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A NEW DELAY PARAMETER DEPENDENT ON VARIABLE ANALYSIS PERIODS AT SIGNALIZED INTERSECTIONS. PART 2: VALIDATION AND APPLICATION

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Abstract. The main objective of the present study is to investigate the performance of the proposed model in Part 1 for variable demand, time and oversaturated conditions. To accomplish this objective and test the proposed model, an experimental study was performed. The proposed delay model for oversaturated traffic conditions was calibrated and verified by the TRAF-NETSIM microscopic simulation program. In the calibration and verification of the proposed model, the simulation study was performed to produce various traffic and time conditions using 48 different scenarios. The delays obtained from the simulations and the proposed model were statistically compared using linear regression analysis. The results indicated that there was a good relationship R^2= 0.989 at 95 % confidence level between the delays generated by the simulations and the delays estimated by the proposed model.

Keywords: delay parameter, simulation, TRAF-NETSIM, regression analysis.

1. Introduction

Simulation is one of the important techniques of traffic engineering to evaluate complex strategies on a real time basis for a given network or freeway system. The major objective of this simulation technique is to compare a finite number of strategies regarding individual real life problems, and to validate and evaluate newly developed analytical models. The simulation models representing the traffic system are typically grouped as either microscopic or macroscopic simulation models. Microscopic models model traffic as individual vehicles and simulate their trajectories as they traverse on the road. Macroscopic models model the overall vehicle flow and simulate the state of the traffic stream (May 1990; Young *et al.* 1989). In this study, the TSIS – Traffic Software Integrated System (TSIS user's… 1997; Daigle *et al.* 1997) – is used to validate the proposed delay model due to the difficulties in obtaining field validation. TSIS is a suite of traffic software tools and integrates a number of widely utilized traffic engineering packages covering a microscopic traffic simulator, a graphical input processor, a traffic visualization package and signal optimization software.

The main part of TSIS is the traffic simulation model CORSIM. CORridor SIMulation (CORSIM) is a microscopic traffic simulation model developed by the Federal Highway Administration (FHWA) for simulating traffic flow on integrated networks of freeways and surface streets (Corsim user's… 1977; Halati *et al.* 1997; Introduction to CORSIM… 1998). CORSIM is a combination of NETwork SIMualtion (NETSIM) and FREeway SIMulation (FRESIM) and simulates the traffic behaviour on the integrated network at a microscopic level through a detailed representation of individual vehicles and their interaction with other vehicles.

Because NETSIM describes in detail the operational performance of vehicles travelling in an urban street network, this component of CORSIM is used for the validation process of the proposed model. In NETSIM model, the vehicles are represented individually and their operational performance is determined uniquely every second. The model uses a number of stochastic processes to adequately represent real world behaviour. For each vehicle entering the network, the vehicle and driver characteristics are generated randomly and the vehicle's position on the link, relationship to other vehicles nearby are updated. As vehicles move from one link to another, their turning movement on the new link is randomly assigned (Rathi and Santiago 1990; Wong 1990; Chang and Kanaan 1990; Andrews *et al.* 1987).

NETSIM does not require a lot of data to run the program because much of the input is optional and has default values. However, NETSIM needs the minimum inputs of link approach length, number of lanes, entry volumes, discharge headway, allowable movements, turning percentages, and signal control parameters to simulate any

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given traffic condition. The outputs provided by NETSIM include a variety of measures of effectiveness, including average speed, delay, queuing, turning movements and estimations of fuel consumption and emission on each link of the network for specified time intervals.

The intersection simulated by NETSIM is graphically constructed with ITRAF which is an interactive traffic network data editor for the integrated traffic simulation system. The main advantage of ITRAF is that it creates the data structure as the network is being developed and simplifies the TRAF models input data process. It also provides error checking to assure that the information provided by user is correct. For any of the simulation models of TSIS, the topology of the network is defined in terms of unidirectional links and nodes. The nodes of the network show the intersections or points where a geometric property changes. The boundaries of the network are determined by external nodes, which represent where traffic enters or exits the network. The external nodes in the network analyzed are numbered in the range of 8000 and 8999. In ITRAF, links represent unidirectional urban streets. Therefore if traffic flows in both directions on a street, it is represented by two unidirectional links (ITRAF user's… 1998; Franzese and Rathi 1997).

The outputs of the microscopic simulation models in TSIS are visualized and analyzed by TRAFVU (TRAF Visualization Utility) that is a graphic post-processor. It provides a graphical presentation of input data, and animates traffic flow and signals on the network analyzed. TRAFVU also displays statistics computed for measures of effectiveness according to simulation outputs (TRAFVU user's… 1997; Koscielny *et al.* 1997).

