SIMULATION AND SPEED CLASSIFICATION OF CAR FOLLOWING MODELS

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Abstract: The hypothesis of this study is that different models by speed classification is more appropriate than single model irrespective of speed in car following model. Field data was collected at three sites in uninterrupted and three sites in interrupted traffic facilities. Using two speed-distance measuring equipment connected to PC, the speed and position of both lead and lag vehicles for a distance of 500m on identical lane at each site were collected. The data covering speed, acceleration and gap distance of each vehicle was analyzed by speed groups to evaluate the best fitting model among 6 currently available car following models. It is found that two separate car following models having speeds more than and less than 90km/h traffic flow conditions should be applied. Relevant car following models by speed classification were suggested and simulation program was developed. The validity of suggested models were testified through the simulation program.

Key Words: Car Following, Simulation, Speed Classification, Traffic Flow, Model Validity

1. INTRODUCTION

Currently, the traffic simulation programs developed home and abroad are applied to Korean traffic operation for traffic signal control and ramp metering etc. These programs, however, are not satisfactory enough to reflect Korean traffic flow characteristics and drivers' behaviors. This study was focused on applying car following models suitable for Korean traffic flows, translating this application into a simulation program and testing this program, as part of the Korean traffic simulator development. After car following patterns on Korean roads were analyzed, this study examined if it was desirable to apply different car following models for different speed classes. The simulation program was developed on this result, and the appropriateness of developed car following model was tested through this simulation.

2. STUDY SITES AND METHODOLOGIES

The spatial range of this study covers 6 sites on Korean roads. Table 1 provides information on the location, traffic volume and average speed of each site. Based on different average speeds, these sites were further divided into two groups--A, B and C for uninterrupted facilities and D, E and F for interrupted facilities.

Table 1. Information of Study Sites

SITES	LENGTH (m)	WIDTH (m)	NUMBER OF LANES	VOLUME (pcphpl)	AVERAGE SPEED (km/h)
A	500	3.75	4	1,602	93.5
B	500	3.75	2	1,663	98.1
C	500	3.75	3	742	102.7
D	500	3.50	4	586	72.1
E	500	3.50	4	750	59.2
F	500	3.50	2	289	68.9

Measurements were conducted during non-peak hours in the weekday afternoon in January and March 2000. Only passenger vehicles were included in this study. Lane change and incidents were not taken into account. This study involved only those basic sections with level grade on tangent road.

Car following models were examined through the review of literature, and what car flowing models have been applied to existing simulation programs was examined. This study established the hypothesis that different car following models should be applied for different speed classifications. This hypothesis was tested through statistical analysis. A simulation program was developed from car following models adopted in this process. Those adopted models were validated through comparison of simulation output data with field data.

3. REVIEW OF CAR FOLOWING MODELS

The microscopic car following analysis for understanding traffic flow patterns on single-lane roads begins with the hypothesis, "A rear vehicle follows a front vehicle." This analysis assumes entire traffic flow patterns from the following pattern of this one pair of cars. The generalized car following model, has the conception--'A driver's response is determined by sensitivity and stimuli (*Response=f(sensitivity, stimuli)*).'

$$\ddot{x}_{n+1}(t+T)=\alpha_0\frac{\dot{x}^{\,m}_{n+1}(t+T)}{[x_n(t)-x_{n+1}(t)]^l}[\dot{x}_n(t)-\dot{x}_{n+1}(t)] \qquad (1)$$

where, $x_n(t)=$ position of vehicle n at time t

$\dot{x}_n(t)=\dfrac{dx(t)}{dt}=$ speed of vehicle n at time t

$\ddot{x}_n(t)=\dfrac{d^2x(t)}{dt^2}=$ acceleration of vehicle n at time t

$T=$ Time lag(reaction time: 1.0sec)

α_0 is parameter of sensitivity

l, m are parameters

Table 2. α_0, l, m of Car following Models

Model	L	Equation of State	Site A, B, C	Site D, E, F
		M=0		
1	0	$q=\alpha[1-k/k_j]$ $\alpha=q_m=1/(reaction\ time)$	α_0 =0.27	α_0=0.27
2	1	$q=\alpha k\ln[k_j/k]$ $\alpha=$ velocity at maximum flow(u_m)	α_0=11.11	α_0=5.56
3	3/2	$q=\alpha k[1-(k/k_j)^{1/2}]$ $\alpha=$ velocity at free flow(u_f)	α_0=27.78	α_0=22.22
4	2	$q=\alpha k[1-k/k_j]$ $\alpha=u_f$	α_0=27.78	α_0=22.22
		M=1		
5	2	$q=\alpha k e^{k/k_0}$ $\alpha=u_f$	α_0=27.78	α_0=22.22
6	3	$q=\alpha k e-\frac{1}{2}(\frac{k}{k_0})^2$ $\alpha=u_f$	α_0=27.78	α_0=22.22

