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Traffic Flow Model Validation and Simulation - A Case Study†

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***Abstract*:** This paper presents a case study of the traffic flow modeling and simulation on a 4.26-km Minnesota State Highway 194 corridor; one of the most heavily traveled and congested roadways in the city of Duluth, Minnesota, USA. The study is to examine the feasibility of applying an existing traffic flow model developed for freeways to local highways for traffic flow estimation. Problems relating to the shorter length of the road segments between signalized intersections and the slower data sampling rate of the traffic detector are overcome by properly modifying the existing model. Based on the data collected from the traffic detector during the PM rush hours, the traffic flow model is calibrated through a model parameter identification process. The procedure is formulated as a minimization problem that is solved by nonlinear programming. The results clearly indicate the applicability of the calibrated model to the corridor with acceptably small estimation error. Using the model calibrated, the simulation system is further developed, integrated, and implemented. The real-time simulation results are then presented. Discussion together with possible improvements is also given. The main purpose of this study is to provide a better understanding of the traffic behavior on the corridor and, thus, to provide for better traffic management by developing an area wide traffic signal timing control strategy to improve the traffic movements in that area.

Keywords: *traffic flow; macroscopic model; parameter identification; least squares minimization; simulation.*

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I. Introduction

The growth of the number of automobiles on the highways has put a higher demand on the traffic control system to efficiently reduce congestion which causes travel delay, fuel consumption, and air pollution. The study of traffic flow and efficient management on roads and freeways is one of the most challenging problems in the transportation area. The availability of adequate mathematical models describing traffic flow phenomena is a prerequisite for application of control theory to various traffic control problems. Generally speaking, mathematical modeling of traffic flow can be classified as microscopic modeling and macroscopic modeling. Microscopic models (or vehicle- flowing models) describe the behavior of each vehicle in a traffic flow in terms of the vehicle immediately ahead. They have been used in longitudinal and lateral vehicle control of individual vehicle (e.g., **1-4**). Macroscopic models describe the traffic stream as a flow and express it in terms of the quantities such as traffic density, volume, and vehicle's mean speed. The analogy between traffic flow and fluid flow formed the basis for the first traffic flow model proposed by Light hill and Whitham (**5**). However, due to certain limitations in describing traffic flow (e.g., traffic phenomena such as congestion, stop-and-go traffic, etc.), various and extended models were suggested by many other researchers (**6-9**). For example, a more sophisticated model was proposed by Papageorgiou (**7, 8**) and has been tested and validated using real traffic data. In general, mathematical modeling of traffic flow results in a nonlinear dynamic system. The nonlinear and complicated characteristics of flow dynamics makes it difficult to have a universal traffic flow model that applies to all traffic situations at all times.

In this paper, we present a case study of the traffic flow modeling and simulation along a 4.26-km road stretch of Minnesota State Highway 194 in the city of Duluth, Minnesota. This arterial is recognized as one of the most heavily traveled and congested roadways in the area. Recurrent heavy traffic flow occurs in both eastbound and westbound directions along the corridor most of the day. The ability to better understand traffic in that area will provide for better traffic management. In this study, we use one of the macroscopic models proposed by M. Papageorgiou (**8**) as a basis to examine the PM rush hours traffic flow behavior. Along this HW 196 corridor between Arlington Avenue and Haines Road, there are nine signalized intersections with speed limits either 48 km/hour or 64 km/hour (i.e., 30 and 40 miles/hour). However, we found that due to the short distance between intersections, the study of directly using the Papageorgiou's model poses a potential problem because this model was developed for freeways. It is interesting to see how the model should be modified and properly calibrated to describe and estimate the actual traffic flow occurring on the corridor. In section II, we introduce the Papageorgiou's traffic flow model and its modifications together with the traffic data we collected. The data were collected using an RTMS (Remote Traffic Microwave Sensor) traffic detector manufactured by Electronic Integrated Systems (EIS) in Toronto, Canada. Based on the modified model, in section III the identification of model parameter values is formulated as a least squares minimization problem, which is then solved by a nonlinear programming method in the *Matlab*[‡] environment. The approach uses iterative comparison of model behavior with real traffic data on the corridor. The results including the time responses of both the eastbound and westbound

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[‡]*Matlab* is a registered trademark of The Math Works, Inc.

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traffic generated by the model are presented. Based on the calibrated model and data base/interfacing system, section IV briefly describes the traffic simulation system developed and the real-time traffic simulation findings are then followed. The possible improvements of the simulation results are also suggested. Finally, section V gives the conclusion. The purpose of this study is to provide a better understanding of the traffic behavior on the corridor, and the ultimate goal is to develop an effective traffic signal timing control strategy to provide more efficient traffic movements in that area.

II. Traffic Flow Model and Data

In this section, we first describe the Papageorgiou's traffic flow model "D" (**8**). The traffic data collection is then followed. Finally, we give the model modifications.

Traffic Flow Model

A macroscopic description of traffic flow implies the definition of adequate flow variables expressing the average behavior of the vehicles at a specific location and time instant. The macroscopic view of traffic flow is based on a hydrodynamic analogy. This point of view is more concerned with the overall average behavior of traffic than with the interactions between individual vehicles. In this section, we briefly present the traffic flow model, i.e., Papageorgiou's model "D", to be used as a basis in our study. For details about this model, please refer to(**8**).

Consider a single highway lane which is subdivided into N segments with lengths L_i, i =1, 2 …, N and each segment has at most one on-ramp and one off-ramp. Let T be a fixed time interval and k the time index (i.e., k = 0, 1, 2, …). We define the following variables for each segment:

$c_j(k)$: traffic density in segment j at time kT (vehicles/km)
$v_j(k)$: mean speed of vehicles within segment j at time kT (km/hr)
$q_j(k)$: traffic volume leaving segment j, entering segment j+1 at time kT(vehicles/hr) (i.e., the number of vehicles which pass from segment j to segment j+1 during the time interval kT and (k+1)T divided byT)
$r_j(k)$: on-ramp traffic volume for segment j (vehicles/hr) $s_j(k)$: off-ramp traffic volume for segment j (vehicles/hr)

Then, the space- and time-discretized traffic flow model can be written as follows:

$$c_j(k+1) = c_j(k) +(T/L_j)[q_{j-1}(k)-q_j(k)+r_j(k)-s_j(k)] \quad (1)$$

$$v_j(k+1) = v_j(k) + (T/\tau) [V(c_j(k))-v_j(k)]+(T/L_j) [v_j(k)(v_{j-1}(k)-v_j(k))sat(c_{j-1}(k)/c_j(k))] + (\nu /L_j)(T/\tau)[(c_j(k)-c_{j+1}(k))/(c_j(k)+\kappa)] \quad (2)$$

$$q_j(k) = \alpha c_j(k)v_j(k) + (1-\alpha)c_{j+1}(k)v_{j+1}(k) \quad (3)$$

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$$V(c_j(k)) = V_f[1-(c_j(k)/c_{max})^l]^m \quad (4)$$

where V_f is the free speed at zero density, c_{max} is the jam density (i.e., the maximum possible density), α ($0 \leq \alpha \leq 1$) is the weighting factor (i.e., a factor that determines to what extent the volume depends on the current segment j or the next segment j+1), and l and m are positive real numbers.

