A HYBRID PROCESS OF MICRO-SIMULATION AND LOGISTIC REGRESSION FOR SHORT-TERM WORK ZONE TRAFFIC DIVERSION

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ABSTRACT
The rapidly growing number of work zones on the Interstate highway system is having significant operational impacts due to the temporary loss of capacity. Work zone impact on safety and mobility creates a strong need to alleviate work zone congestion and protect the road users and workers, which requires a sufficient understanding of work zone impact on traffic flow. Previous studies and field observations demonstrated the importance of considering diversion phenomena when performing work zone impact analysis. To overcome the limitations of deterministic queuing approaches applied in most work zone impact analysis tools, a hybrid process combining micro-simulation and logistic regression was developed to imitate diversion behavior dynamically in work zone approaching area with a number of entrance and exit ramps. Specifically, the logistic regression model based on the field observations was incorporated into a well-calibrated VISSIM model to simulate traffic flow on work zones with diversion behavior. The integration of the two models was achieved via the development of diversion calculation module using COM interface provided by VISSIM. The comparison between simulation outputs and field observations suggested that the diversion calculation module based on logistic analysis can simulate the queue propagation process due to lane closure in an efficient and effective manner. It was demonstrated that the hybrid process can improve work zone impact analysis in simulation environments by utilizing real-time traffic feedback information to emulate the diversion phenomenon upstream of work zones.

KEY WORDS: Work Zone, Diversion, Micro-simulation, Logistic Regression Analysis

INTRODUCTION

Much of the national Interstate highway has existed for more than fifty years. Due to expiration of the road material's life-span and constantly expanding road usage, reconstruction and maintenance work is needed to provide a safe and comfortable driving environment for highway users. Consequently, work zones are becoming more ubiquitous on all types of highways in order to meet the need to upgrade the highway infrastructure. The rapidly growing number of work zones on the Interstate highway system is having significant operational impacts due to the temporary loss of capacity. Work zone impact on safety and mobility creates a strong need to alleviate work zone congestion and protect road users and workers. In addition to the MUTCD guidelines, a number of work zone management strategies have been applied to mitigate work zone impacts on traffic flow (*1,2,3,4*).

The identification of appropriate work zone configurations and management strategies requires sufficient assessment of work zone impact on traffic flow. In response, several tools such as Queue and User Cost Evaluation of Work Zones (QUEWZ) and QuickZone were designed to estimate queue length, delays, and user costs associated with alternative work zone designs and some work zone management strategies. In addition, as an attempt to gain a better understanding of work zone operations, micro-simulation software packages including INTEGRATION, CORSIM, VISSIM, and PARAMICS were commonly used to study work zone situations and to evaluate the effectiveness of the proposed work zone management strategies. For example, Nemeth and Rouphail built a microscopic simulation model to address the merging operations and speed reduction under lane closure situations (*5*). Maze et al. established a lane closure model to replicate the merge behavior in Iowa work zones (*6*). Moreover, several work zone simulation models were developed to evaluate the performance of work zone management strategies (*7,8,9,10*).

Generally, most work zone impact analysis tools use historical traffic demand under normal conditions as inputs to estimate the influence of lane closure on traffic flow. However, traffic demand upstream of work zones may decrease due to the increased detour volume via freeway exit ramps. Ullman referred this phenomenon as "natural diversion" (*11*). The "natural diversion" occurs when drivers decide to leave the freeway by off-ramp locations or not enter the freeway from on-ramp locations to avoid congestion downstream based on their observations of prevailing traffic conditions. According to Ullman's study, significant reduction in entrance ramp traffic volume upstream of lane closures and limited reduction in exit ramp traffic volume were observed. This combined diversion pattern resulted in stabilization of the queue. Ullman suggested that the diversion behavior should be taken into account when evaluating work zone impacts. In response, another study was conducted by Ullman to develop a theoretical approach to predicting work zone queuing with consideration of interaction between diversion and traffic queuing (*12*). This approach regarded the freeway segment with lane closure as a section of permeable pipe and applied macroscopic fluid-flow theory to analyze diversion under lane closure using historical data. The implementation of the method required relatively large inputs to estimate the corridor permeability factor describing the diversion potential of roadway corridors.

Another approach to forecast the diversion behavior under lane closure is to reflect diversion by taking drivers' socioeconomic characteristics into account. Peeta et al. applied logit models to study the diversion phenomenon under VMS messages on the basis of driver surveys including several socioeconomic variables such as sex, age, education level, and persons in household (*13*). Those socioeconomic related parameters were significant in drivers' diversion behavior. However, collecting socioeconomic data usually involves significant effort and time, which is not a practical and economical approach to estimate the work zone impact for each lane closure, especially short-term work zones.

The limitations of previous work zone impact analysis studies include intense data requirements and inaccurate impact estimation from historical data without the consideration of diversion. To overcome these issues, a hybrid process combining micro-simulation and logistic regression was developed to imitate diversion behavior due to lane closure by dynamically determining diversion under varying traffic conditions in work zone approaching area. The proposed process was an effort to avoid the limitation of overestimated usage of alternative routes via an optimal equilibrium (*14*). Accordingly, instead of using the built-in origin-destination (OD) dynamic assignment function provided by micro-simulation software programs, this paper presented a new approach to represent the alternative route choice based on logistic regression analysis. As a result, it was feasible to provide a more accurate work zone simulation model to analyze work zone impact and to yield realistic estimations.

Specifically, the objective of this paper was to investigate and quantify the impact of entrance/exit ramp presence combined with queuing due to lane closure on drivers' diversion behavior upstream of work zones. A logistic regression analysis was conducted to investigate the impact of several traffic related factors on ramp traffic under work zone situations. Furthermore, a diversion algorithm based on the logistic regression was integrated into work zone simulation models to mirror the diversion phenomenon under varying traffic conditions in work zone approaching areas with a number of entrance/exit ramps. The algorithm was validated using field observations and exhibited consistency with field data in terms of the length of queue and traffic volume on the mainline and ramps.

DESCRIPTION OF WORK ZONE SITES AND DATA COLLECTION

Study Sites

Four work zone sites were selected from the Milwaukee freeway system to conduct field studies as shown in Figure 1. All four work zones were located close to the Milwaukee downtown area with a number of entrance/exit ramps along the work zone approaching area. One out of three lanes for the first three work zones and one out of two lanes for the fourth work zone were temporary closed starting from 9 AM to 2 PM for maintenance work. The summary of these work zones is listed in Table 1. All work zones were managed without advanced traveler information systems, such as provision of delay time and travel time, which echoed Ullman's definition of "natural diversion".

TABLE 1 Description of Work Zone Sites

Work Zone	Location	Work Date	AADT	Truck Percent	Configuration	Duration
1	I-94 Westbound between 108th Street and 121st street	August 25, 2005	87,900	10%	3-to-2	5 hour
2	I-94 Eastbound between 68th Street and Hawley Rd	September 30, 2005	86,800	9%	3-to-2	5 hour
3	I-94 NB @ College Ave	October 4, 2004	65,300	9%	3-to-2	5 hour
4	I-94 Wastbound between 84th Street and Zoo Interchange	November 8,2005	41,400	15%	2-to-1	5 hour

