EXPERIMENTAL ANALYSIS OF CAR FOLLOWING DYNAMICS BASED ON RTK GPS DATA*

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1. Introduction

The microscopic approach of analyzing traffic flow dynamics has been given more importance in recent years in solving traffic and safety engineering problems. It has two important applications, first in simulation modeling where car following model amongst others controls the motion of vehicle in the network, and second in advance vehicle control and safety system (AVCSS) that is being introduced as a driver safety aid in an effort to minimize traffic accidents due to human errors. In the last five decades, a large number of empirical, analytical and simulation models have been developed in an effort to imitate the car following dynamics in a precise manner[1), 2) 3) 4) 5) 6) 7)]. This study attempts to investigate further the microscopic driving characteristics e.g. perception response time and drivers' sensitivity from a new viewpoint. Some selected models with different background assumptions are calibrated and evaluated in an effort to reach to a better understanding about their performances.

The specific objectives of this study are as follows:

- Investigate the perception response time of individual drivers as a variable term
- Investigate drivers' sensitivity to stimulus based on instantaneous response time
- Analyze the stability of platoon based on numerically derived criteria
- Evaluate the performance of microscopic traffic flow models based on how good they fit with RTK GPS data
- Set up a broader calibration scheme to accommodate different calibration prospects in a consistent manner
- Calibrate GM model for reliable estimation of its parameters
- Investigate the GM model parameters and characterize them

2. Car Following Experiment

Several car following experiments were conducted in a test track using ten test vehicles equipped with RTK GPS receivers. The test track consists of two 1.2 km long straight sections connected by two semicircular curves 50m each. In an attempt to emulate various driving conditions of real world, two types of experiments were performed: first emulating uninterrupted traffic in straight section and second interrupted traffic at intersection. The speed patterns tested for the leader driver in the case of uninterrupted traffic experiments includes half wave, one wave, two wave, three wave, random and constant speed patterns, while the same in the case of interrupted traffic experiments include acceleration tendency, deceleration tendency, random and constant speed patterns. The weather condition around the test track area was fair through out all experiments. The RTK GPS receivers output time, position and speed data at every 0.1 sec interval. It has a position accuracy of 10mm+2ppm and speed accuracy of less than 0.2 km/h. The traffic flow variable including headway, relative speed, acceleration and density were computed from the position and speed data. The headway and relative speed were computed from the position and speed of successive vehicles respectively. A polynomial fitting technique was implemented to compute acceleration by the differentiation of the speed data[8)]. Further details of these experiments can be found in the reference[9)].

3. Human Factors and Stability of Traffic Flow

Among three components of traffic systems i.e. human, vehicle and road and environment, human are generally held responsible at the most for significant influence on traffic flow dynamics. We have investigated the perception response time of individual drivers considering it as a variable term[9)]. The sensitivity factor is determined and investigated based on the instantaneous response time[10)]. **Fig. 1** presents the variations in the instantaneous response time and **Fig. 2** presents the variations in the sensitivity factor for individual driver under different driving conditions. **Table 1** presents the results of chi-square distribution test performed to characterize the response time. **Fig. 3** presents the scatter plot of response time versus sensitivity factor for half-wave speed pattern to examine the stability of platoon. A large number of instantaneous response time data and corresponding sensitivity factor were estimated using a computer program developed based on the methods proposed in the references[10), 11)]. The investigations based on these produced the following outcomes:

(1) Instantaneous Response Time

- The average response time of drivers' varies with in the range of 1.27 to 1.55 sec.
- The speed patterns and position in the platoon do not have much influence on driving behavior, while intrapersonal variations are found to be the dominant factor.
- The instantaneous response time is found distributed in lognormal function for the most of the drivers.

