane increased. Increase in traffic flow in the first lane created longer queues.

3. Figure-6 shows the relationship between speed and distance of the driver from the parked vehicle at the instant when the driver changes his lane. The lines show the leeway time before the driver hits the parked vehicle. It is obvious that as traffic volume increases, the frequency of shorter leeway time also increases rapidly. Table 6 shows the percentage of leeway times less than 5 seconds. The table shows that the condition defined by λ=0.6 and μ=2.0 is most dangerous in terms of leeway time. The condition defined by the above parameters approximates the current condition of the site.

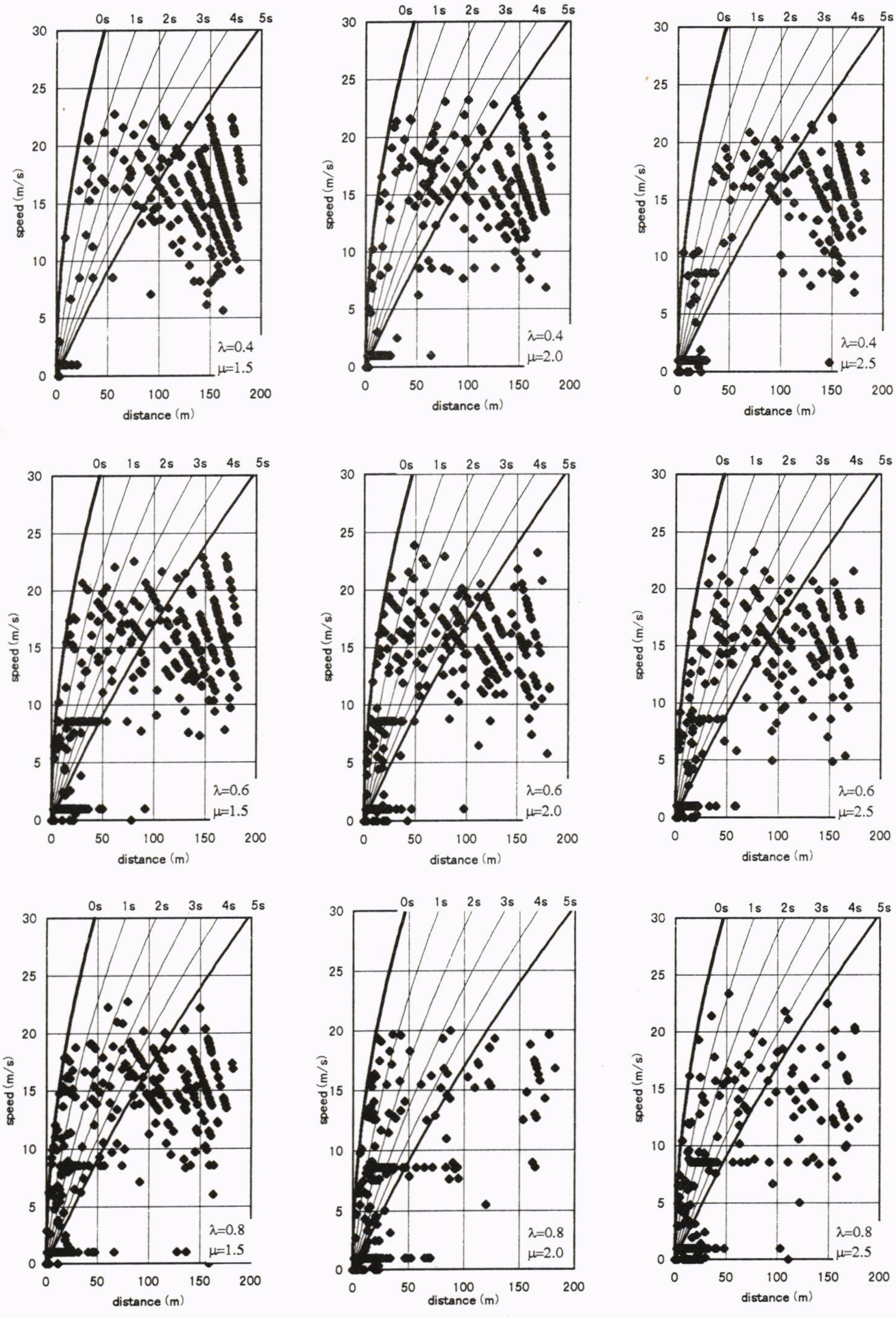

Figure-6 Relationship between the speed and distance to roadside parking car at lane change in each traffic flow

4.2 Evaluate the leeway time in the whole traffic flow

In the former section, the degree of danger of car1 in the first lane to the car2 is understood. However, the danger of traffic accident also comes from the whole traffic flow. In this section, the degree of danger in the whole traffic flow is understood by changing the traffic flow where the ratio of it in the first/second lane is fixed.