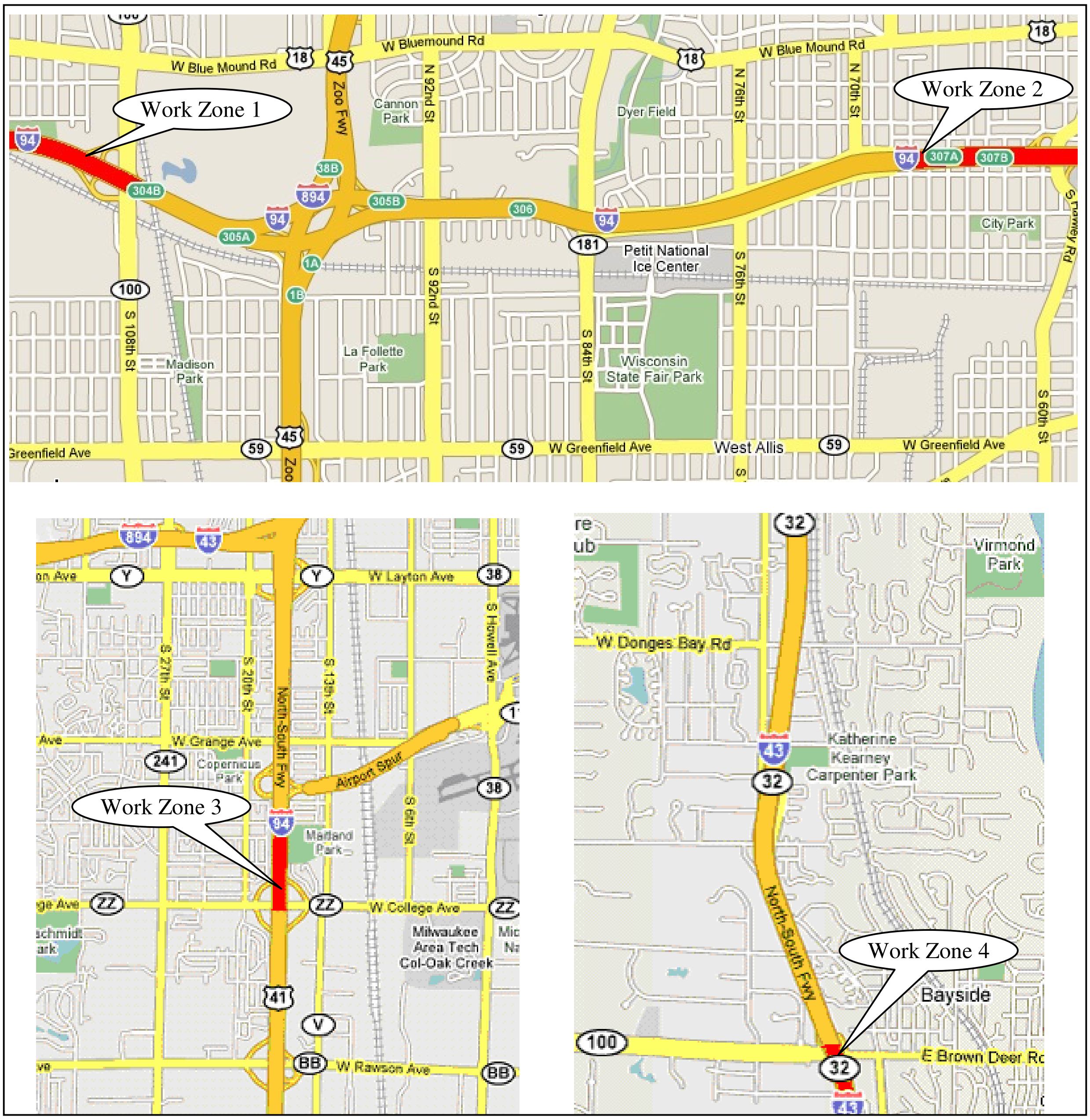


FIGURE 1 Work zone locations.
(Source: http://www.google.com)

Data Collection

Recall that one of the objectives of this research was to study the impact of queuing, due to work zone congestion, on drivers' diversion behavior. The measurement applied here was the change in entering/exiting traffic volume on entrance/exit ramps before and during the maintenance work. Therefore, traffic volume data at 15-minute intervals for the day with lane closure were retrieved from the existing permanent loop detector locations on freeway segments and entrance/exit ramps. Additionally, to eliminate the variation in traffic patterns for different weekdays, volume data for five same-day weekdays before the lane closure were obtained from the detector system and averages over these before data were used to estimate entering/exiting traffic volume under normal conditions without lane closure.

In addition to the volume data, length of queue was collected via a GPS equipped vehicle continually running through the work zone area during the duration of the lane closure. The GPS equipped vehicle started from the free flow segment without congestion and then joined the end of queue and went through the work zone approaching area and activity area up to the work zone termination area. Typically, the GPS equipped vehicle passed through the entire work zone area and vehicle queue at least twice per hour. Thus, the location and speed data were recorded and used to calculate the length of the queue after downloading data from the GPS device. As it can be seen Figure 2, the obtained GPS signals were graphed and the length of queue was determined through visual observation.

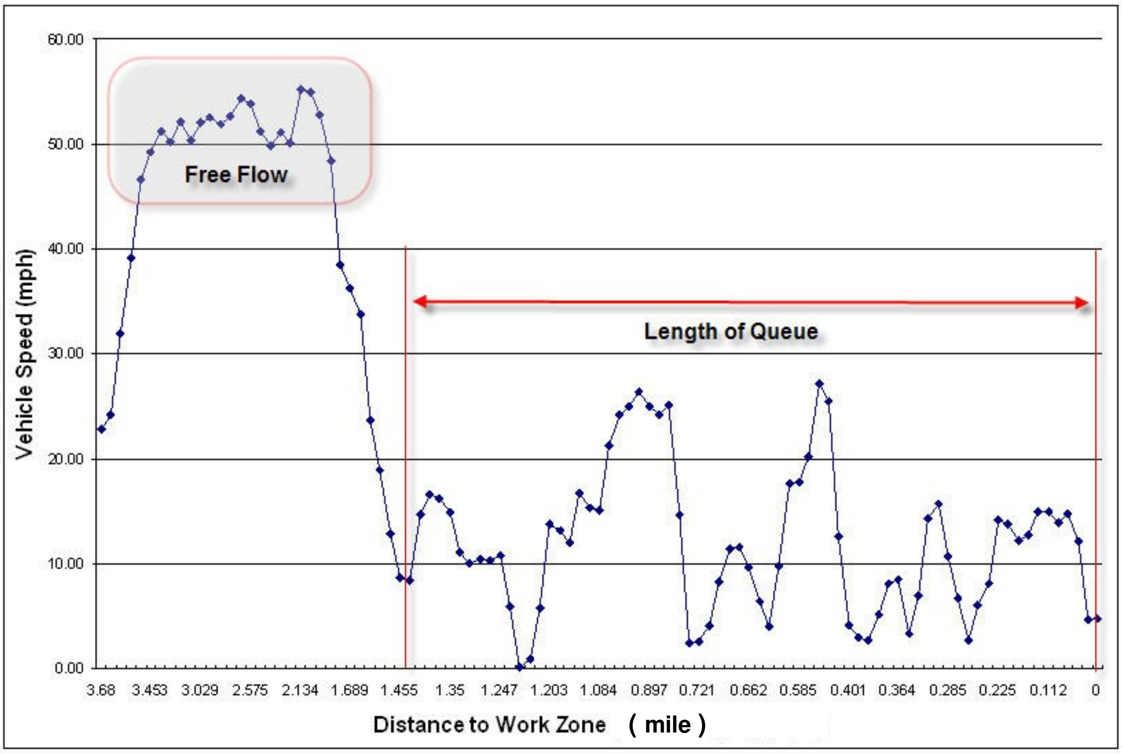


FIGURE 2 Queue length from GPS data

Field Observation Summary

Table 2 presents the propagation of queuing upstream of each work zone over the duration of lane closure. As shown in Table 2, queues developed quickly at work zone 2, 3, and 4 then stabilized during the lane closure. Although the queuing pattern in work zone 1 indicated a relatively long period (3 hours) to reach the maximum queue length or near-maximum queue length, the queuing propagation process still demonstrated a relatively stationary queue length with fluctuations. It was reasonable to assume that the stabilization state was achieved due to the decrease in volume upstream of the lane closure. In other words, drivers' unprompted reactions to the congestion on freeway segments resulted in diversion behavior including leaving the freeway via exit ramps and not entering via freeway entrance ramps. The diversion behavior efficiently maintained the balance state with relatively stabilized queue length.

TABLE 2 Length of Queue in Work Zones

Time	WZ 1 (mi)	WZ 2 (mi)	WZ3 (mi)	WZ 4 (mi)
9:30	0.5	1.4	2.2	2.0
10:00	0.5	1.4	2.4	2.5
10:30	0.7	1.4	2.3	3.1
11:00	0.8	1.4	2.3	2.6
11:30	1.7	1.1	2.2	3.1
12:00	2.5	1.4	2.1	3.2
12:30	1.9	1.1	1.7	3.1
13:00	1.8	1.2	1.8	2.9
13:30	2.6	1.5	1.9	3.1
14:00	2.9	1.5	2.2	3.1

Since the on/off ramp traffic data for work zone site 3 was not available, Table 3 only illustrates the change in volume of entrance and exit ramps for work zone 1, 2, and 4 with and without lane closure. Additionally, the entrance and exit ramps listed in Table 3 only include the ramps where traffic operations were affected by queuing due to lane closure. For instance, the queue developed in work zone 1 extended to the third interchange upstream of the work zone taper and therefore only three entrance and exit ramps were affected. The percentages listed in Table 3 support the above-mentioned assumption. Firstly, the diminishing traffic volume shown in the first half of the table indicates that less traffic entered into the freeway segments during lane closure compared to before lane closure. Secondly, the increasing traffic on exit ramps shown in the second half of the table implies that more drivers decided to leave the freeway segments compared to without lane closure. Although both of them accounted for the decrease in traffic demand upstream of work zones, the decrease in entrance ramps tended to be more significant than increase in exit ramps. The familiarity with the detour route might contribute to the discrepancy. Drivers on the freeways may or may not have knowledge of the local roadway and they hesitated to leave the freeway. In contrast, drivers planned to take entrance ramps from local roadways were assumed to be quite familiar with adjacent area and they could be more inclined to choose another route once they observed the queue on the freeway. Also, limited gaps for ramp traffic to enter into the congested freeway might contribute to the reduction in entrance traffic. Thirdly, it can also be observed that there were increases in entrance volume on ramps during the early stage of lane closure. For example, entrance volume increased at 10 AM on all on-ramps of work zone 1 and volume continued to increase at 11 AM on the 70th Street entrance ramp. According to queuing propagation records shown in Table 2, the queue did not extend beyond 84th street exit before 11 AM and 70th street exit ramp before 12 PM. It is logical to conclude that the traffic conditions on freeways had little influence on the on-ramp traffic when the end of the queue could not be observed. The same reason can be applied to explain why the negative increase at exit ramps at the early stage of queuing. The increase in entrance ramps and decrease in exit ramps were tested for significance using t-test. The results showed that the entrance/exit traffic was significantly lower/higher than normal condition for work zones at 95% confidence level.