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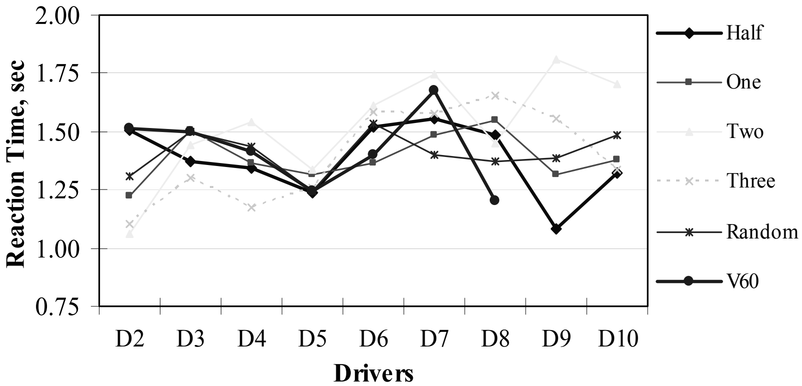

Fig. 1 Variations in instantaneous response time for individual drivers

Table 1 Chi-square distribution test for instantaneous response time

Drivers	Sample	Mean	SD	Normal	Log-Normal
D2	233	1.28	0.54	32.9	13.4
D3	210	1.43	0.64	22.9	26.1
D4	223	1.36	0.55	47.2	22.3
D5	283	1.27	0.53	49.5	7.6
D6	228	1.49	0.59	14.0	22.6
D7	160	1.55	0.61	20.0	11.7
D8	174	1.48	0.58	19.2	9.7
D9	134	1.37	0.55	19.2	9.7
D10	138	1.43	0.59	17.1	21.8

χ^2 at 5% significance level = 19.7

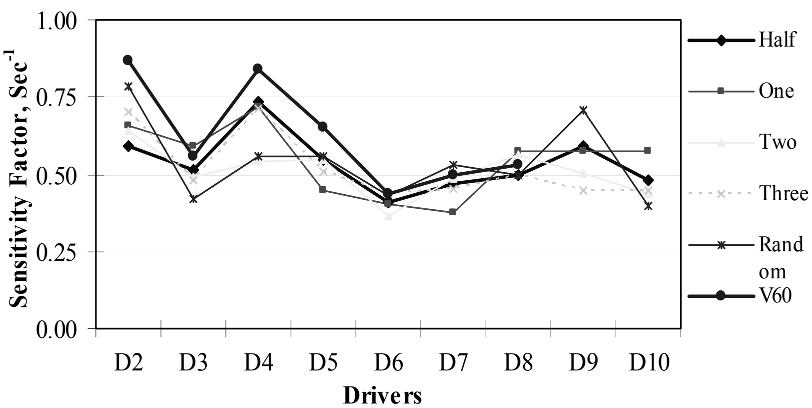

Fig. 2 Variations in Sensitivity Factor for Individual Drivers

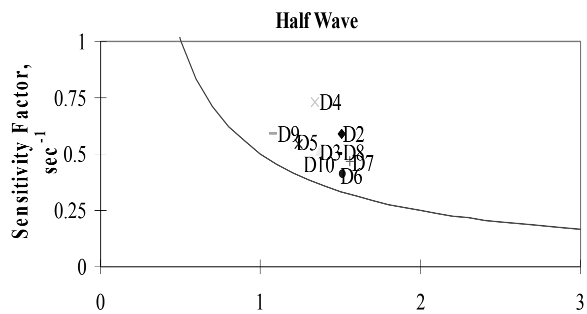

Fig. 3 Scatter plot of response time versus sensitivity factor for half wave speed pattern

(2) Sensitivity Factor

- The average sensitivity factor varies with in the ranges of 0.42 to 0.67.
- The intrapersonal variation is found to be the influential factor when compared with the influences from speed patterns and drivers' position in the platoon.

(3) Stability of Platoon

- In many cases, the average value for the stability factors exceeded the threshold value, indicating that the average responses of drivers are unstable both locally and asymptotically.
- The lead vehicle's speed fluctuations do not have much influence on the stability of platoon.