The index of danger is defined to understand the danger of traffic accident. This index is calculated by following procedure.

I. 5 area is divided by leeway time of leading car in the first lane to the parking car (Figure-7).
II. Count the number of data in each area, and calculate the percentage of it (P_i).
III. 5 continuous numbers (1 to 5) are valued in each area (D_i).
IV. Summarize the average index of data ($\Sigma P_i D_i$).

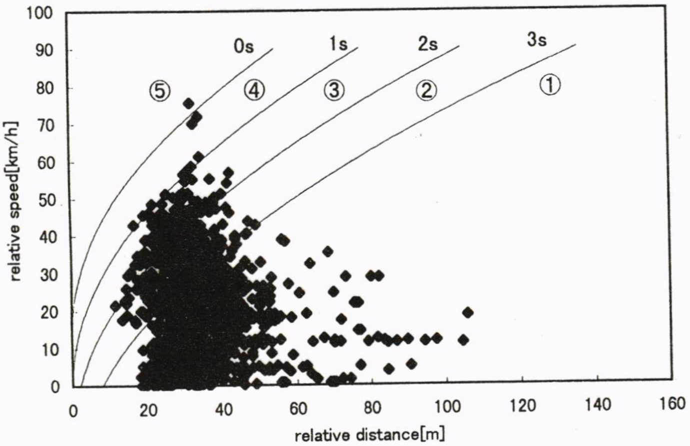

Figure-7 Relationship between the distance and speed

Figure-8 shows the index of danger in each traffic flow and ratio. "1:4" shows that there are 4 times of traffic flow in the second lane, and "0:1" shows that there is no traffic flow in the first lane. It is found from the video observation that the ratio is "1:4".

Important Findings:

1. It is found that the point that 2 lines are separated from each other tend to move left side (lower traffic) as the traffic flow ratio in the first lane is getting higher. This shows that the higher ratio brings the higher degree of danger even if traffic volume is no so high.

2. It is found that increase of the degree of danger is not high from certain ratio. That is, lower ratio brings the higher increase of danger.

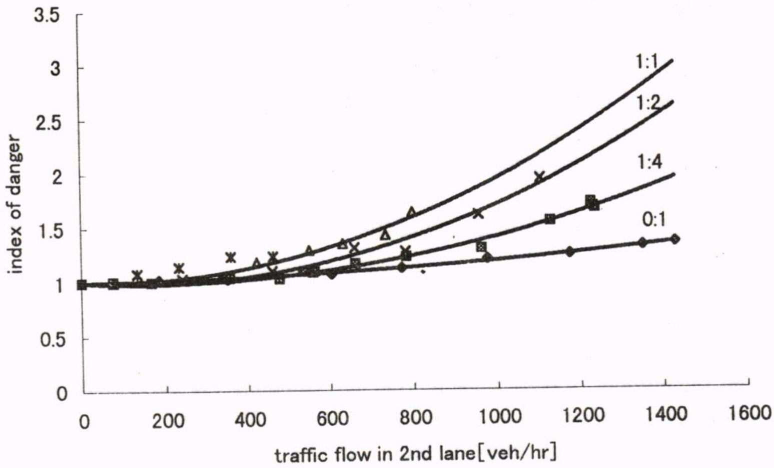

Figure-8 Comparison between the index of danger and traffic flow in 2nd lane

5. CONCLUTION

This study showed the importance of developing a traffic simulation model in analyzing the influence of roadside parking on the traffic flow conditions. The model utilized in this study satisfactorily reproduced or simulated the current road conditions as shown in the output utilizing calibrated parameters.

It was revealed that roadside parking decreased traffic volume by 7.7% from the result of the comparison between "with" and "without" roadside parking scenarios. And it is found that increase of the degree of danger is not high from certain ratio. That is, lower ratio brings the higher increase of danger.

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