Since the changes in on/off volume shown in Table 3 varied by time and location, it was plausible to assume that the prevailing traffic conditions in the mainline, including the location of the end of the queue and the traffic volume on freeway segments might account for the variations. It was worthwhile to investigate how these traffic-related factors impacted the changes in volume and interacted with drivers' diversion decisions.

TABLE 3 Ramp Volume Changes within Work Zone Approaching Area

	Work Zone	Ramp Location	Distance to Taper (mi)	Time					
				9 AM	10 AM	11 AM	12 PM	1 PM	2 PM
Entrance Ramp	1	70th Street	2.05	-14.7%	11.3%	3.7%	-14.4%	-15.5%	-0.8%
		84th Street	1.45	-13.2%	5.3%	-10.3%	-18.7%	-26.5%	-13.8%
		Zoo Interchange	0.6	2.7%	0.3%	-14.6%	-9.6%	-31.7%	-29.2%
	2	84th Street	0.71	-20.6%	-1.3%	-19.7%	-38.6%	-44.0%	-3.5%
		70th Street	0.11	11.0%	-13.1%	-2.9%	-7.6%	1.7%	-1.0%
	4	STH 167	3.2	-1.6%	-7.4%	-4.7%	-10.5%	-12.4%	-5.7%
		County Line Rd	1	-3.8%	-5.7%	-5.7%	-5.0%	-3.9%	-2.5%
Exit Ramp	1	70th Street	2.05	-0.7%	-0.8%	0.8%	2.1%	1.4%	2.1%
		84th Street	1.45	-2.1%	0.6%	7.4%	1.9%	6.6%	1.9%
		Zoo Interchange	0.6	1.0%	1.3%	12.5%	9.6%	9.6%	2.4%
	2	84th Street	0.71	0.8%	0.2%	6.1%	7.4%	8.9%	-2.1%
		70th Street	0.11	5.0%	3.0%	4.0%	5.0%	5.0%	12.0%
	4	STH 167	3.2	4.5%	16.5%	13.3%	10.6%	13.5%	11.2%
		Brown Deer Rd	0.2	6.5%	8.8%	14.4%	18.1%	16.6%	9.6%

LOGISTIC REGRESSION ANALYSIS

Logistic Regression Analysis Approach for Estimating Ramp Traffic with Diversion

Based on the field observations shown in the previous section, several variables such as traffic volume on entrance/exit ramps without lane closure, mainline traffic, and queue length, might play roles in affecting entering/exiting volume under work zone situations. Ordinary linear regression is a widely used approach to examining what variables significantly impact the response variables and also predicts the response variable given a set of independent variables. Notice that the proportions of ramp traffic have maximum and minimum values of 1 and 0. Ordinary linear regression might produce outcomes above 1 or below 0, which has no predictive use. Therefore, a logistic model was applied to examine what factors were significantly associated with ramp traffic under work zone situations and further to determine the ramp traffic in the work zone simulation model under prevailing simulated traffic condition. The typical form of the logistic regression is given as (*15*,*16*):

$$\pi(x) = \frac{e^{\beta_0 + \boldsymbol{\beta}\mathbf{X}}}{1 + e^{\beta_0 + \boldsymbol{\beta}\mathbf{X}}} \tag{1}$$

Where:

$\pi(x)$ – Conditional mean of the ramp traffic given **X**
$\mathbf{X}$ – Vector of predictor variables
$\boldsymbol{\beta}$ – Vector of Coefficients.

Further, a logarithmetic transformation of $\pi(x)$ leads to a linear expression shown as follows:

$$\log it(x) = L(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \mathbf{\beta X} \quad (2)$$

The response variable $\pi(x)$ stands for the portion of ramp traffic. Specifically, $\pi(x)$ for the exit ramp was defined as the proportion of traffic that took the off-ramp to leave the freeway. The $\pi(x)$ for each entrance ramp was defined as the proportion of traffic entering from the entrance ramp to merge freeway traffic. Figure 3 illustrates the $\pi(x)$ for exit/entrance ramps.

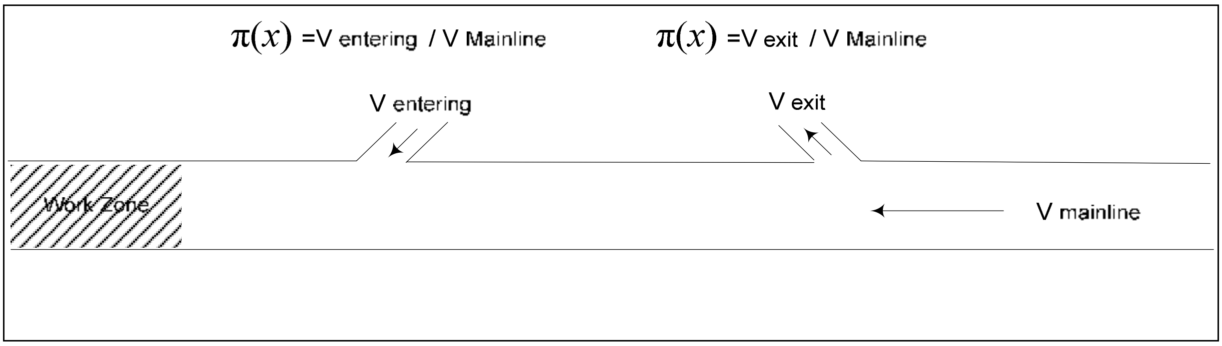


FIGURE 3 Definition of $\pi(x)$ for Exit and Entrance Ramp

The vector of predictor variables **X** includes volume, queue length, and proportion of ramp traffic before lane closure, etc. In an attempt to select the best subset of predictor variables for the logistic regression model, Akaike Information Criteria (AIC) based on the fitted log-likelihood function was used. Since computing the AIC for all possible regression models with different subsets of variables was not practical, a stepwise procedure was introduced to select the best regression model with minimum AIC value (*17*). R statistical software was used to perform the variable selection procedure (*17*). The goodness-of-fit of the regression model was measured by the coefficient of determination R^2 and likelihood ratio test.

Logistic Regression Results

Field data collected from work zone 1 and 2 were used to develop the logistic regression model to show how traffic-related variables impacted the change in traffic on entrance and exit ramps. Variables used to develop the regression model for exit traffic included the percentage of traffic taking exit ramps under normal conditions, volume on the freeway and queue length. Regression results for exit ramps are presented in Table 4, including the estimates of coefficient, standard error, t-statistic, and p-value.

High R^2 value suggested the model fitted the field data well. Besides, the likelihood ratio test was performed to compare the fitted model with base model with the constant only. The small p-value implied the model was significantly different from the one with the constant only. All the three predictors have p-values less than 0.05, which suggested that volume, percentage of traffic taking exit ramps without lane closure, and queue length significantly influenced the percentage of ramp traffic. Additionally, the interaction factor of volume and proportion of exiting traffic before lane closure also had a significant impact on the percentage of ramp traffic.

TABLE 4 Logistic Regression Model Results for Exit Ramps

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Constant	-6.643	0.815	-8.154	0.000*
Main Effect				
Percentage of traffic taking exits (normal)	15.134	3.392	4.462	0.000*
Mainline upstream volume (vph)	0.003	0.001	5.214	0.000*
Queue length (mile)	0.246	0.073	3.353	0.001*
Interaction Effect				
Percentage of exiting traffic (normal) × Volume	-0.009	0.003	-2.966	0.004*

* Statistically significant coefficient at 5% significant level
Residuals: Std. Error = 0.289
Fit: Multiple R-Squared = 0.942, Adjusted R-squared = 0.938
Model Test: F-statistic [4, 56] = 227, p-value: < 2.2e-16
Likelihood ratio: Chi-square = 196.03 $> \chi^2_{0.05}$, P-value < 0.05

Table 5 illustrates the regression analysis results for entrance ramps. Unlike exit ramps, only one variable, the percentage of entering volume under normal conditions, significantly affected entering volume at the 5 percent level of significance when lane closure was present. In addition, the interaction between the percentage of entering volume under normal conditions and volume under work zone conditions also played a significant role in the volume on entrance ramps.

TABLE 5 Logistic Regression Model Results for Entrance Ramps

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Constant	-46.473	20.608	-2.255	0.032*
Main Effect				
Percentage of entering volume (normal)	462.705	216.874	2.134	0.042*
Mainline upstream volume (vph)	0.034	0.017	1.997	0.056
Interaction Effect				
Percentage of entering volume (normal) × Mainline upstream volume	-0.376	0.179	-2.099	0.045*

* Statistically significant coefficient
Residuals: Std. Error = 1.287
Fit: Multiple R-Squared = 0.476, Adjusted R-squared = 0.420
Model Test: F-statistic [3, 28] = 8.473, p-value: 3.657e-4
Likelihood ratio: Chi-square = 29.651 > $\chi^2_{0.05}$, P-value < 0.05

DIVERSION ALGORITHM IN WORK ZONE SIMULATION MODEL

Simulation Software VISSIM

VISSIM is a microscopic, behavior-based traffic simulation program developed at the University of Karlsruhe, Germany. VISSIM provides a variety of driver behavior parameters to assist in developing different traffic scenarios. In addition, VISSIM supports access to model data and simulation through a COM interface, which allows extending its capabilities and customizing built-in features in VISSIM simulation. As stated, the work zone simulation model was designed to reflect the drivers' diversion behavior according to varying traffic conditions. The COM interface makes it possible to incorporate the diversion algorithm into the simulation environments to represent the diversion behavior under lane closure situations.