The model equations given above contain eight parameters, i.e., V_f, c_{max}, l, m, α, ν, κ, and τ, which need to be identified by the calibration of the model using traffic data. Note that the mean speed $v_j(k+1)$ in Eq. (2) is influenced by three terms, a relaxation term, a convection term, and an anticipation term. The relaxation term (i.e., the first bracket term) accounts for the evolution of the mean speed $v_j(k)$ toward its density independent equilibrium speed $V(c_j(k))$; the convection term, the second bracket term, represents the influence of the incoming traffic on the mean speed evolution in segment j (i.e., the propagation of a speed difference into segment j); and the anticipation term, the third bracket term, reflects the driver's anticipation to a foreseen relative density change which is weighted by a sensitivity factor ν. The parameter κ takes into account that this effect becomes negligible for low-density values.

We use the traffic model shown above with some necessary modifications to perform the traffic flow study on the Highway 194 corridor. The 4.26-km road stretch, shown in Fig. 1, contains eight road segments with two signalized intersections at both ends of each road segment. We divide these eight consecutive segments into six road sections with each section containing three consecutive segments. The road segments are labeled from east to west (i.e., from Arlington Avenue to Haines Road) in a sequential order and the same labeling also used for the road sections. That is, the road section i contains the segments i, i+1, and i+2, for i=1, 2, …,6. The segment lengths on this corridor are: L_1= 0.24 km, L_2= 0.64 km, L_3= 0.4 km, L_4= 0.4 km, L_5= 0.97 km, L_6= 0.32 km, L_7=0.32km, and L_8= 0.97 km. The speed limit on road segments L1– L3 is 48 km/hour (or 30 miles/hour) and the rest is 64 km/hour (or 40 miles/hour).

Traffic Data

The traffic data (i.e., volume and average speed) were collected using an RTMS Model X2 detector side-fired mounted to an existing pole and a road sign structure, roughly in the middle of two consecutive intersections. Figure 2 shows a detector mounted on an extension structure close to Cottonwood Avenue. The RTMS is a general-purpose traffic detector which uses microwaves with 3-cm wavelength to detect presence, volume, occupancy, speed, and classification information. The detector transmits a microwave beam and receives energy reflected by objects (targets) in its path, and the nominal frequency of 10.525 GHz is varied continually in a 45 MHz band (**9**). A single side-fired RTMS, installed on the side of the road pole, can cover up to 8 individual lanes (range 3 m to 60 m). In general, the detector is positioned about 5 m above ground with 6 m setback from the first traffic lane, and its field of view covers the area defined by: elevation angle 45^o and azimuth 15^o. The required minimum setback depends on the number of lanes to be covered. We used two DC batteries with total 24 volts to power the detector. The data were collected every 3 minutes and downloaded to a laptop PC once a week. The time periods for which data were recorded during the year of 2001 are given in Table 1.

The EIS supplied RTMS Data Analyst Program is used to perform analysis and filtering based on the data recorded by the RTCP (Remote Traffic Counting Package) traffic counting system (**10**). A typical weekly's data (i.e., volume and average speed) recorded in segments 8 and 1 are shown in Fig. 3 and Fig. 4, respectively. We found that the data at other locations show a very similar pattern. For smoothness, data from different days during the same hours were averaged. Note that when the data were averaged, care was taken so that the data came from those days showing consistent and similar patterns. Data collected during weekends and holidays are excluded due to the possibility of abnormally high or low traffic volume occurred during that periods. We conducted normal weekday traffic flow study over the time period 2:30 pm - 7:00 pm which includes the evening rush hours. The weekly data collected were compiled into two sets of data for each road segment. The first set is for eastbound traffic (i.e., inbound traffic - two lanes of traffic headed into the city) and the second is for westbound traffic (i.e., outbound traffic - two lanes of traffic leaving thecity).

Model Modifications

Our preliminary study indicates that the model equations, i.e., Eqs. (1)-(4), didn't perform well in our case. There are two possible causes for this. The first is that the model was developed for a two-lane freeway with segment length much longer, while the arterial we studied has four lanes with relatively shorter segment length. Another possible cause is due to the data sampling time. The RTMS detector collects data every 3 minutes (i.e., T = 3 min in Eqs. (1) and (2)) and according to (**7, 8**), a segment of comparable length to ours, for example, should have a sampling time of approximately 10 seconds. However, due to the limited memory size of the traffic detector and the frequency of data downloading, we decided to keep T unchanged. The traffic flow model in section 2.1 was slightly modified by eliminating the saturation term (i.e., sat(.)) in Eq. (2) and letting $\alpha = 1$ in Eq. (3). This is based on our field observation that the traffic density and vehicles' mean speed of the next road segment have less impact on that of the current road segment.

III. Model Validation and Results

In this section, we identify the model parameter values by solving a least squares nonlinear minimization problem. The results generated from the calibrated model are presented followed by discussion.

Parameter Identification

Based on the traffic data, we identify the model parameter values that give the best coincidence between the model and the real process. Note that the output performance is measured in terms of traffic volume (q) only although the model equations Eqs. (1)-(4) are implemented in the estimation of traffic flow. The measured data at both ends of the section are treated as system inputs and the system output is taken from a third location insidethe section (**7, 8**). For instance, the inputs of the section 1 include q_1(i.e., the traffic volume in segment 1 between Arlington Avenue and Basswood Avenue) and q_3 (i.e., the traffic volume in segment 3 between Anderson Road and Mall Entrance), and the system output is the predicted traffic volume $q_2$in segment 2 between Basswood Avenue and Anderson Road. The same notations are used in the rest of five road sections.

Consider the road section i (i = 1, 2, …,6) which includes segments i, i+1 and i+2. Let us define the vector of the unknown model parameters in this road section as $\beta = [V_f, c_{max}, l, m, \kappa, \tau, \nu]$ and $\{\hat{y}(k), k = 1, 2, \ldots\}$ be the time sequence of the measured data from the traffic detector. Note that $\hat{y}$ includes the measured traffic volumes at the three road segments. Then the parameter identification problem can be formulated as the following least squares error problem

$$\min I(\beta) = \min \sum_k [(\text{measured data at segment 2}) - (\text{model-based, calculated data atsegment2})]^2 \quad (5)$$

That is, given the time sequences of the traffic volumes at both ends of the road section (i.e., segment i and i+2), we try to predict the traffic volume in the middle segment of the section (i.e., segment i+1) so that the predicted data are as close to the actual data as possible.