* α_0 : m/sec

α_0 in Model 1 of this study means 1/reaction time, so it becomes 0.27m/sec when the reaction time is 1.0 second, equal to the step progress time in the simulation. α_0 in Model 2 is the velocity at maximum flow(u_m). It was 11.11m/sec (40km/h) at A, B and C sites and 5.56m/sec(20km/h) at D, E and F sites. α_0 in Models 3 to 6 is the velocity at free flow(u_f). According to the methods for calculating the velocity at free flow in TRB's Highway Capacity Manual, it was 27.78m/sec (100km/h) at A, B and C sites and 22.22m/sec (80km/h) at D, E and F sites.

4. DATA COLLECTION

To analyze car following patterns at 6 test sites on Korean roads, the location and change in the speed of the lead and lag vehicle, and change in the gap distance between the lead and the lag vehicle were measured. Additionally, the traffic volume at the sites was measured during the measurement hours. To collect data necessary for analyses, image processors or video cameras were used.

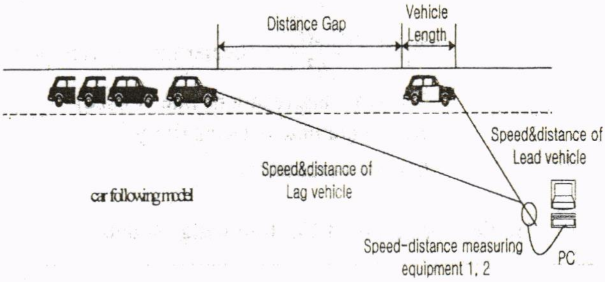


Figure 1. Method of Data Collection

In this study, two speed-distance measuring equipment were connected to COM ports of a laptop computer, as shown on Figure 1, for giving and receiving data by means of serial communication. Changes in the speed and the location measured by 2 speed-distance measuring equipment were stored in a file constantly. For data validation, video camera was installed at the test sites to measure the traffic volume and the headway. The file stored in the laptop computer is shown on Figure 2(a). COM1 in the first column of this source data is ID of the lead vehicle, while COM5 is ID of the lag vehicle. Data on the lead vehicle is input to the COM1 port, while data on the lag vehicle to the COM5 port. The second column tells the time when data was collected. The third column is the speed of a vehicle at the point. The fourth column is the distance from the measurement point to the vehicle. This data was transformed into the form shown on Figure 2(b). Acceleration of the lead and the lag vehicles was found by differentiating their speed by time.

COM1	15:53:55	101km/h	273.6m
COM5	15:53:55	100km/h	307.6m
COM5	15:53:56	101km/h	279.4m
COM1	15:53:56	102km/h	241.2m
COM5	15:53:57	98km/h	251.8m
COM1	15:53:58	100km/h	200.7m
COM5	15:53:58	96km/h	225.0m
COM5	15:53:59	90km/h	199.2m
COM1	15:53:59	98km/h	160.1m
COM1	15:54:00	98km/h	132.9m
COM5	15:54:00	90km/h	173.5m
COM5	15:54:01	90km/h	148.6m
COM1	15:54:01	96km/h	105.1m
COM5	15:54:02	90km/h	123.5m
COM5	15:54:07	0km/h	284.1m
COM1	15:54:15	99km/h	273.0m
COM5	15:54:15	102km/h	314.0m
COM1	15:54:17	96km/h	221.6m
COM5	15:54:17	101km/h	266.7m
COM5	15:54:18	101km/h	238.5m
COM1	15:54:19	91km/h	169.3m
COM5	15:54:19	100km/h	209.6m
COM5	15:54:20	100km/h	181.8m