Implementation of Diversion Algorithm in Simulation

Work Zone Simulation Model Development

Work zone 1 was selected to implement the diversion algorithm based on the previously presented logistic regression analysis in VISSIM simulation. The schematic map for work zone 1, including the work activity area and approaching area impacted by congestion due to lane closure is presented in Figure 4. Three entrance ramps and three exit ramps are located at the upstream of the work zone. The distances between these interchanges are shown in the bottom of the schematic map. In addition to the geometry data, volume data at 15-minute interval for work zone upstream and entrance ramp during the five-hour lane closure were input into the work zone model. Corresponding route choice data (i.e., portion of traffic taking exits) for each exit ramp were also determined by field data. For example, the portion of traffic taking exits was estimated by the volume on exit ramps over the freeway segment volume before exit ramps.

To obtain the prevailing traffic condition data during the simulation, emulated detectors and queue counter were placed in the simulation model as shown in Figure 4. The detectors collected traffic volume data and the queue counter recorded the location of the queue end.

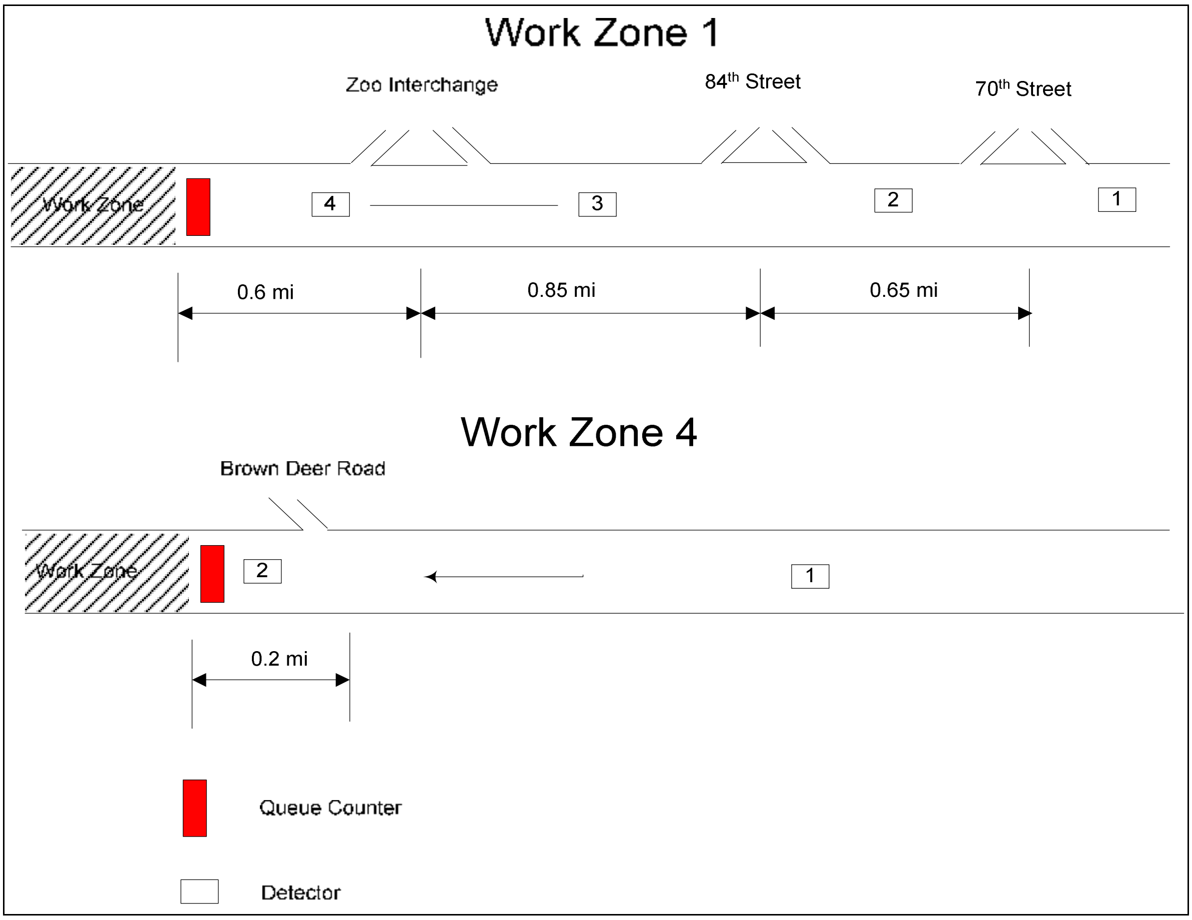


FIGURE 4 Schematic map for work zone 1 and 4.

Work Zone Simulation Model Calibration Using Field Data

In addition to an accurate geometry coding, driver behavior parameters also play important roles in producing reasonable outputs. The calibration process was conducted to specify related driver behavior parameters in the VISSIM simulation under work zone situations. Work zone throughputs and queue length are the most useful measures to describe the performance of work zones. Also, it is convenient to observe and collect these two measurements in the field. Accordingly, throughput and queue length were selected as performance measures for model calibration. Volume counts at each detector were also compared with field data in an attempt to calibrate the drivers' diversion behavior when approaching the work zone with the presence of entrance and exit ramps.

The calibration process sought the optimal combination of parameter values generating outputs, such as volume and queue length, with the smallest deviation from observed field data. Calibration started with an initial run using the default values for parameters in VISSIM. Next, the adjustments for the related parameters were made according to immediate observation and simulation results. Since there were no field observed volume data for detector 4, Figure 5 only shows the comparison of the observed and average of simulated volume data from multiple runs at 15-minute interval for the work zone activity area and three detector locations in Figure 4. Figure 5 suggests that the simulated volume data matched well with observed field data in both work zone activity and approach area.

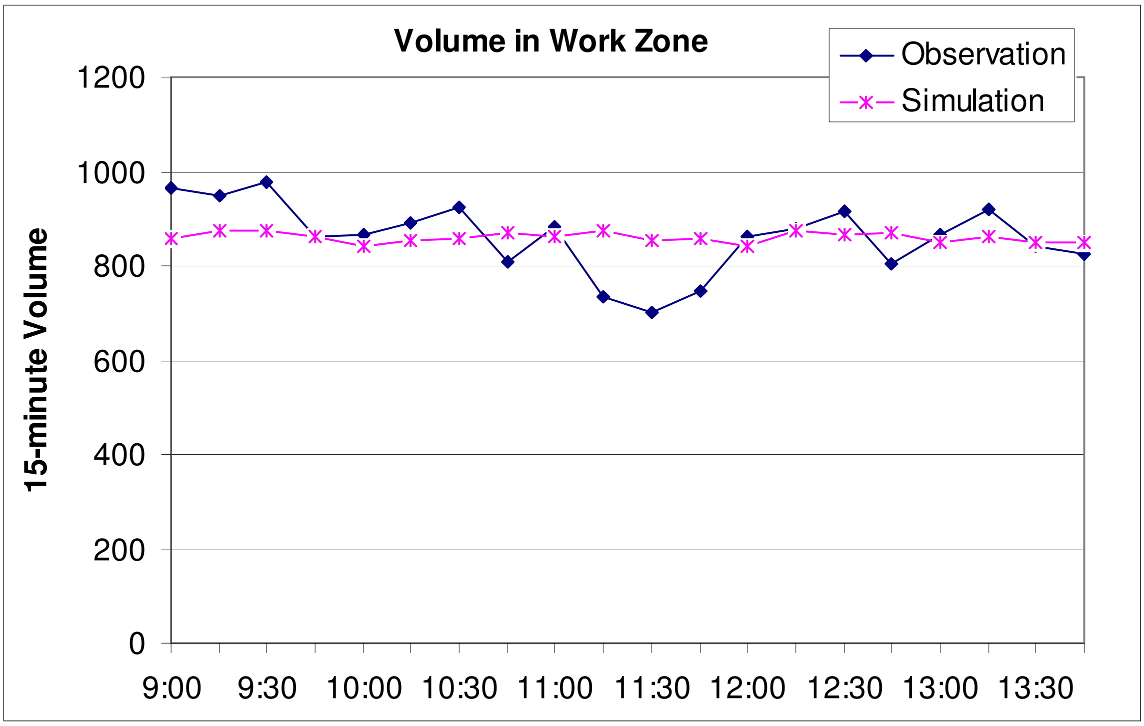
A commonly used statistical measure, mean absolute percentage error (MAPE), for volume data was calculated to examine the goodness of fit for the observed and simulated volume data. The MAPE is expressed as:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\left(\frac{Y_o(i) - Y_s(i)}{Y_o(i)}\right)\right| \tag{3}$$

Where:

Y_o – Observed volume
Y_s – Simulated volume
i – i^{th} time interval
n – Number of time intervals

The values of MAPE for the four locations were 6.8%, 9.0%, 4.8%, and 4.8%, respectively. In addition to volume data, the queuing patterns from simulation and field observations also functioned as another measure of calibration. Figure 6 presents the queue lengths for simulation and field data at each 15-minute interval during lane closure. Although the simulation produced relatively longer queue length than field data, the two lines representing the queue length over time show a similar growth pattern. Under both simulation and field environments, the queue length continued to increase until 12 PM and started to decrease after reaching the longest queue length (over 2.5 miles). Therefore, it can be concluded that the work zone simulation model was well calibrated and can reflect the traffic condition under lane closure situations, which ensured the implementation of the diversion algorithm in the simulation environments.