Since no direct derivative of the performance index I(β) with respect to β is available, optimization algorithms that use gradients cannot be applied. Therefore, we use a simplex search algorithm (e.g., **11, 12**, **13**) and the following pseudo code performs the implementation

```
Initialize β
While (the error can be further improved) {
Apply model using current β and traffic data in segments 1 and 3
Calculate error using segment 2 data
Update a new β}
```

The above process is repeated until a set of parameters is achieved that results in the least possible error. The model equations were implemented in *Matlab* programming language and we solved the above minimization problem using the *Matlab's* Optimization Toolbox (**13**).

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Base on the collected data and the modified model equations, we performed the model parameter identification in both eastbound and westbound directions for all six road sections. The minimization was carried out with the initial set of model parameter values chosen as V_f= 48 km/hour, c_{max}= 200 veh/km, l = 4.0, m = 1.4, κ = 20 veh/km, τ = 0.01 hour, and ν = 21.6 km^2/hour. This initial set of parameter values, except V_f, was directly takenfrom (**7**), which was used for a one-way, two-lane freeway. Since very similar performance found in all six road sections, in the following, only the results from the first two are presented. The sets of the parameter values we found are:

Road section 1 (Arlington Avenue – Mall Entrance at Cub Foods/Home Depot)

Parameter	V_f	c_{max}	l	m	κ	τ	ν
Eastbound	35.3960	108.492	4.6653	0.9092	44.2999	0.0030	31.5033
Westbound	77.5502	178.512	0.3134	0.8447	25.7344	0.0017	31.3955

Road section 2 (Basswood Road - Trinity Road)

Parameter	V_f	c_{max}	l	m	κ	τ	ν
Eastbound	68.1876	286.691	0.5686	2.4434	13.3906	0.0024	26.3713
Westbound	27.0392	131.692	4.7196	1.0323	15.3366	0.0028	33.5637

Note that the road section 1 includes three segments; Arlington Avenue-Basswood Avenue, Basswood Avenue-Anderson Road, Anderson Road-Mall Entrance at Cub Foods/Home Depot; and the section 2 covers Basswood Avenue-Anderson Road, Anderson Road-Mall Entrance at Cub Foods/Home Depot, Mall Entrance-Trinity Road (please refer to Fig. 1). The observation period was from 2:30 pm to 7:00 pm. The sampling period T was chosen to be 3 minutes which means that each simulation run over the given time period contained 90 data points (i.e., k = 90 in (5)).

Results and Discussions

Note that the calibrated model uses data from two end segments to predict traffic in the middle segment. The time response of the eastbound traffic between Basswood Avenue and Anderson Road (i.e., the road section 1), generated by the calibrated model, is given in Fig. 5 together with the measured sequence of the real traffic process. The corresponding westbound traffic in the same segment is shown in Fig. 6. In Fig. 5, we found that the maximum error in the eastbound direction is about 15 vehicles, which occurred around 6:20 pm. This is good considering that the data are taken over a 3- minute period and cover two lanes of traffic. In other words, the calibrated model is basically off by two or three vehicles per lane per minute, at its worst. We found very similar performance in the westbound direction. For example, from Fig. 6 we can see that the maximum error is also about 15 vehicles which occurred around 4:10 pm. Note that the outbound traffic is much heavier than the inbound traffic during the afternoon between 2:30 and 6:00 pm. The opposite was observed in the morning time period. From Fig. 5, we also see that the model performance becomes worse as the traffic volume drops in the late evening time. High traffic volume situation seems to produce better results.

Similarly, the time response of the eastbound and westbound traffic between Anderson Road and Mall Entrance at Cub Foods (i.e., the road section 2) is shown in Fig. 7 and Fig. 8, respectively. After comparing these figures, it is clear that the worst case occurred in the estimation of the eastbound traffic. In Fig. 7, the maximum error is about 17 vehicles, which occurred around 5:40 pm; again, it is an acceptable error (i.e., about three vehicles per lane per minute) given the average volume of 20-25 vehicles per minute during the time period considered. The model generates a very good estimation of traffic flow in the westbound direction as can be seen from Fig. 8, where the maximum error is only seven vehicles which occurred at about 6:50 pm.

Overall, the modified and calibrated model has a maximum error of 15 vehicles per three- minute period in each direction for the four-lane highway considered. This corresponds to an error of approximately two or three

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vehicles per minute in each lane, acceptably small when compared to the total volume of 20-25 vehicles per minute during the time period considered. The results clearly show the applicability of our calibrated model. While it accounts for the differences between Highway 194 and an open freeway, the calibrated model still retains the core logical concepts of the original one.

IV. Traffic Simulation

The calibrated models on the corridor are used in our real-time traffic simulation study. In this section, we briefly describe our simulation system structure and then present the simulation results. Discussion and possible improvements are also given.

Simulation System Architecture

The simulation system architecture basically consists of three parts. The first part is the traffic detector. The detector takes the volume counts and measurements of vehicles' mean speed and store them in its memory for three minutes. We access the data directly from the sensor via the data-interfacing program. The second part is the data base system, which stores the previously recorded data on the corridor. The recorded data to be used is for two road segments prior to and following the road segment that the current data is being collected. The third part is a computer program, which includes the calibrated traffic flow models and data interfacing/handling system. This program interfaces directly to the RTMS detector, loads the values from the past collected data and queries the detector every three minutes to be in synchronous with the previously collected data. Using the current time values for these three road segments, the volumes for the next time segment can be calculated. In other words, the computer program itself has two parts. The first part is the interface with the RTMS, which is provided by the EIS. The second part of the program implements the calibrated models (one for each road section). The necessary modifications include having the program contact the detector every three minutes to retrieve data, retrieving data from the previous data section files, and performing two mathematical calculations (using all the retrieved data). One calculation is to find vehicles' mean speed and the second is to find the traffic density. The results of these calculations are used to find the volume of the current road segment in the next time interval.

Simulation Results

We performed on-site real-time traffic simulation using a laptop computer for all six road sections. The duration time for each simulation run was one hour. Again, only the results from first two sections are presented here. The simulation was conducted between 2:30- 3:30 pm on July 12, 2002 (road section 1) and July 5, 2002 (road section 2). Note that the day of the week and the time that the simulation was run matched the day of the week and time of the old data that was used. For each section, based on the three corresponding sets of traffic data (i.e., two sets of recorded data plus one set of real-time data) and traffic flow models, the computer program then calculated the traffic volume and mean speed for the next time interval in the selected intersection. These predicted values were compared instantly to the actual values (i.e., real-time data) from the traffic detector for eastbound, westbound, and total traffic flows for that road section.