4.0 Evaluation of Microscopic Traffic Flow Models

Six car following models are evaluated based on how good they can fit with the RTK GPS data measured from car following experiments. The model parameters are calibrated first using an optimization technique based on genetic algorithm (GA). A percentile error function is used as the objective function to be minimized.

$$J(e) = \text{Min}\,\frac{\sum_{i=1}^{n}\left|y_i - \hat{y}_i\right|}{\sum_{i=1}^{n}\left|y_i\right|} \qquad (1)$$

Here, y_i and $\hat{y}_i$ are the measured and estimated values for the objective variable and n is the total number of data points in a data set. The models are calibrated and evaluated using two different data sets: first using speed and second using spacing as the objective variable to be optimized. **Table 2** presents the percentile error estimated using speed data, while **Table 3** presents the same using headway data. The average value of the discrepancies between speed and headway measurements remained at 0.87% with a standard deviation of 0.52%. These investigations produced the following outcomes[11].

(1) Speed Based Evaluation

- Most of the models performed well with speed data producing average error less than 5%, while Bando model produced relatively higher percentile error.
- The interpersonal variations are found relatively higher than the inter-model variations in the most of cases.

Table 2 Percentile error in speed estimation

Model No.	Models	Percentile error		
		Mean	SD	COV
1	Krauss model[6]	4.19%	1.18%	28.19%
2	Gipps model[3]	4.30%	1.09%	25.26%
3	Newell model[7]	4.71%	1.54%	32.76%
4	ECS model[10]	3.87%	1.64%	42.41%
5	Bando model[4]	8.46%	3.11%	36.73%
6	Castello model[5]	4.42%	1.48%	33.60%

Table 3 Percentile error in headway estimation

Model No.	Models	Percentile error		
		Mean	SD	COV
1	Krauss model[6]	12.04%	4.53%	37.60%
2	Gipps model[3]	12.20%	4.65%	38.09%
3	Newell model[7]	12.91%	5.13%	39.72%
4	ECS model[10]	15.38%	7.34%	47.69%
5	Bando model[4]	18.47%	9.20%	49.80%
6	Castello model[5]	20.99%	12.19%	58.05%

(2) Headway Based Evaluation

- The average percentile error in headway estimation is found higher than those in speed estimation.
- The interpersonal variations are found influential in this case also.

5.0 Calibration of GM Model

Fig. 4 presents a three dimensional calibration prospects to accommodate various alternatives for the calibration of the GM model. Here, GM1 represents the General Motors model[1), 2)], while the response time T is used as a constant term in this case.

$$a\,(t+T)=\alpha\ \frac{v_n\left(t+T\right)^m}{\Delta x\,(t)^{\ell}}\ \Delta v\,(t) \qquad (2)$$

In the case of GM2 the response time T is used as a variable term, while GM3 also uses the response time as a variable term; however a linear relationship derived using log scale is used instead. The Traffic Steam Model (TSM) is the steady state equations derived from the generalized GM model i.e. Equation (2). The genetic algorithm (GA) used in this study is based on GENECOP III as proposed by Z. Michalewicz[13)].

The GM model parameters are calibrated for the following sets of combinations to compare the influence of each calibration prospect and to improve the consistency of the results.

- Scheme I: GM3/UD/LR
- Scheme II: GM1/UD/GA
- Scheme III: GM2/UD/GA
- Scheme IV: TSM/ID/GA

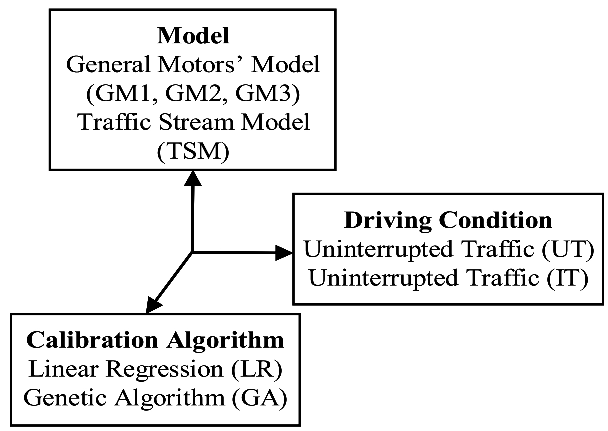

Fig. 4 A three dimensional framework for calibration

There are some improvements in the R^2 values in the case of Scheme I, when compared with those obtained by Gurusinghe[14)], but remain far from being satisfactory. **Fig. 5** presents the calibration results for scheme III, while **Fig. 6** presents the same for scheme IV. These investigations produced the following outcomes.