Volume in Work Zone
Observation
Simulation
15-minute Volume
1200
1000
800
600
400
200
0
9:00
9:30
10:00
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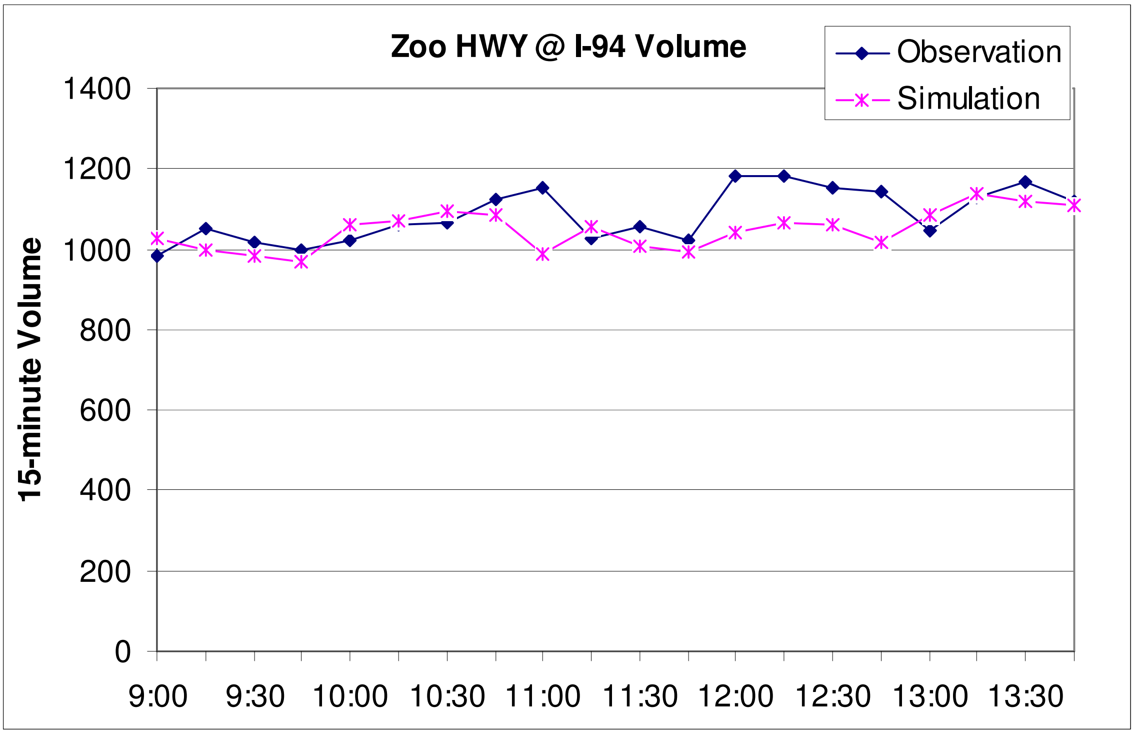
Zoo HWY @ I-94 Volume
Observation
Simulation
15-minute Volume
1400
1200
1000
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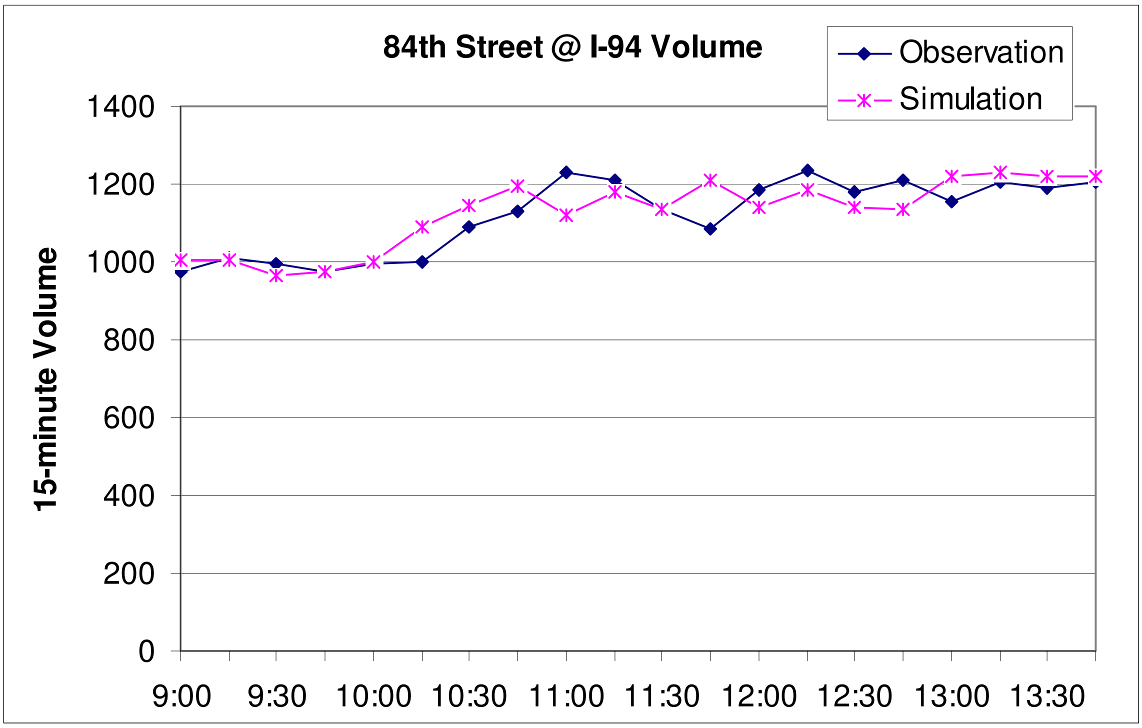


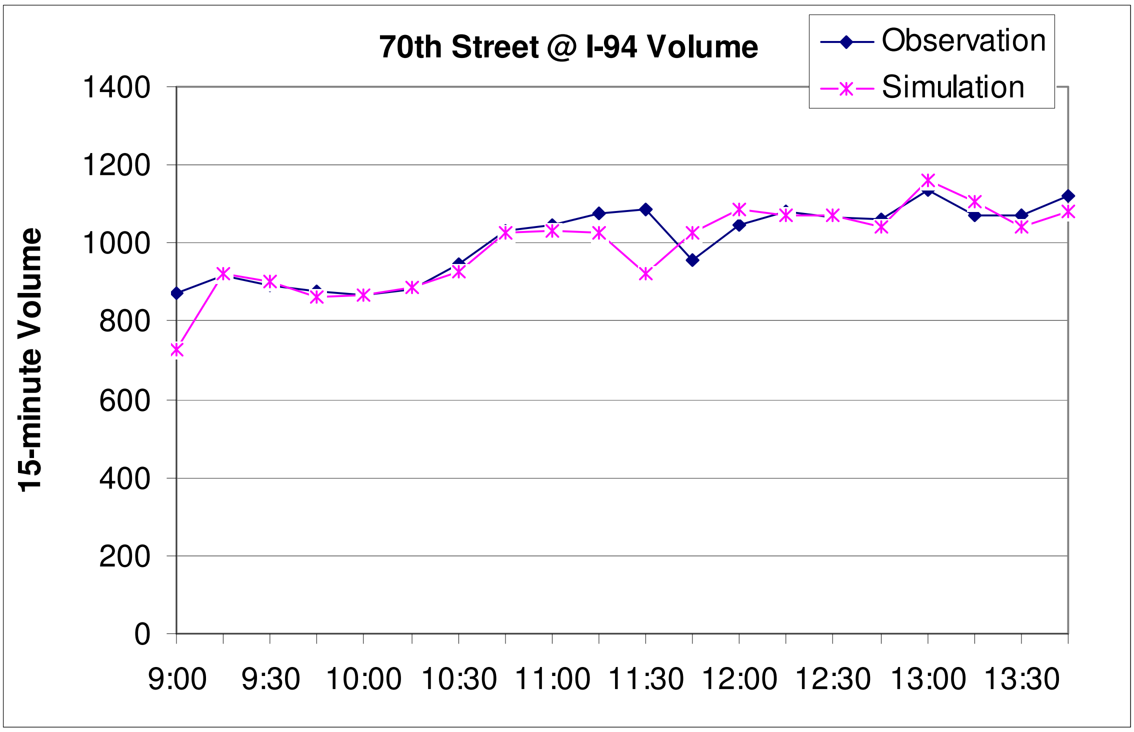


FIGURE 5 Field observed and simulated work zone volume.