The simulation results are summarized in Figs. 9 and 10. In these figures, the dark blue line represents the predicted traffic volumes while the light pink line represents the actual volumes collected. Each figure gives the simulation performed at a certain road section (indicated in total traffic volume in both eastbound and westbound directions). For example, the figure labeled "Section 2 – Total" (i.e., Fig. 10) shows the predicted and actual traffic on Highway 194 between Anderson Road and Mall Entrance at Cub Foods/Home Depot. The predicted traffic volume was calculated based on the following:(i) past data collected between Basswood Avenue and Anderson Road, and between Mall Entrance at Cub Foods/Home Depot and Trinity Road, (ii) real-time data from the traffic detector located between Anderson Road and Mall Entrance at Cub Foods/Home Depot at the time the simulation was performed, and (iii) traffic flow model associated with the corresponding road segments and their parameter values identified in the previous section. This also applies to the first road section. Instead of showing the total traffic in both directions at the given segment, both eastbound and westbound traffic prediction can also be shown separately.

Discussion and Possible Improvements

From the figures, we found that the maximum error is about six to fourteen vehicles per minute per direction.

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Overall speaking, the predicted traffic seems to overestimate the actual traffic volume. Note that even though there is a substantial error in the comparison of volumes of these two series of data, the pattern of the predicted volumes still resemble the pattern of the actual volumes delayed by three minutes. The phenomenon of this delay is evident in these two figures. In other words, although the simulation results seem quite different, they show a similar pattern. That is, the predicted values, no matter how far off from the actual values, mimic the pattern of the actual values, just delayed by three minutes. This delay is due to the fact that the computer program tries to predict the traffic volume in the next time interval by using the data in the previous one. The "real-time" data we received is actually the data from the RTMS three-minute ago, this is because the sensor delivers the data every three minutes. As a result, the predicted volumes will mimic the pattern of the actual volumes that occurred in the previous three-minute interval. Apparently, if traffic is more erratic, the program will be less effective in accurately predicting traffic volumes.

The larger error may be due to a number of reasons. First, old data was used instead of real-time data for the surrounding road segments. This was probably the largest contribution to the error. Secondly, the sample traffic data collection, which the model parameter identification work was conducted, is based on the assumption that the traffic pattern during typical working days should be consistent. However, we know that this may not always be true. Even though the day of the week and time matched, the time of the year that the old data was collected did not match the time of the year that the real- time simulation occurred. Different times of the year could produce different traffic flow. This would be enough to skew the results of the simulation. Therefore, a sense of a real- time simulation was performed, but the only data that was truly real-time was the selected intersection.

The simulation results can be greatly improved if the real-time data at neighboring road segments can be obtained. This means that we need to use three RTMS detectors instead of one when perform the real-time simulation study. In other words, we believe that simulation results can be greatly improved if multiple traffic detectors are used. In addition, the current sampling time (i.e., T = 3 minutes) of the traffic detector should also be reduced so that the data can more accurately represent the real-time data when the traffic becomes heavier. One way to counteract the effect of the sampling time T is to shift the predicted traffic volume at the current time by T minutes (i.e., time-advance). The results can also be improved if extensive simulations over a longer period of time can be performed.

V. Conclusion

This paper presents a traffic flow modeling and simulation study on a section of Minnesota State Highway 194 between Arlington Avenue and Haines Road, one of the most heavily traveled and congested roadways in the Duluth area. Problems relating to the short length of the road segments and the long sampling time (due to the traffic detector) are overcome by modifying the Papageorgiou's model D. While it accounts for the differences between the state highway and an open freeway, the calibrated model still retains the core logical concepts of the original one. The model uses data from two end segments to predict traffic in the middle segment. We found that the modified and calibrated model has a maximum error of about 15-20 vehicles per three-minute period in each direction for the four-lane highway considered. This corresponds to an error of approximately three vehicles per minute in each lane, acceptably small when compared to the total volume of 20-25 vehicles per minute during the time period considered. The results clearly show the applicability of our calibrated model. Next, the traffic simulation system architecture is briefly described and then followed by the simulation results. The traffic simulation was conducted during the PM rush hours. Both the past data and real- time data were used in this simulation study. The results indicate that the real-time simulation should be useful in approximating traffic volume statistics at the signalized intersections if its results are delayed by three minutes. That is, the data collection sampling time used by the RTMS traffic detector. Several possible ways to further improve the results are also discussed. The ultimate goal of this traffic flow modeling and simulation study is to develop an efficient traffic signal timing control plan (i.e., optimal split times and offsets) to improve the traffic flow in the area we studied

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References

[1.] S. E. Shladover, Automatic vehicle control development in the PATH program, *IEEE Trans. Vehicular Technology*, 40(1), 1991,114-130.

[2.] J. K. Hedrick, M. Tomizuka, and P. Varaiya, Control issues in automatic highway systems, *IEEE Control Systems Magazine*, December issue, 1994,21-32.

[3.] H. Raza and P. Ioannou, Vehicle following control design for automated highway systems, *IEEE Control Systems Magazine*, December issue, 1996,43-60.

[4.] P. Ioannou, *Automated Highway Systems,* Plenum Press, New York, NY,1997.

[5.] J. J. Lighthill and G. B. Witham, On kinematic waves II: a theory of traffic flow on long crowded roads, *Proc. of the Royal Society of London, Series A*, 229(1178), 1955, 317-345.

[6.] H. J. Payne, Models of freeway traffic and control, *Mathematical Models of Public Systems, Simulation Council Proceedings*, 1, 1971,51-61.

[7.] M.CremerandM.Papageorgiou,Parameteridentificationforatrafficflowmodel,
[8.] *Automatica*, 17(6), 1981, 837-843.

[9.] M. Papageorgiou, *Applications of automatic control concepts to traffic flow modeling and control,* Springer-Verlag, New York, NY,1983.

[10.] Electronic Integrated Systems, *RTMS User Manual*, *Issue 2.1,* EIS, Inc., Toronto, Canada, March2000.

[11.] Electronic Integrated Systems, *RTCP User Manual,* EIS, Inc., Toronto, Canada, March1999.

[12.] D. G. Luenberger, *Introduction to Linear and Nonlinear Programming,* Addison Wesley, Reading, MA,1973.