2. Validation of the proposed delay model for variable demand, time and oversaturated conditions

The proposed model displayed reasonable results for a given traffic condition, but the comparison analysis in Part 1 (Akgüngör 2008) could not represent the model performance when the arrival flow as well as the time profile change since it was an analytical study. Therefore, an experimental study was performed by using TRAF-NETSIM simulation program to calibrate and verify the delay model proposed for variable demand, varying time and oversaturated traffic conditions. In the experimental study, simulation was conducted in three consecutive time periods by designing 48 different scenarios to cover variable traffic and time conditions. Then, the delays simulated by TRAF-NETSIM and the delays estimated by the proposed model were statistically compared using linear regression analysis.

Experimental study and scenario design. Simulated intersection was constructed using interactive traffic network data editor for integrated traffic simulation systems. It consisted of one lane on each approach with the major approaches having the actual flow variations over time. In the experimental study, a mean start-up lost time of 2.0 seconds, a free flow speed of 30 mph (~48 km/sa), a mean discharge headway of 2.0 seconds per vehicle and a lane width of 12 feet (~3.65 m) were used as input values of both the minor and major approaches. The link lengths of the major and the minor approaches were 4000 feet (~1220 m) and 3000 feet (~914 m) respectively. For all simulation runs, traffic on the minor approaches was governed by undersaturated conditions with a degree of saturation 0.5. The intersection was operated at a common cycle length of 90 seconds. The ratio of the minor approach green to major approach green was set at 30/50.

In the validation of the model, the simulation period of 60 minutes was divided into three consecutive time periods to reflect the demand and time variation in the traffic flow. The first period was an initial time period and had duration of 5 minutes with a constant degree of saturation 0.7 for all cases. During this period, the intersection was initialized without transferring a queue to the second period. The second period, which was the actual analysis period, had one of four oversaturated traffic conditions with the degree of saturation ranging between 1.1 and 1.4, and six analysis time periods varying from 5 minutes to 30 minutes. The third and last period was the dissipation period, with degrees of saturation of 0.5 and 0.7. The duration of this period depended on the duration of the second period, as it was necessary to dissipate the queues that had built up over the second period. The combination of these values yielded a total of 48 scenarios to be tested. Each of these scenarios was replicated by changing the random seed numbers. Different random seed numbers yielded different event sequences, and different delay estimates. To account for random traffic arrivals and obtain sound average delay estimates for each scenario, 10 replications were conducted. For these 10 replications, 20 data points were obtained for each scenario because there were 2 major approaches. As a result, this study incorporated a total of 480 TRAF-NETSIM runs and 960 data points for the 48 scenarios.

3. Discussion and comparison of results

As seen from Table 1, depending on duration of analysis period, average simulated delays varied from 45 to 330 sec/veh for the traffic conditions 0.7-O/S-0.5 and from 46 to 348 sec/veh and for the traffic conditions 0.7-O/S-0.7. The analysis of the simulation results indicated that the changes in the degree of saturation during the last period (the dissipation period) had no significant effect on the average delay as long as the arrival flow is less than the capacity in this period. In this study, estimated delays from the proposed model ranged between 47 and 388 sec/veh for both traffic conditions above. According to these results, delays estimated by the proposed model were in close agreement with those simulated by TRAF-NETSIM. For visual comparison, delay values for both flow profiles are tabulated in Table.

The data obtained from simulation results for traffic conditions 0.7-O/S-0.5 and 0.7-O/S-0.7 were grouped for a linear regression analysis. The statistical comparison was conducted using the proposed model as dependent variable and the simulated output as independent variable in the linear regression analysis. The proposed delay

Comparison of total delays produced by the proposed delay model and existing models and the TRAF-NETSIM simulations for the 0.7–O/S–0.5 and 0.7–O/S–0.7 traffic conditions

Analysis time period (min)	Proposed delay model estimates	Australian delay model estimates	Canadian and HCM 2000 delay model estimates	TRAF-NETSIM simulations for the 0.7-O/S-0.5 traffic condition	TRAF-NETSIM simulations for the 0.7-O/S-0.7 traffic condition
			Degree of saturation = 1.1		
5	47.16	46.67	46.22	45.71	46.68
10	65.59	64.28	63.68	60.68	62.14
15	82.55	80.57	79.88	77.54	79.72
20	98.92	96.38	95.63	94.34	96.83
25	115.15	112.13	111.33	111.21	114.24
30	130.97	127.54	126.70	128.05	131.53
			Degree of saturation = 1.2		
5	59.13	59.78	58.30	56.48	58.9
10	91.00	91.24	89.47	86.29	90.19
15	121.77	121.66	119.74	117.25	122.61
20	152.24	151.86	149.85	148.58	155.17
25	182.92	182.31	180.24	179.87	187.95
30	213.14	212.33	210.22	211.44	221.15
			Degree of saturation = 1.3		
5	72.32	73.66	71.60	73.39	77.42
10	118.66	119.75	117.40	120.08	126.23
15	164.01	164.86	162.39	164.63	173.57
20	209.18	209.85	207.31	210.15	222.81
25	254.80	255.31	252.73	254.08	268.93
30	299.83	300.20	297.59	286.04	300.98
			Degree of saturation = 1.4		
5	86.15	87.93	85.51	88.95	97.49
10	147.32	148.90	146.24	157.99	167.39
15	207.45	208.85	206.09	218.12	232.26
20	267.46	268.71	265.90	271.18	290.29
25	328.13	329.26	326.41	307.13	324.89
30	388.05	389.06	386.19	330.80	348.74