(1) Parameter Identification

- The least mean square method is not adequate to calibrate the GM model.
- The genetic algorithm is an effective tool for the optimization of the GM model parameters.
- For uninterrupted traffic, the R^2 values are significantly improved with the sensitivity parameters converged to a relatively narrow range in the case of Scheme III.
- For interrupted traffic, though estimated R^2 values are better, the distribution range is some what wider than those for uninterrupted traffic particularly in the case of parameter m.

(2) Influence of Driving Conditions

- The uninterrupted and interrupted traffic conditions have some influence on the sensitivity parameters.
- There is not much influence of speed patterns might on the sensitivity parameters, while the individual drivers' performance and driving stages of accelerating or decelerating are found to have some influence on them.

(3) Characterization of Sensitivity Parameters

- The sensitivity parameters are found distributed in log-normal function.

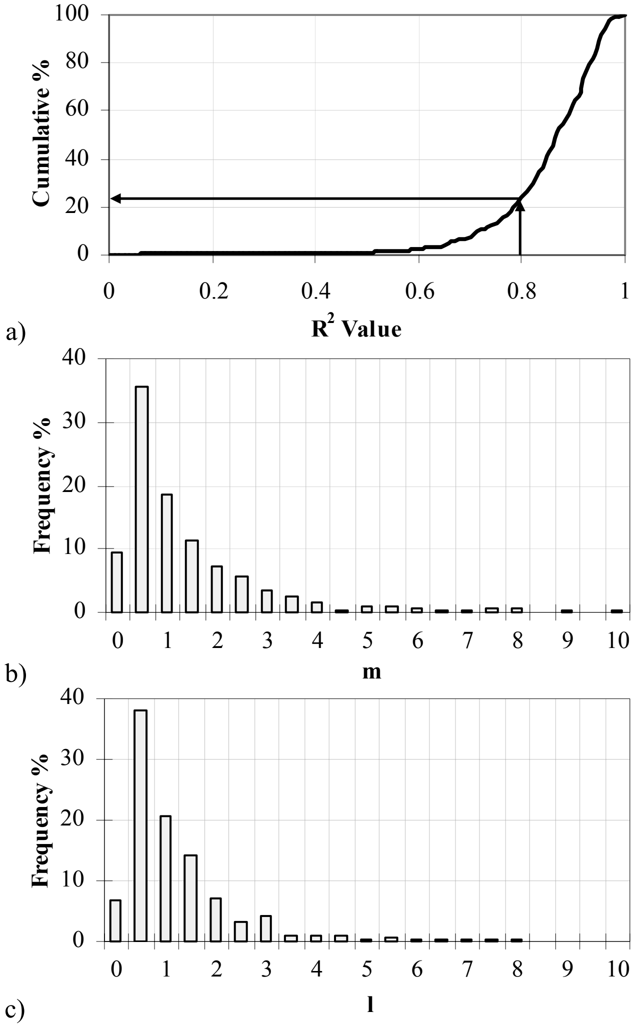

Fig. 5 Calibration results for Scheme III

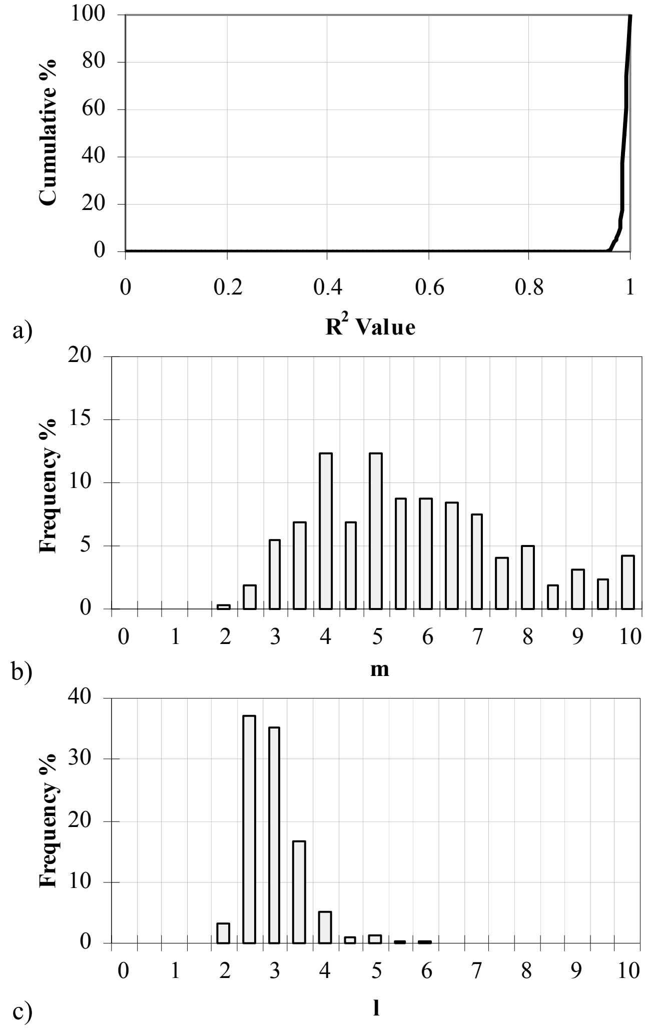

Fig. 6 Calibration results for Scheme IV

References

1) Chandler, R.E., Herman, R., Montroll, E.W. (1958): Traffic Dynamics: Studies in Car Following, *Operations Research* 6, Operations Research Society of America, pp 165-184.
2) Gazis, D.C., Herman, R., Rothrey, R.W. (1961): Non Linear Follow the Leader Models of Traffic Flow. *Operations Research* 9(4), pp. 545-567.
3) Gipps, P.G. (1981): A Behavioral Car Following Model for Computer Simulation, *Transportation Research* B15, pp. 105-111.
4) Bando H. Hasebe K., Nakayama A., Shibata Y. (1995): A Dynamical Model of Traffic Congestion and Numerical Simulation, *Physics Review*, Part E, Vol. 51, No. 2, pp. 1035-1042.