[13.] J. C. Lagarias, J. A. Reeds, M. H. Wright, and P. E. Wright, Convergence properties of the Nelder-Mead simplex method in low dimensions, *SIAM Journal of Optimization*, 9(1), 1998,112-147.

[14.] *Matlab Optimization Toolbox User's Guide*, Version 2, The MathWorks, Inc., Natick, MA,2000.

[15.] C.-C. Chien, Y. Zhang, and P. A. Ioannou, Traffic density control for automated highway systems, *Automatica*, 33(7), 1997,1273-1285.

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Road Segment	Data Recorded
Segment 1: Arlington Avenue - Basswood Road	Oct. 28-Nov. 8; Nov. 14-19; Nov. 25-29
Segment 2: Basswood Road - Anderson Road	April 10-13; April 17-23; May 1-21
Segment 3: Anderson Road - Mall Entrance	May 21-27; May 29-June 9; June 11-14
Segment 4: Mall Entrance - Trinity Road	June 21-July 20
Segment 5: Trinity Road – Cottonwood Avenue	Nov. 30-Dec. 1; Dec. 11-17; Feb. 7-9 □
Segment 6: Cottonwood Avenue – J. C. Penny's Mall Entrance	July 20-Aug. 8
Segment 7: J. C. Penny's Mall Entrance – Maple Grove Road	Aug. 8-Aug. 24
Segment 8: Maple Grove Road – Haines Road	Aug. 29-Sept. 28; Oct. 4-Oct. 11

Table 1 Time periods for which the data were recorded.

□Due to unexpected road construction delay in segment 5, part of the data at this location were collected in February 2002.

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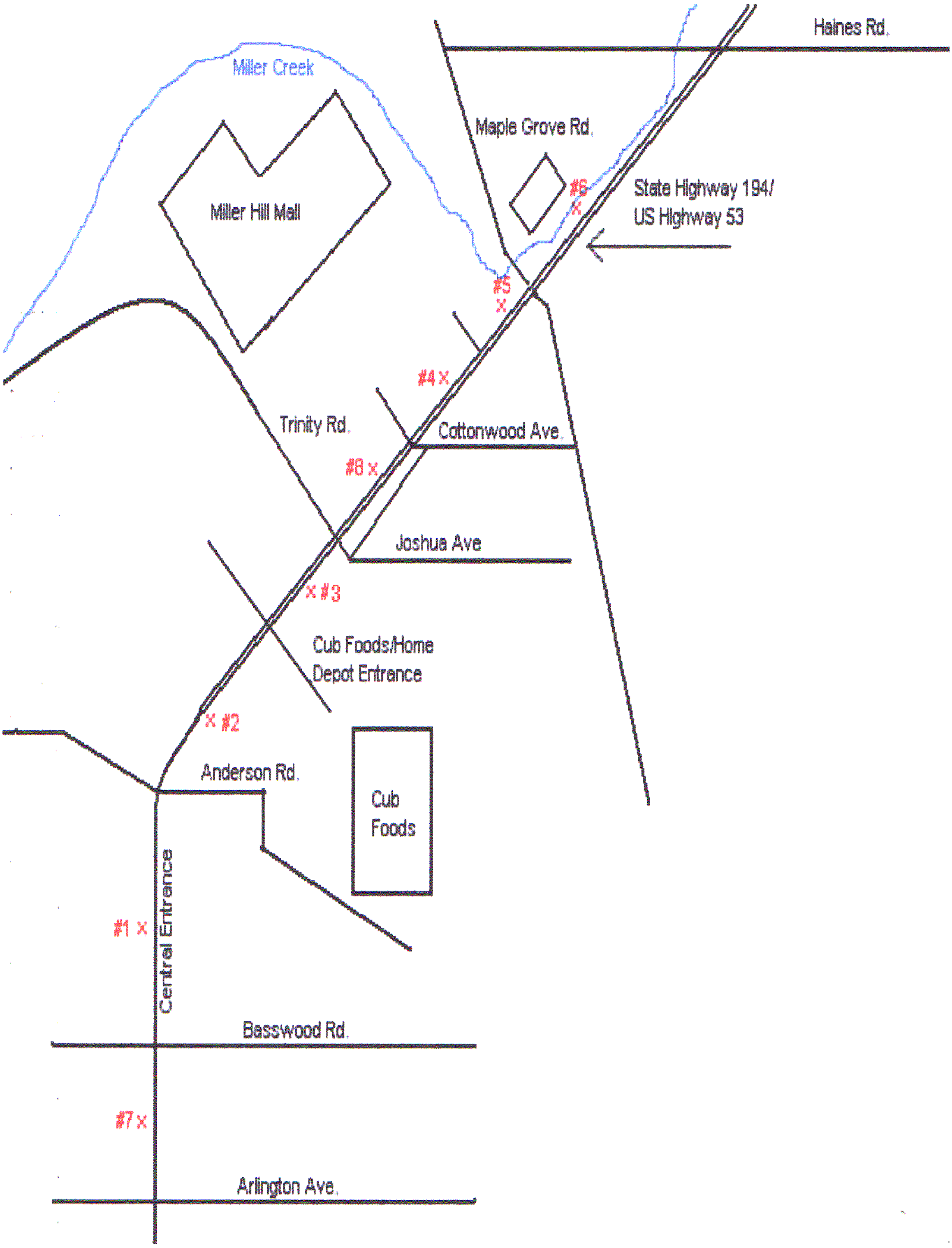

Fig.1 Area map showing the locations (marked in red “x”) where data was collected.