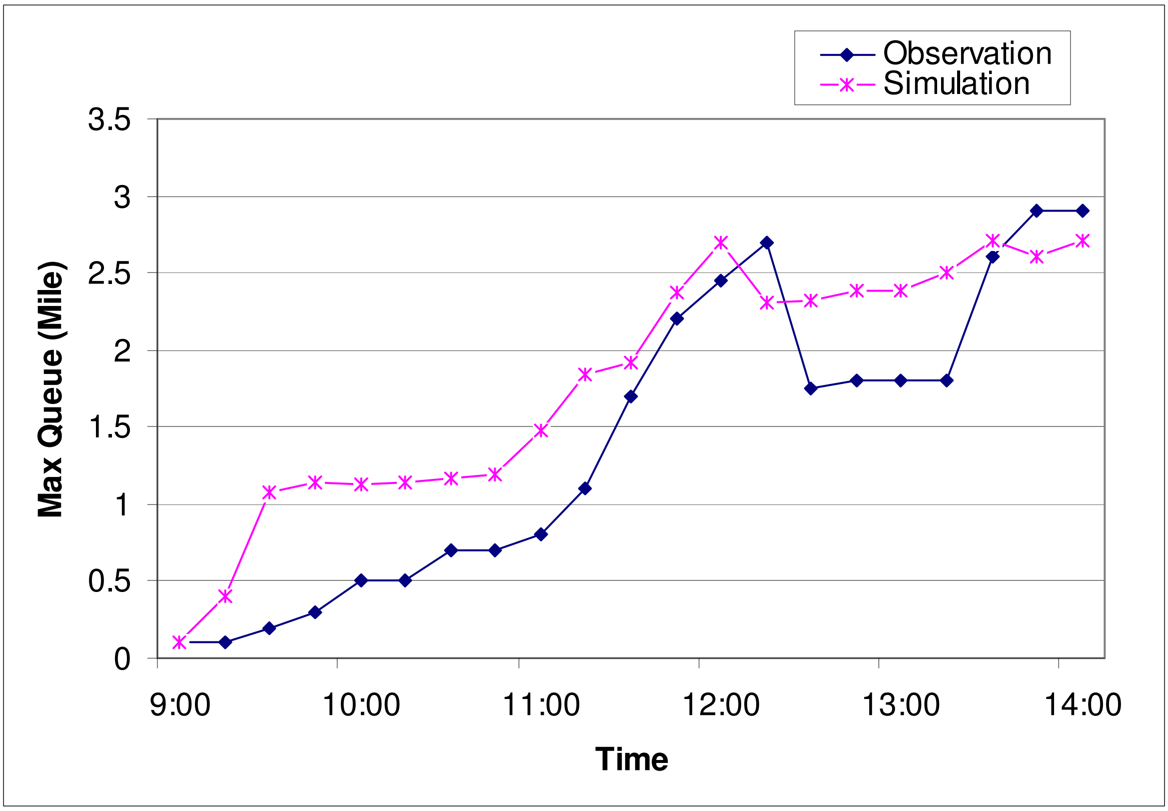


FIGURE 6 Queue length comparison.

Design of Diversion calculation Algorithm in Simulation

The design for implementing the diversion algorithm in the work zone simulation model is shown in Figure 7. This design was aimed at simulating the diversion behavior under lane closure using the proposed diversion algorithm given normal traffic conditions. In other words, the design provided an approach to foresee the potential diversion behavior under simulated work zone traffic condition using historical traffic data for typical days. Unlike the calibration process in the previous section, the traffic inputs were the volume data on mainline and percentage of on/off ramp traffic for a typical day without lane closure. Additionally, the entering/exiting traffic from entrance/exit ramps were dynamically decided by the diversion algorithm based on prevailing traffic conditions and historical volume.

The design consisted of three main components: VISSIM simulation, diversion calculation plug-in module, and routing decision plug-in module. During each simulation interval, the VISSIM simulator generated emulated traffic flow and provided system performance measures and traffic data from detectors to feed them into the diversion calculation plug-in module. The diversion calculation plug-in module processed real-time data collected from detectors and queue counters and determined the portion of ramp traffic for the next simulation iteration. Specifically, the diversion calculation plug-in module collected and input the related data including the percentage of traffic taking exit or entrance ramps under normal conditions, freeway segment volume, and queue length, into the previously developed logit models shown in Table 4 and 5 and estimated the percentage of traffic taking each ramp. The calculated percentage of ramp traffic was then sent to the routing decision plug-in module to perform the diversion control for entrance and exit ramps. In short, the functions of diversion calculation module include 1) collecting volume and queue length data; 2) calculating the percentage of ramp traffic; and 3) sending the percentage of ramp traffic to routing decision module.

By iteratively interacting between simulation model and logit model, the entire process can dynamically adjust the percentage of traffic for each ramp according to prevailing traffic conditions and implement the route selection that replicates the drivers' diversion behavior under lane closure scenarios.

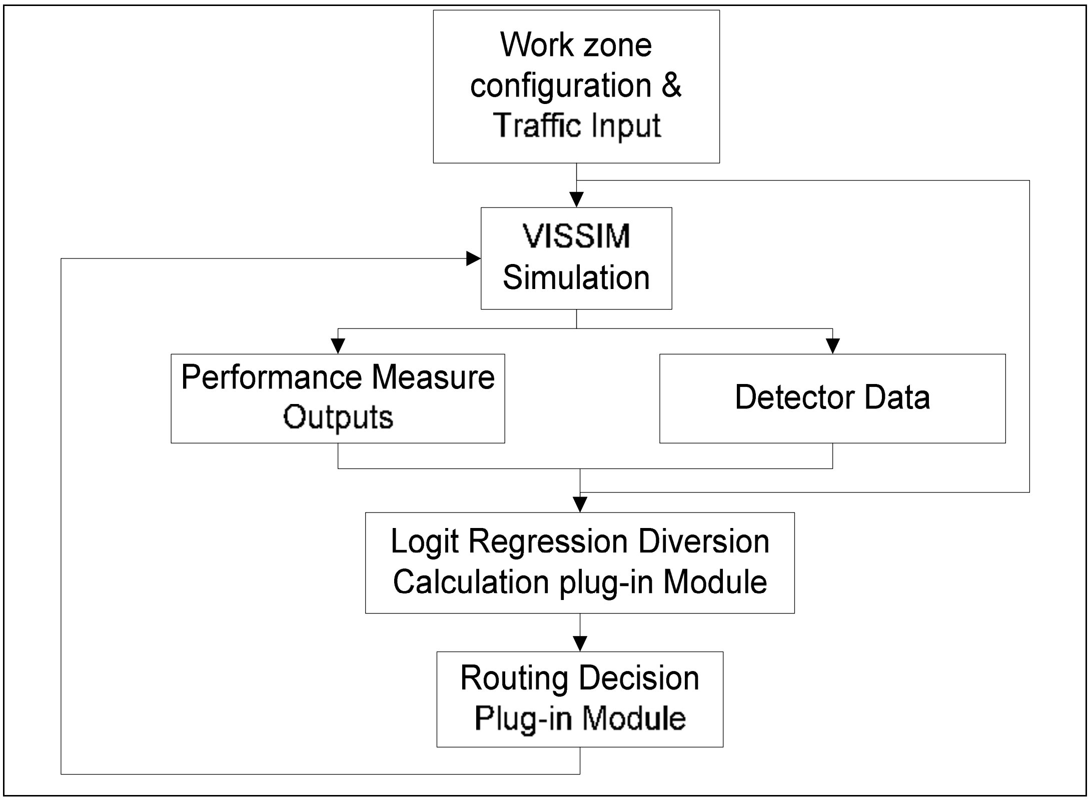
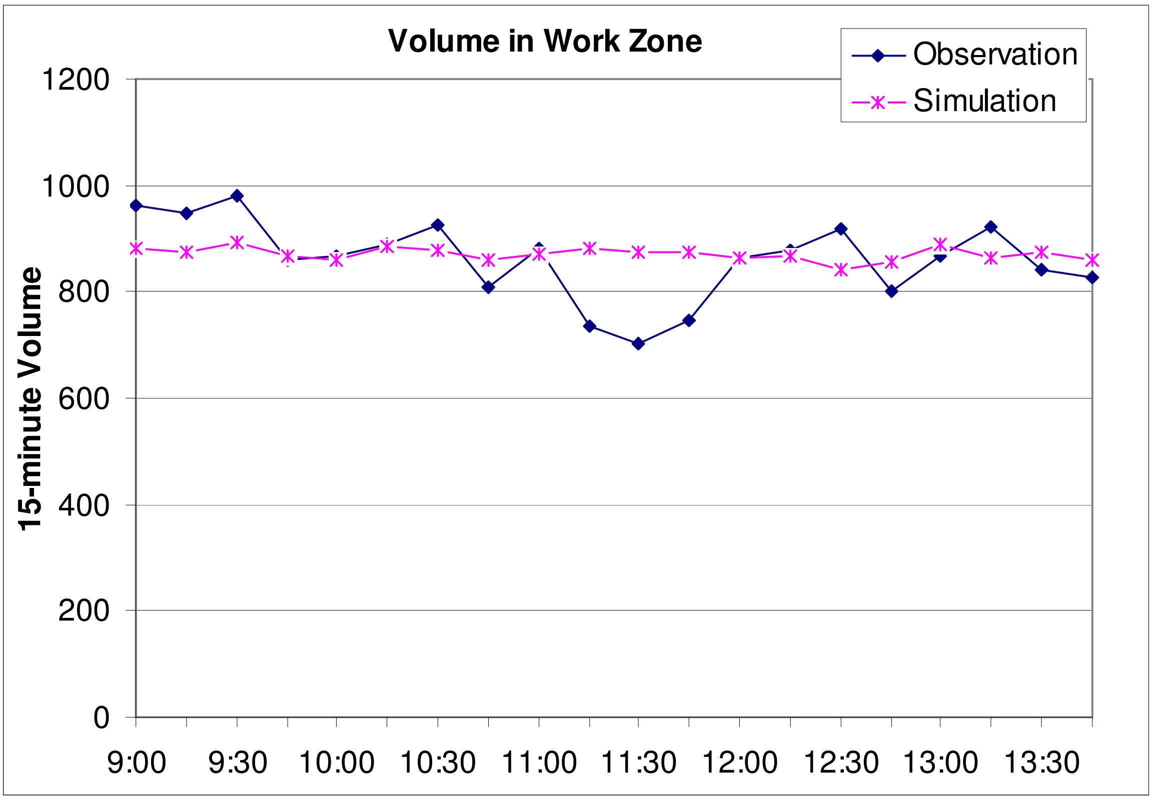
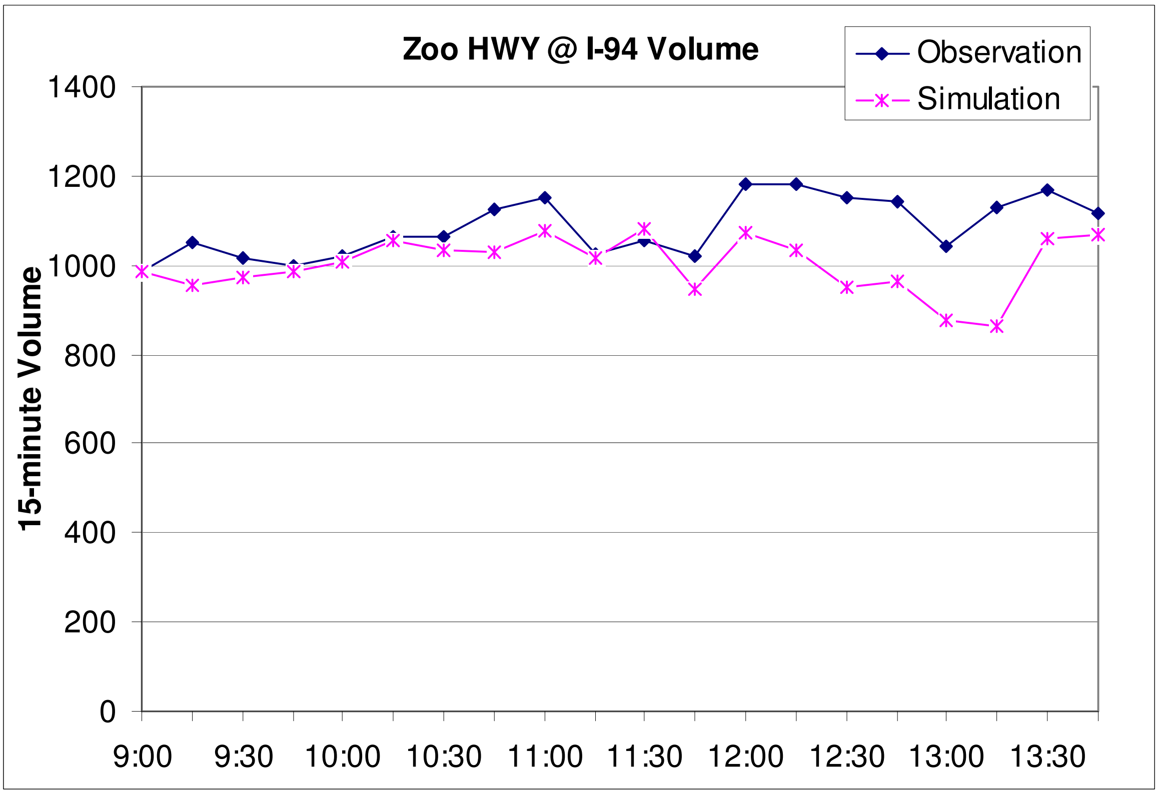