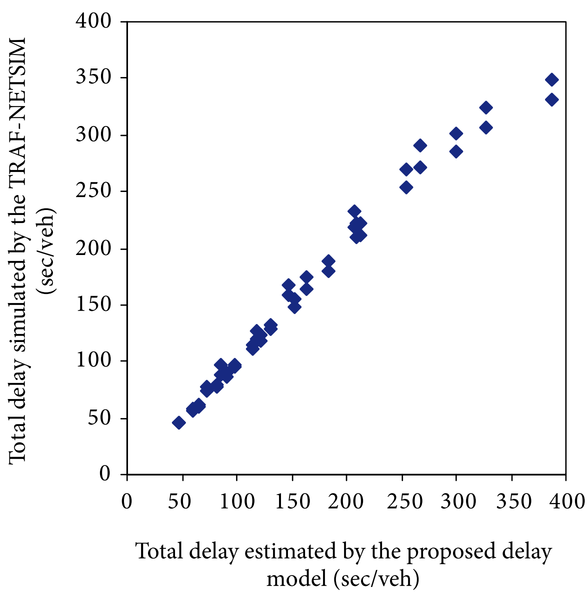
model was analyzed for two different cases, one with a regression constant and the other passing through origin (Equations 1 and 2). For the latter case, the regression equation was forced through zero because the delay by the model should be zero when simulation generates zero delay. The former case was also considered since it presents the actual magnitude of the differences between the dependent and the independent variables without effecting originality of the data. For both cases, the coefficients of determination are over 0.97.

$$d_m = -5.216 + 1.033 d_n, \quad R^2 = 0.979, \qquad (1)$$

$$d_m = 1.0083 d_n, \quad R^2 = 0.979, \qquad (2)$$

where d_m – average total delay of proposed model and d_n – average total delay of TRAF-NETSIM.

As shown in Fig., there is a linear relationship between the proposed model and the simulation model estimates until delay values reach 350 seconds after which a deviation appears. The analysis of the deviated points revealed that they represent the last two scenarios for the traffic condition of 30 minute analysis period and degree of saturation of 1.4. When the deviated points, being ac-



Comparisons of proposed model estimates and TRAF-NETSIM for 0.7-O/S-0.5 and 0.7-O/S-0.7

cepted as outliers, were taken out, an improvement in regression models was obtained (Equations 3 and 4).

$$d_m = 1.185 + 0.980 d_n, \quad R^2 = 0.989, \tag{3}$$

$$d_m = 0.986 d_n, \quad R^2 = 0.989, \tag{4}$$

in which d_m – average total delay of proposed model and d_n – average total delay of TRAF-NETSIM.

These results indicate that delays estimated by the proposed model and delays estimated by the simulation model are in agreement. Consequently, the proposed model can be used as a reliable tool to estimate delays at signalized intersection for varying flow and time conditions.

Although traffic simulations are useful tools to represent the traffic characteristics in real life, there can be some differences between simulation results and real life observations. Therefore, field data should be used to test the validation of a model. However, obtaining field data for 48 different scenarios used in this study would be a timely process since, for every scenario, some of the traffic characteristics should be kept constant. Meanwhile, field study to obtain data for some of scenarios has been started. When the field study is completed, the comparison of field data and simulation data as well as the model performance will be presented in future studies.

4. Conclusions and suggestions

The use of a time-dependent variable delay parameter would be more meaningful and realistic for delay estimation instead of a constant delay parameter. According to simulation results used in modeling of delay parameter k when the analysis period T is getting longer, the delay parameter also increases. In the regression analysis, delay estimations of the proposed model and the simulation model are close to each other (R^2 = 0.989 at 95 % confidence level). As long as the saturation level is less than the capacity, the changes in the degree of saturation during the last period (i.e. the dissipation period) had no significant effect on the average delay. Finally, the simulation results and regression analysis illustrated that the proposed model can be used as a reliable tool for delay estimations at signalized intersections for varying time periods as an alternative model.

Since analysis period effect on delay is more obvious in oversaturated traffic conditions, unsaturated delay conditions are not considered in validation section of this study. To test the effectiveness of model as a whole, unsaturated traffic conditions should be investigated in future studies. The delay models in this research were developed for fixed time traffic signals. Further studies should be performed for vehicle actuated signal controls. Finally, future research associated with more field data could better specify the performance of the delay model developed in the research.

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