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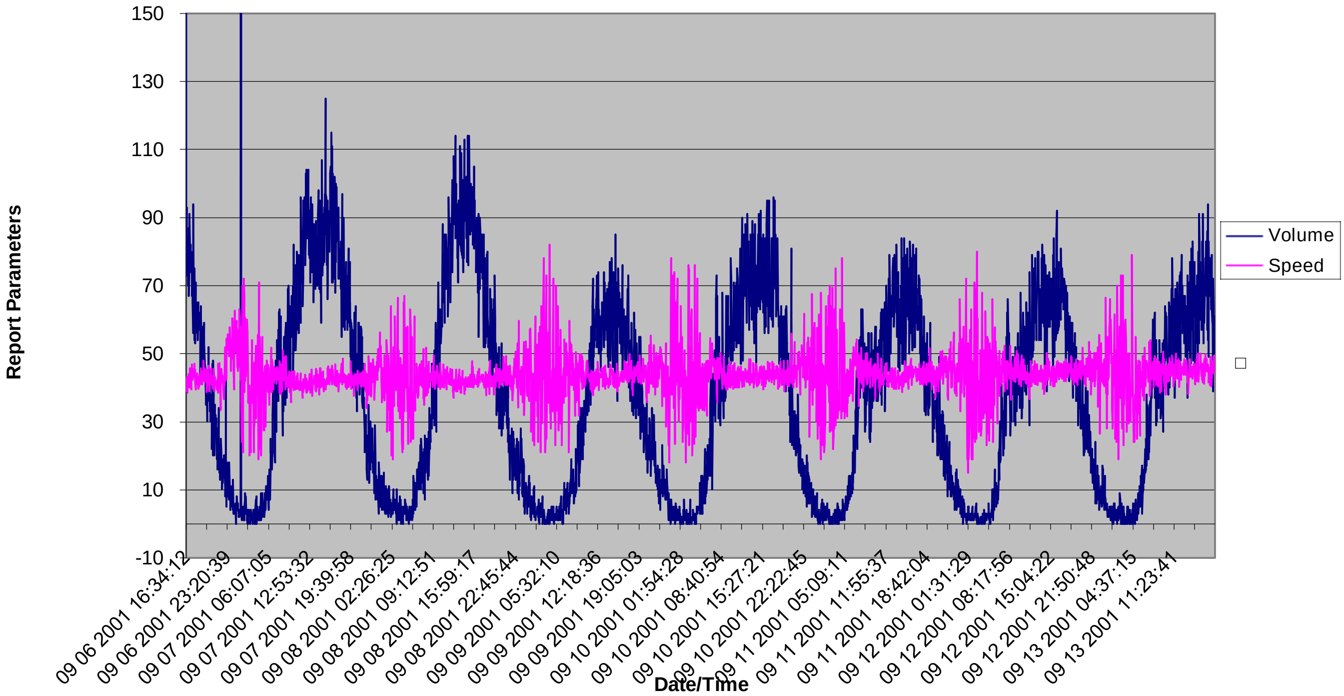
Fig. 2 The side-fired mounted RTMS detector at location # 4 close to Cottonwood Avenue.



(Station ID: 6, Active Zones: 11110000, Filtered Slice(sec): 170[original])

Fig. 3. A sample of the traffic data collected in road segment # 8 (Maple Grove Road- Haines Road).

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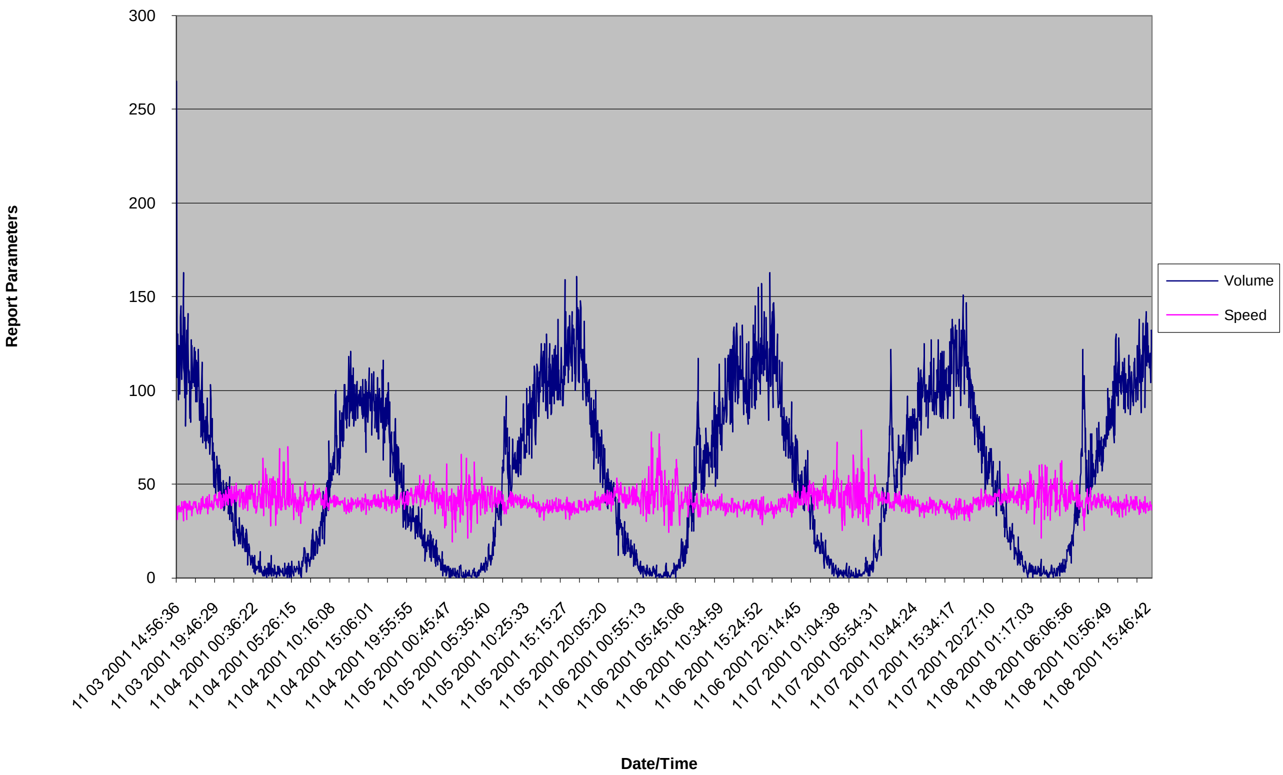

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Fig. 4 A sample of the traffic data collected in road segment # 1 (Arlington Avenue- Basswood Road).