(a) Type of Raw Data

Time	Speed of Lead Veh. (km/h)	Speed of Lag Veh. (km/h)	Distance Gap (m)	Accel. of Lead Veh. (m/sec^2)	Accel. of Lag Veh. (m/sec^2)
15:53:55	101	100	29.0		
15:53:56	102	101	33.3	0.278	0.278
15:53:58	100	96	19.4	-0.278	-0.694
15:53:59	98	90	34.2	-0.556	-1.667
15:54:00	98	90	35.8	0	0.694
15:54:01	96	90	38.8	-0.556	0
15:54:15	99	102	313.6		
15:54:17	96	101	266.3	-0.417	-0.139
15:54:19	91	100	209.1	-0.694	-0.139
15:54:20	85	100	181.2	-1.667	0

(b) Type of Transformed Data

Figure 2. Type of Raw Data from Equipment and Type of Transformed Data

5. Data Analysis

Assuming that acceleration after the reaction time in field data is an 'observed value(X_i)' and acceleration after the reaction time in the model is an 'expected value(Y_i),' the hypothesis was tested by paired comparison to see if there was any difference between the observed value and the expected value of each pair. Here, the difference (X_i - Y_i = D_i) was assumed to follow the normal distribution, and $\alpha = 0.05$ was used.

$$H_0 : \mu_D = 0, \qquad H_a : \mu_D \neq 0$$

$$T = \frac{\overline{D} - 0}{S_D / \sqrt{n}} \qquad (2)$$

where, $\overline{D} = \frac{1}{n}\sum_{i=1}^{n} D_i$

$$S_D^2 = \frac{1}{n-1}\sum_{i=1}^{n}(D_i - \overline{D})^2$$

As a result of testing the hypothesis by paired comparison based on integrated data about A, B and C sites, Model 2 was found proper for these sites. For D, E and F sites, Model 4 was found suitable. Out of those models found not significantly different as a result of testing the hypothesis, the model with the lowest MSE (mean square error) was adopted as an appropriate model. Different results were obtained from one group of A, B and C test sites and another group of D, E and F sites. This is because the α_o value failed to reflect different speeds at maximum flow and free flow of each road. Therefore, it is determined to apply the α_o value by classifying a road by speed groups.

Table 3. Selection of the Most Suitable Car following Model

Model	Site A, B, C			Site D, E, F		
	Result of Paired T	MSE	The Most Suitable	Result of Paired T	MSE	The Most Suitable
Model 1	**Accepted**	2.942		Rejected		
Model 2	**Accepted**	**2.574**		Rejected		
Model 3	Rejected			**Accepted**	0.577	
Model 4	Rejected			**Accepted**	**0.450**	
Model 5	**Accepted**	216.069		Rejected		
Model 6	Rejected			**Accepted**	0.702	

For speed classification at two site groups, the number of classes and class width are determined as follows:

Determination of Class (Equation of Sturges)

$$k = 1 + \log_{10} n / \log_{10} 2 \qquad (3)$$

where, n is number of measured value
k is number of class

Determination of Class width

$$class\ width = \frac{\max(measured\ value) - \min(measured\ value)}{(number\ of\ class)} \quad (4)$$

The initial class grouping of A, B and C sites were divided into 8 areas based on the car following speed, while D, E and F sites into 9 areas. According to the results obtained from SAS-based Scheffe grouping, the sites A, B and C could be divided into 4 different speed classes, while the sites D, E and F into 4 classes.

Table 4. Speed Classification as Scheffe Grouping

Site A, B, C		Site D, E, F	
Speed Class	Sample Size	Speed Class	Sample Size
Upper 107km/h ~ under 116km/h	35	Upper 81km/h ~ under 90km/h	32
Upper 98km/h ~ under 107km/h	85	Upper 69km/h ~ under 81km/h	93
Upper 90km/h ~ under 98km/h	92	Upper 60km/h ~ under 69km/h	103
Upper 81km/h ~ under 90km/h	39	Upper 51km/h ~ under 60km/h	42
SUM	251	SUM	270

As a result of testing the hypothesis using paired comparison at the 5% level of significance for each of uninterrupted and interrupted traffic flow areas, the hypothesis was rejected only for speed class 4 of the A, B and C sites group. For other speed classes, the hypothesis was not rejected.