FIGURE 7 Design of dynamic diversion control in work zone simulation.

Results for Simulation with Diversion Algorithm

Figure 8 compares the traffic counts for field observations and simulation in the activity area and other detector locations in the approaching area of work zone 1 shown in Figure 4. Typically, simulated volumes were similar to field observations on each freeway segment. The MAPE for the four locations were 6.7%, 7.7%, 4.9%, and 4.6%, respectively, which illustrated that the simulation controlled by the diversion algorithm matched field data well. Additionally, the similar queuing propagation patterns for simulation and field observations illustrated in Figure 9 demonstrated that the diversion behavior could be described by the diversion algorithm integrated in the simulation.


Volume in Work Zone
Observation
Simulation
15-minute Volume
1200
1000
800
600
400
200
0
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30


Zoo HWY @ I-94 Volume
Observation
Simulation
15-minute Volume
1400
1200
1000
800
600
400
200
0
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
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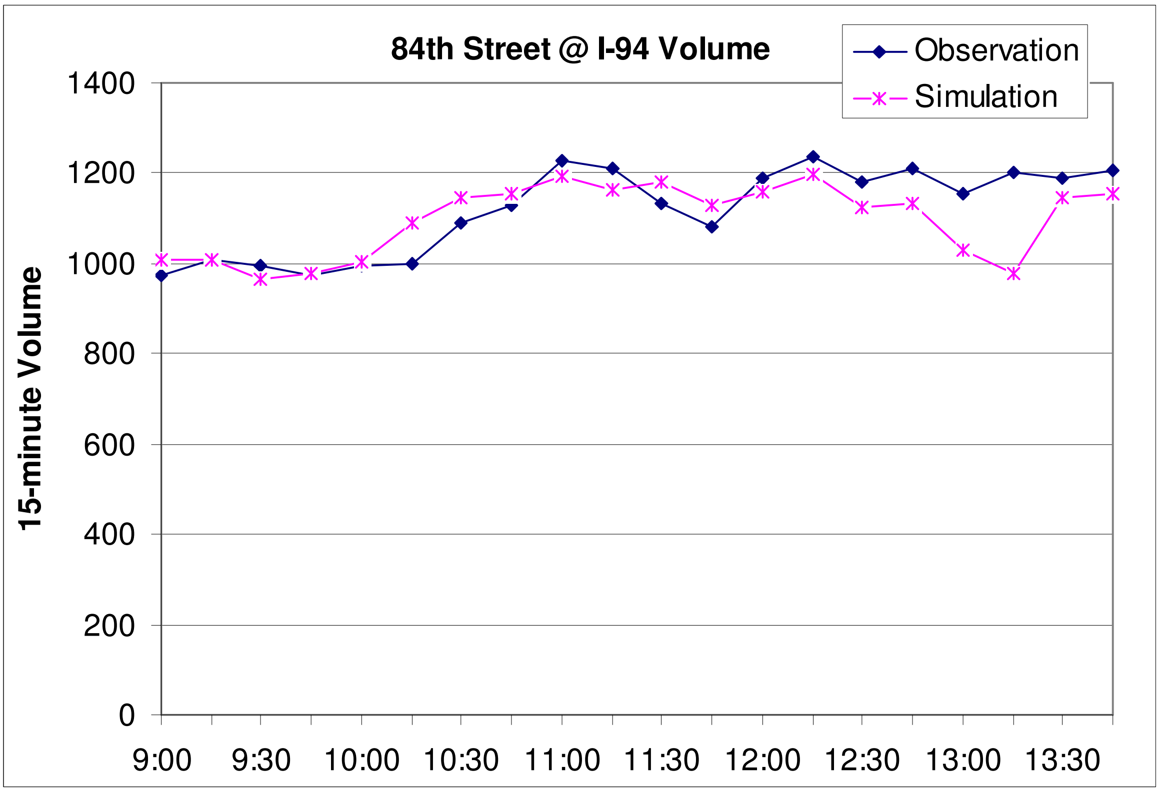