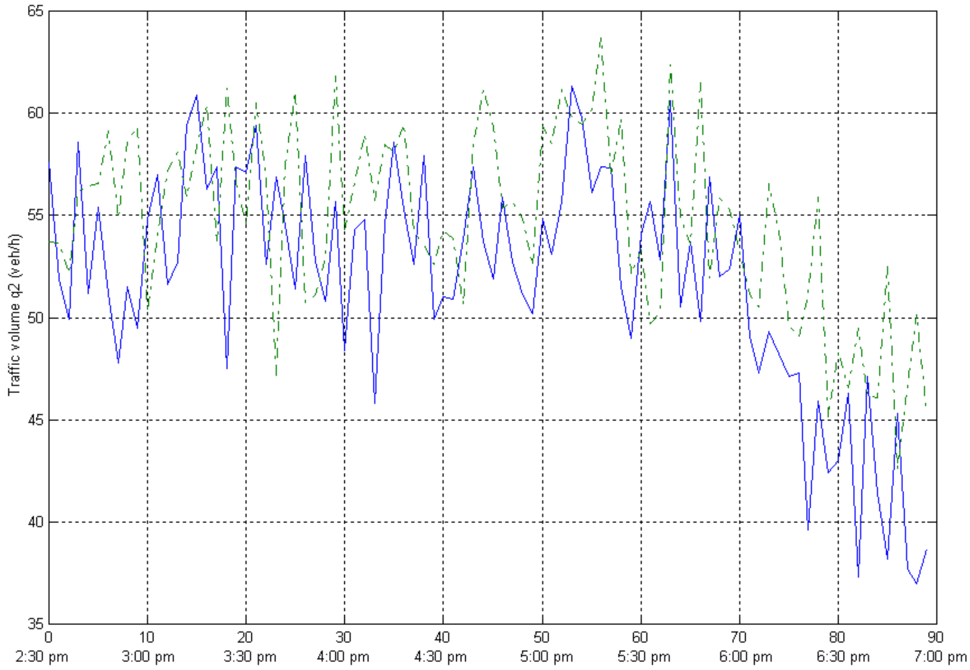

Fig. 5 Time response of the eastbound traffic between Basswood Avenue and Anderson Road. (blue solid line – data from RTMS; green dotted line – calibratedmodel)

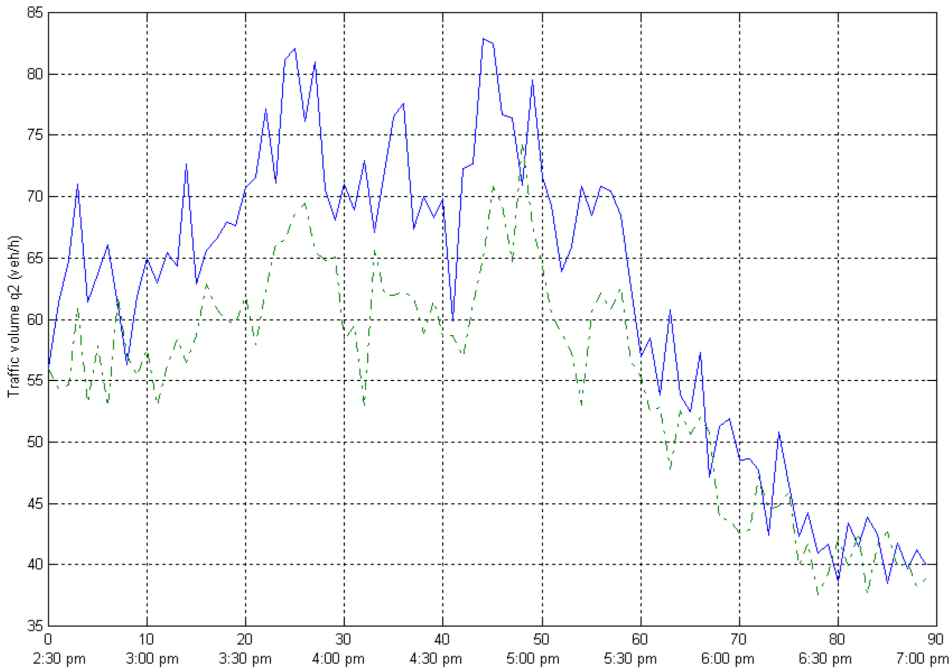

Fig. 6 Time response of the westbound traffic between Basswood Avenue and Anderson Road. (blue solid line – data from RTMS; green dotted line – calibratedmodel)

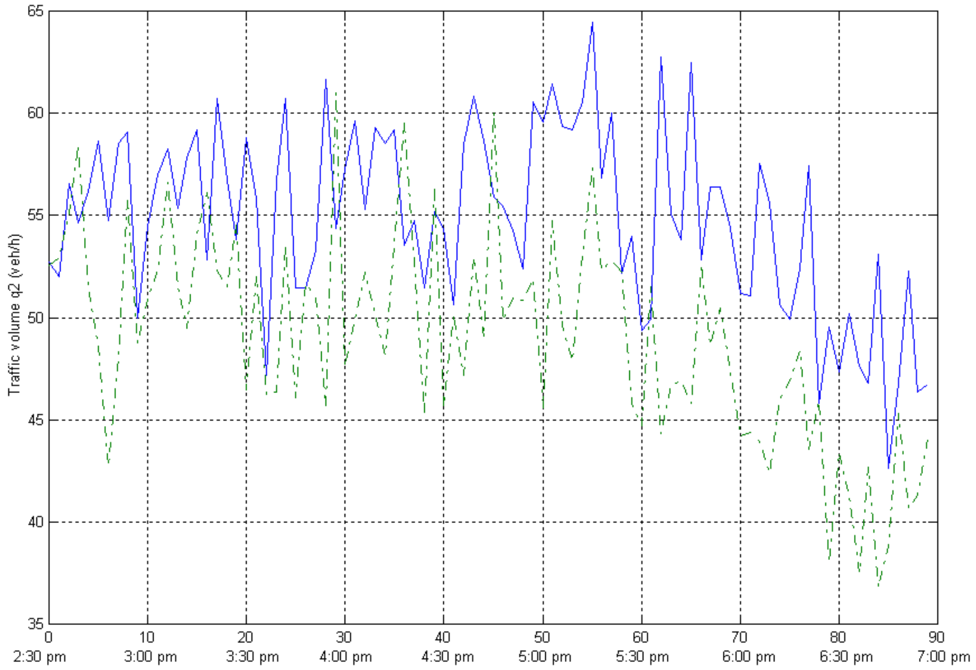

Fig. 7 Time response of the eastbound traffic between Anderson Road and Mall Entrance at Cub Foods. (blue solid line – data from RTMS; green dotted line – calibratedmodel)