Table 5. Result of Paired Comparison as Speed Classification (Site A, B, C)

Model 2	Speed Classification of Site A, B, C			
	Class 1	Class 2	Class 3	Class 4
	upper 107km/h ~ under 116km/h	upper 98km/h ~ under 107km/h	upper 90km/h ~ under 98km/h	upper 81km/h ~ under 90km/h
$\alpha = 0.05$	**Accepted**	**Accepted**	**Accepted**	Rejected

Table 6. Result of Paired Comparison as Speed Classification (Site D, E, F)

Model 4	Speed Classification of Site D, E, F			
	Class 5	Class 6	Class 7	Class 8
	Upper 81km/h ~ under 90km/h	upper 69km/h ~ under 81km/h	upper 60km/h ~ under 69km/h	upper 51km/h ~ under 60km/h
$\alpha = 0.05$	**Accepted**	**Accepted**	**Accepted**	**Accepted**

Because it was found that Model 2 was not proper for speed class 4 of the A, B and C sites group, a proper model was found by testing the hypothesis again using paired comparisons for 6 models. Model 4 was found most suitable for this speed class.

Table 7. Result of Paired Comparison for Speed Class 4(Site A, B, C)

Class 4 at Site A, B, C	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$\alpha = 0.05$	Rejected	Rejected	**Accepted**	**Accepted**	**Accepted**	**Accepted**
MSE	-	-	0.980	**0.413**	321.770	1.368
The Most Suitable						

It was found that model 2 is proper for speed conditions over 90km/h from Table 5. It was also found that model 4 is proper for speed conditions under 90km/h from Table 6 and 7. Therefore, it was drawn that it was desirable to use two separate car following models on the basis of 90km/h.

Accordingly, the models shown in Table 8 were applied for different speed classes for simulation of car following models in this study.

Table 8. Car following Models as Speed Classification

	Class 1	Class 2	Class 3	Class 4,5	Class 6	Class 7	Class 8
	upper 107km/h ~ under 116km/h	upper 98km/h ~ under 107km/h	upper 90km/h ~ under 98km/h	upper 81km/h ~ under 90km/h	upper 69km/h ~ under 81km/h	upper 60km/h ~ under 69km/h	upper 51km/h ~ under 60km/h
Model	Model 2			Model 4			
α_0	11.11m/sec			22.22m/sec			
λ	1			2			
μ	0			0			

6. DEVELPOMENT OF THE CAR FOLOWING SIMULATION PROGRAM

6.1 Program Development

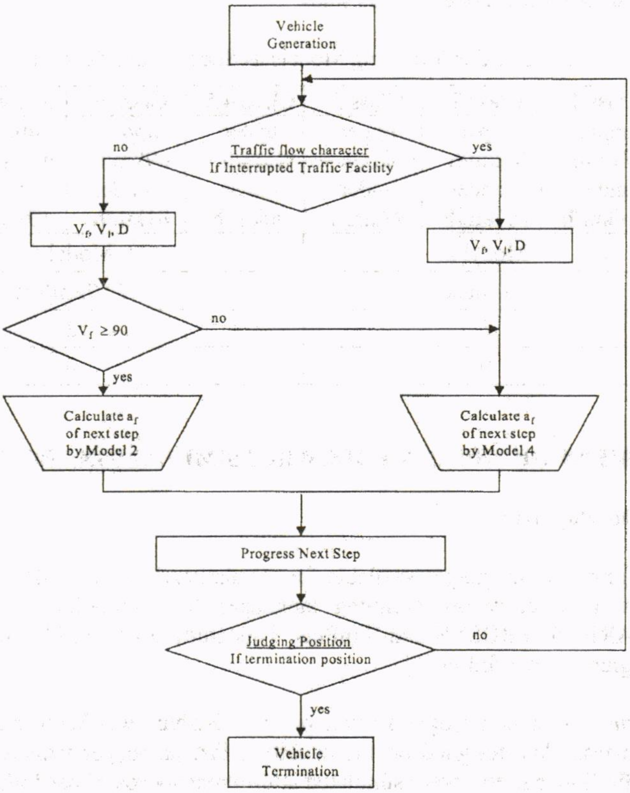
Universal programming languages available for simulations include FORTRAN, C and C^{++}. There are also proprietary programming languages for simulations, such as SIMAN, SIMSCRIPT, ARENA, PROSYS and SimPlus. This study used SimPlus in developing the simulation program for car following.

The car following simulation program developed in this study was based on the 4-lane road. The simulation was also designed on the condition that passenger vehicles do not change lanes. The traffic flow patterns were simulated at different speeds of car following models. In the simulation section, the lane width is 3.5m, and the section length is 500m. The simulation time was 15 minutes and could be set as needed. This study included only passenger vehicles whose length is 5m.