5) Castillo, J.M.D (1996): A Car Following Model Based on the Lighthill-Whithan Theory, In: Lesort J.B. (Ed.), Transportation and Traffic Theory, I3 ISTTT, Pergamon, NewYork.
6) Krauss, S. (1997): Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics, Ph.D. Thesis, University of Cologne, Cologne, Germany.
7) Newell, G. F. (2002): A Simplified Car Following Theory: A Lower Order Model, *Transportation Research* B36, pp. 195-205.
8) Suzuki, J., Nakatsuji, T., Azuta, Y., Ranjitkar, P. (2003): Experimental Analysis of Reaction Time of Car Following Model, JSCE, *Infrastructure Planning Review*, Vol. 19, No.4, pp 861-868.
9) Gurusinghe, G.S., Nakatsuji, T., Azuta, Y., Ranjitkar, P., Tanaboriboon, Y. (2002): Multiple Car-Following Data with Real-Time Kinematic Global Positioning System, *Transportation Research Record* 1802, TRB, Washington D.C., pp 166-180.
10) Gurusinghe, G.S., Nakatsuji, T., Tanaboriboon, Takahashi, K., Suzuki, J. (2001): A Car Following Model Incorporating Excess Critical Speed Concept, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 4, No. 2, pp 171-184.
11) Ranjitkar, P., Nakatsuji, T., Azuta, Y., Gurusinghe, G.S. (2003): Stability Analysis Based on Instantaneous Driving Behavior Using Car Following Data, *Transportation Research Record* 1852, TRB, Washington D.C., pp 140-151.
12) Ranjitkar, P., Nakatsuji, T., Motoki, A. (2004): Performance Evaluation of Microscopic Traffic Flow Models Using Test Track Data, 83rd TRB Annual Meeting, Washington D.C., Preprint CD-ROM (to be published).
13) Michalewicz, Z. (1992): *Genetic Algorithms + Data Structures = Evolution Programs,* Springer.
14) Gurusinghe, G.S. (2002): Development of Microscopic Car-Following Model with a New Concept, Doctoral Dissertation, Asian Institute of Technology, Bangkok.