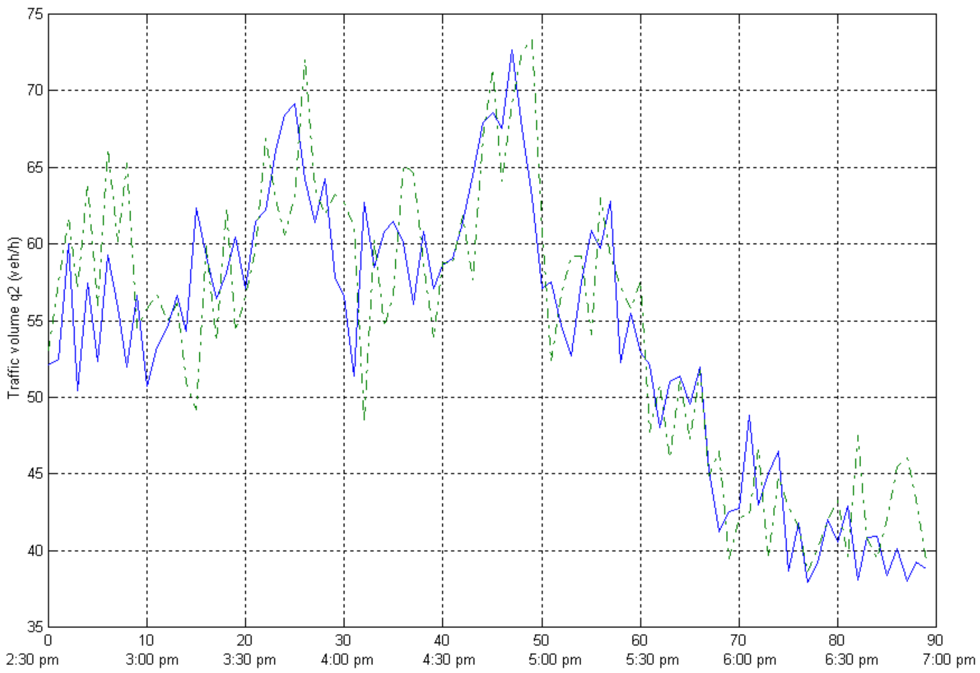

Fig. 8 Time response of the westbound traffic between Anderson Road and Mall Entrance at Cub Foods. (blue solid line – data from RTMS; green dotted line – calibrated model)

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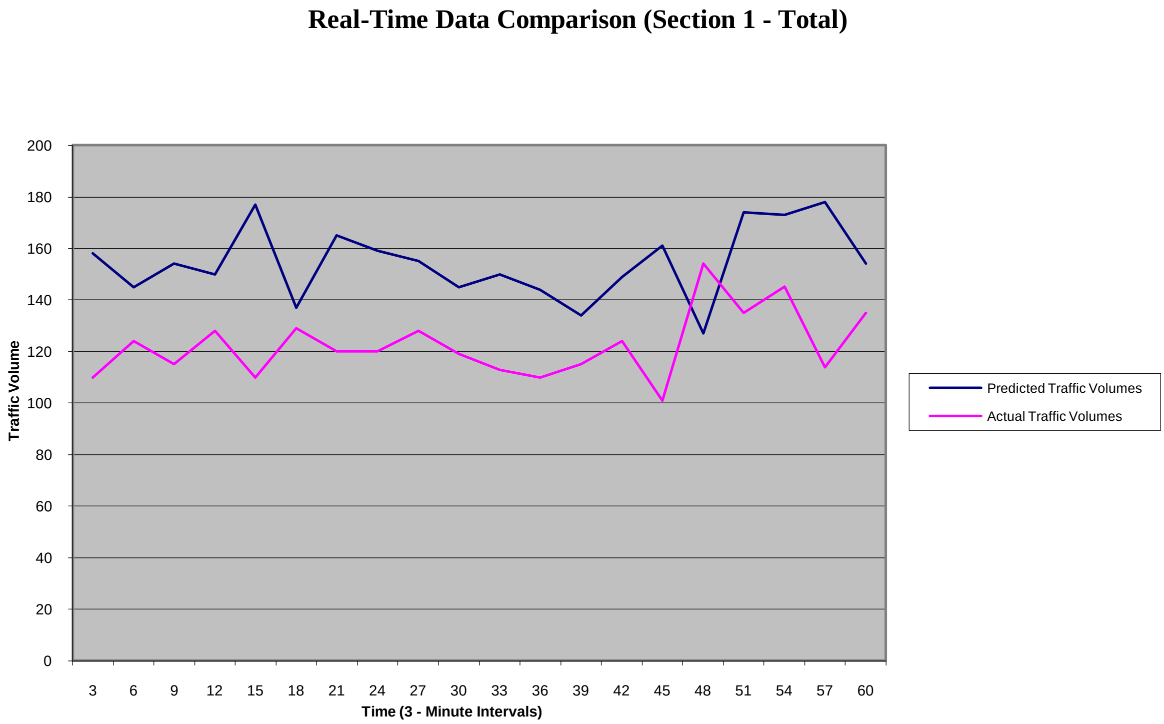

Fig. 9 Simulation results in road section #1.

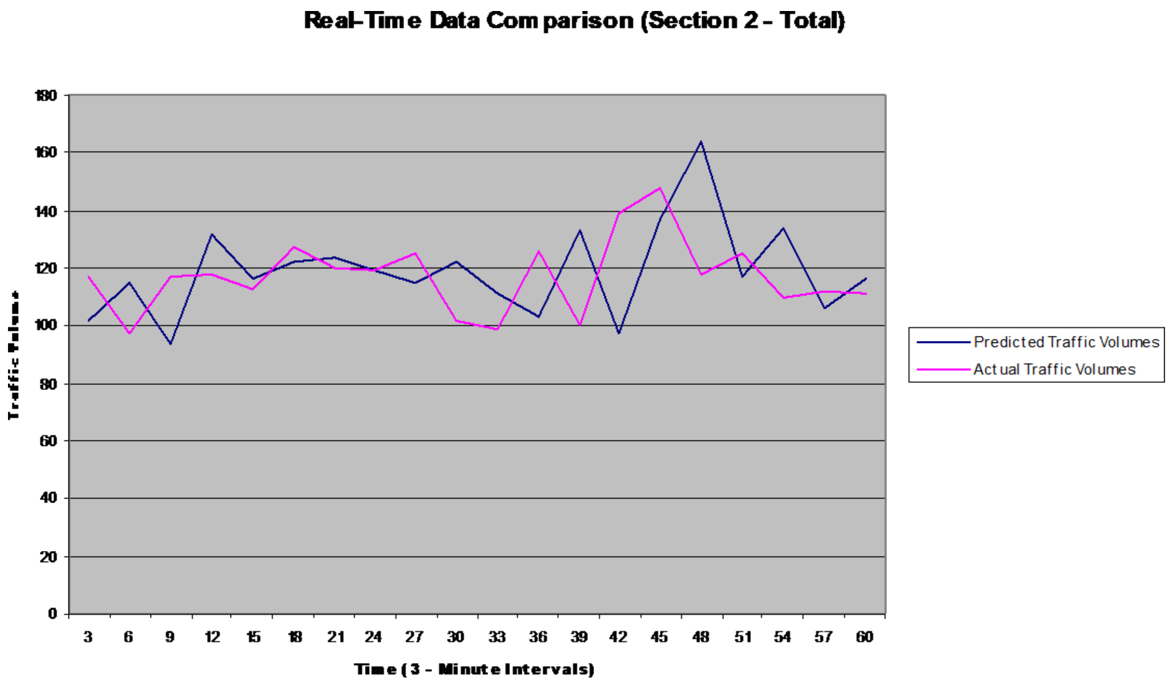

Fig. 10 Simulation result in road section #2.