The algorithm for simulating car following models is shown on Figure 3. If a vehicle enters the simulation area, it perceives its speed, the speed of the lead vehicle and the gap distance. The vehicle determines its acceleration at the next step based on the car following model and runs at the acceleration rate. When the vehicle reaches to the next location, it checks its location. If it is still in the simulation section, it again perceives the speed of the lead vehicle and the gap distance. It repeats calculating the acceleration rate at the next step. For random seeds of the simulation, it was designed to set the seed value for the random number stream supplied by SimPlus.

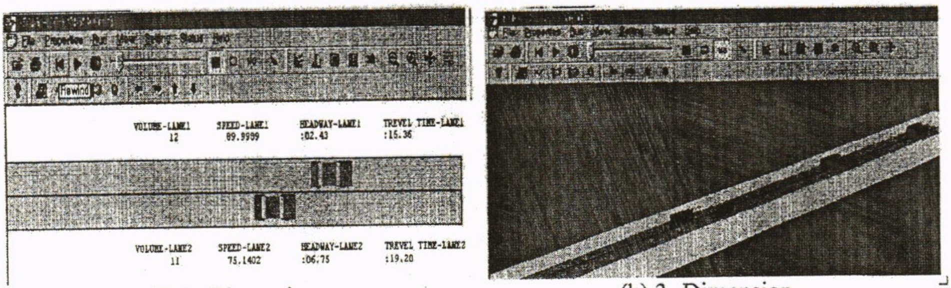
Figure 4(a) shows the 2-dimension animation of the simulation of car following models developed in this study. Figure 4(b) is the 3-dimension animation of the simulation.

The outputs of the simulation were divided into two types--the output showing information about vehicles during the simulation, and the report file prepared after the end of simulation. First, the volume passed on each lane for each simulation time, and the speed and the headway of vehicles were displayed, and the travel time spent in passing through the simulation section was reported.



where, V_f = speed of following vehicle
V_l = speed of lead vehicle
D = (position of lead vehicle) – (position of following vehicle)
A_f = acceleration of following vehicle
A_l = acceleration of lead vehicle

Figure 3. Algorithm of Car following



(a) 2- Dimension (b) 3- Dimension

Figure 4. Animations of Car following Simulation Program

Second, data prepared in the form of a report file after the simulation terminated included the length of the simulation section, the number of lanes, lane characteristics (uninterrupted traffic facilities or interrupted traffic facilities), the simulation time and the traffic volume per hour by lane. To check if the simulation embodies actual circumstances, the program was designed to report the speed and the headway of vehicles by real time on each lane. The program was also designed to calculate the total travel time.

6.2 Validation

To validate car following model applied in this study, the speed and the headway of vehicles collected in the field and simulated by the program were compared. The speed and the headway of vehicles at a new site, which was not used in applying models, were compared with the speed and the headway of vehicles in the simulation. The traffic volume at the field was 1,148 veh/hr, and the speed and the standard deviation were 102.43km/h and 7.17km/h. These data were input as the traffic volume and the speed of the simulation.

The average speed of the traffic flow at the field was 102.43 km/h, while the average speed of the simulation was 98.75km/h. As a result of the t test conducted to see if there was any difference between the speed of the traffic flow at the field and that of the simulation, it was found that these two speeds were not significantly different at the 5% level of significance. Figure 5 is the comparison of the speed distribution at site and by the simulation.

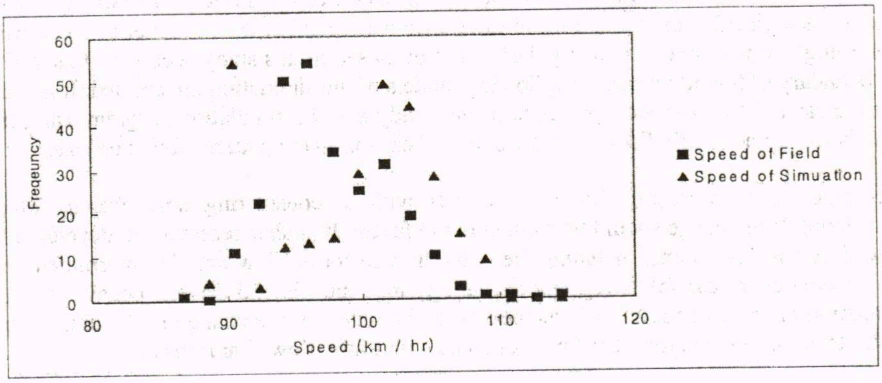


Figure 5. Speed of Field and Simulation Distribution

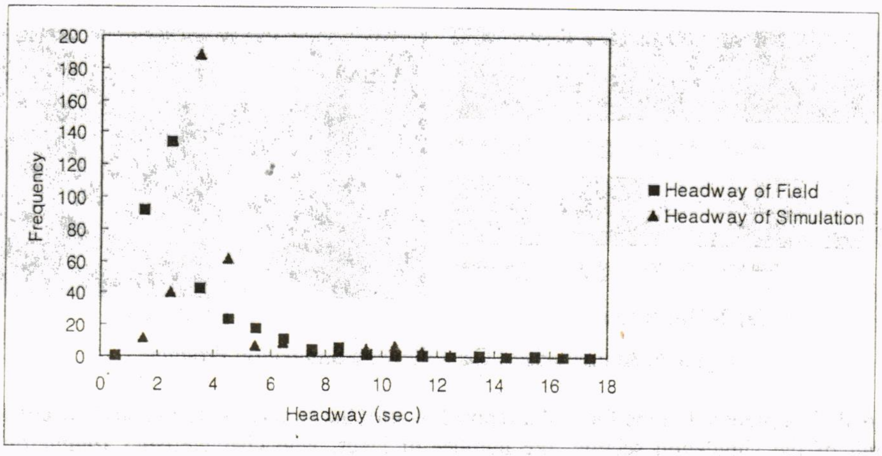


Figure 6. Headway of Field and Simulation Distribution

The average headway of traffic flows at site was 2.63 seconds, while the average headway of the simulation was 2.71 seconds. The results of t tests conducted to see if there was any difference between the headway of traffic flows at site and by simulation, it did not show any significant difference at the 5% level of significance. Figure 6 shows the comparison of the headway at site and by simulation.

7. Conclusion and Future Studies

This study collected data on car following patterns at 6 sites on Korean roads and found most suitable models among 6 car following models. Data was divided into 8 speed classes and the difference between acceleration measured in the field and acceleration calculated in the model was compared statistically. According to statistical analyses, Model 4 was found proper for the class where the speed was slower than 90km/h, while Model 2 was found suitable for the class at the speed of 90km/h or faster.

Further, simulation program using two separate car following models by speed classes were developed and was compared with the new field data. For the speed and headway between field and simulated data, no significant difference was found at the 5% level of significance. Accordingly, it is desirable to apply the models proposed in this study according to speeds on the boundary of 90km/h when car following models of the simulation are applied. It is judged that the car following models proposed in this study and the simulation program using these models can reflect traffic flow characteristics and car following patterns found on roads.

This study dealt with car following models without considering lane change. Models considering lane change should be studied in the future. It is also necessary to develop traffic flow simulation programs, including the uninterrupted traffic flow and the interrupted traffic flow, which cover car following models, lane change models and drivers' behaviors. Future simulation programs should be developed as to simulate the interchange in the uninterrupted traffic facilities and the toll plaza in accordance with traffic flow characteristics.

In defining the car following model in which the lag vehicle follows the lead vehicle, it is necessary to subdivide the definition of car following models by studying the case that the lag vehicle follows the lead vehicle and the case that the lag vehicle doesn't follow the lead vehicle in relation with the gap distance. This study was based on the classes at speeds between 51km/h~116km/h, but future studies need to cover wider speed variations than this.

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REFERENCES

Transportation Research Record (1997) **Traffic Flow Theory**, Special Report 165, 10.1-10.23, USA, Washington, D.C.

Transportation Research Record (1999) **Highway Capacity Manual**, Special Report 209, 3.20-3.22, USA, Washington, D.C.

Richard L. Scheaffer (1995) **Probability and Statistics for Engineers**, fourth edition, Duxbury Press, 376-368, 436-437.

T. Kim, M. Chang, and K. Lee (1998) **Development of Simulation Model to Evaluate and Manage Urban Freeways**, Journal of Korean Society of Transportation, Vol. 16, No.1, 165-185.

M. F. Aycin and R. F. Benekohal (1999) Comparison of car-following models for simulation, **Transportation Research Record 1678**, TRB, 116-118.