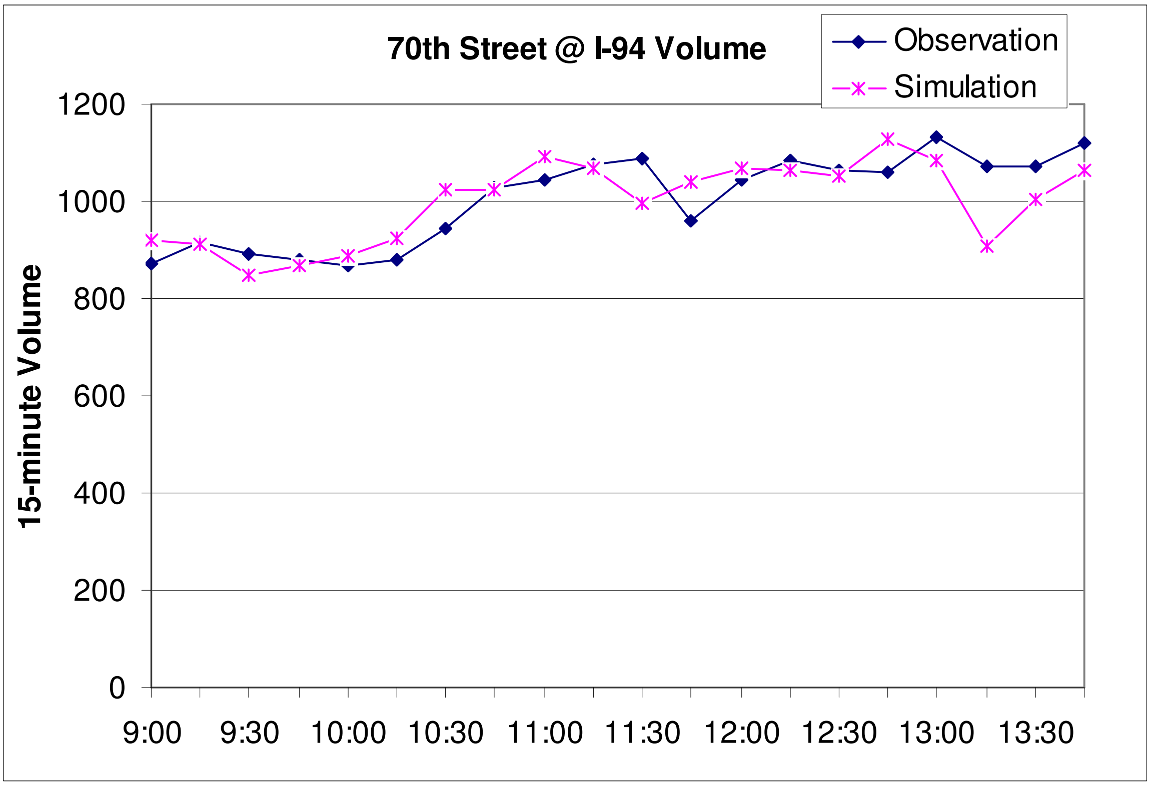


FIGURE 8 Field observation and simulation with diversion algorithm.

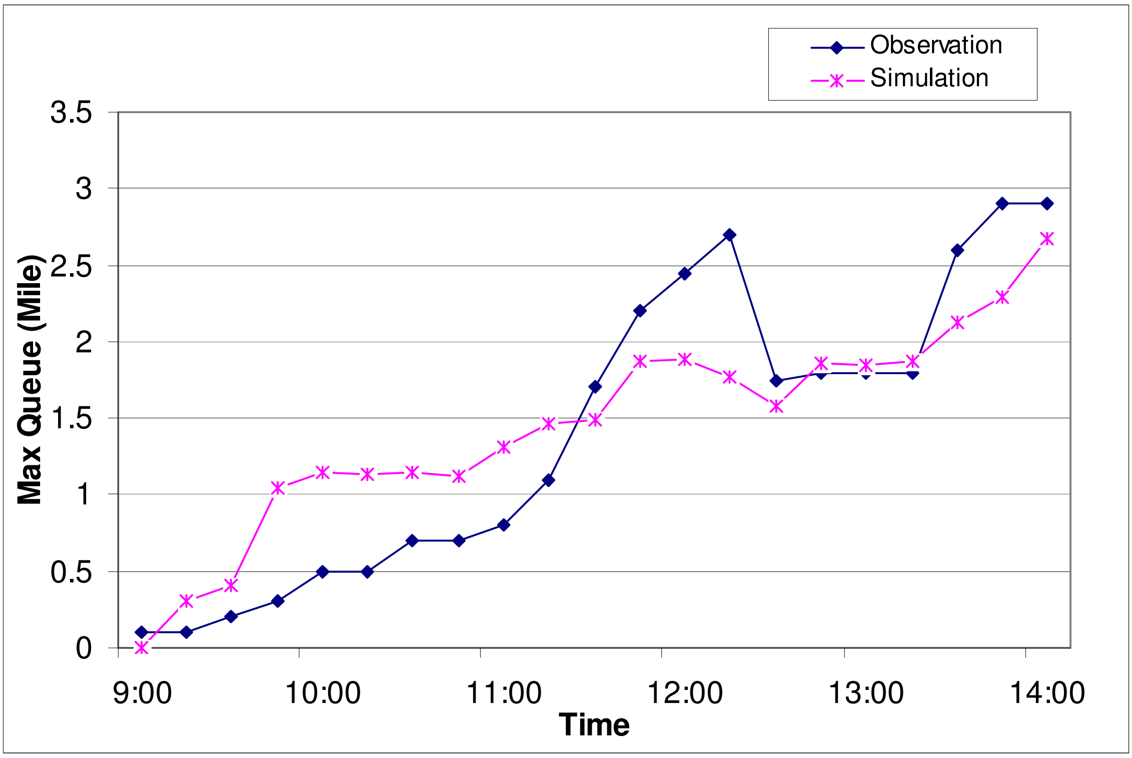


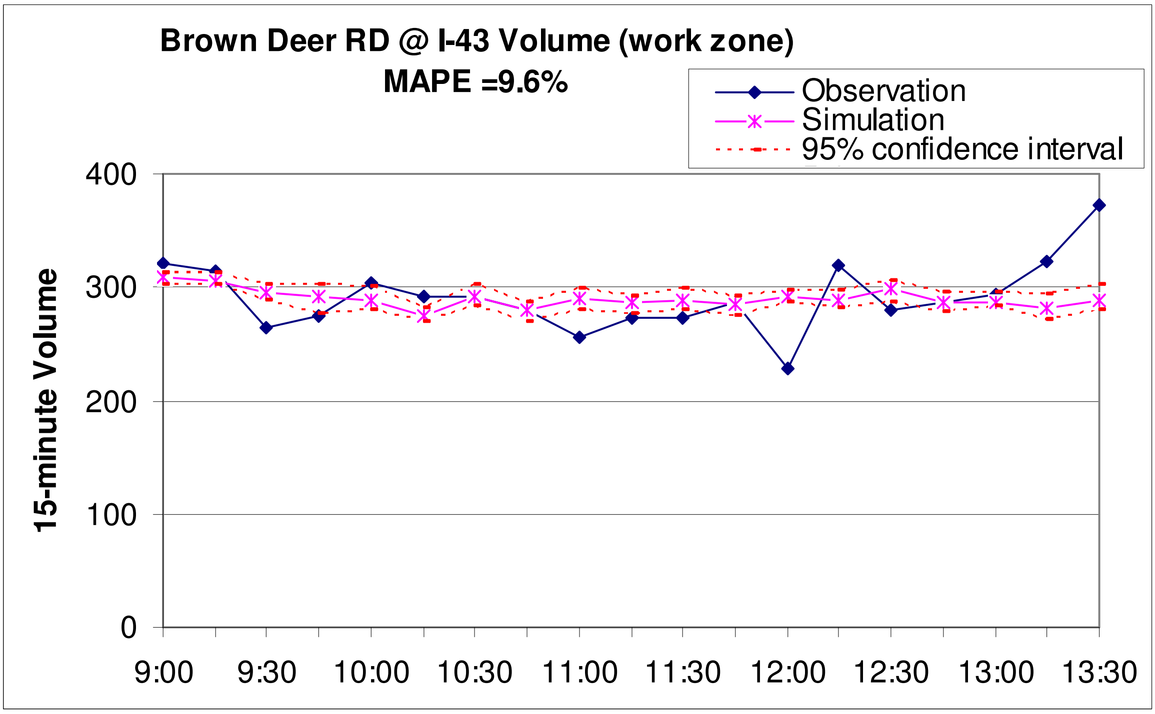
FIGURE 9 Queue length comparison.

Validation of Diversion Algorithm

Validation was used to determine whether the work zone simulation models can be the accurate representations of the real work zone situations. Rather than model calibration process focusing on improvement of model performance, validation was to assure the correctness and credibility of the models based on the comparison between simulation outputs and observed data. Volume for the mainline and the ramp, and queue length data for work zone 4 was used to validate the diversion algorithm. The schematic map for work zone 4 is shown in Figure 4.

The average simulated traffic counts for two detector locations, upstream of work zone and within work zone, were compared with field obtained data. The comparison is illustrated in Figure 10. Dashed lines represent the 95% confidence intervals from simulation. The MAPE for the two locations were 9.8% and 6.0%, suggesting that the diversion algorithm was valid by producing similar work zone traffic volume. The validation of the diversion algorithm can also be demonstrated by the similar patterns of queue propagation process for the simulation and field observations shown in Figure 11.

The comparison for the percentage of ramp traffic by hour is shown in Figure 12. Normal stands for the ramp volume percentage under normal condition without work zone presence. Similar to traffic counts and queue length, the average and 95% confidence interval for ramp traffic are also illustrated in the figure. It can be observed that the work zone significantly increased the exiting traffic. Although the observation did not fall into 95% confidence interval from simulation, the largest difference between simulation and observation was less than 5% and the standard deviation of the difference was 0.018 (1.8%). The comparison for ramp volume reinforced that the diversion algorithm can reproduce the field observations.



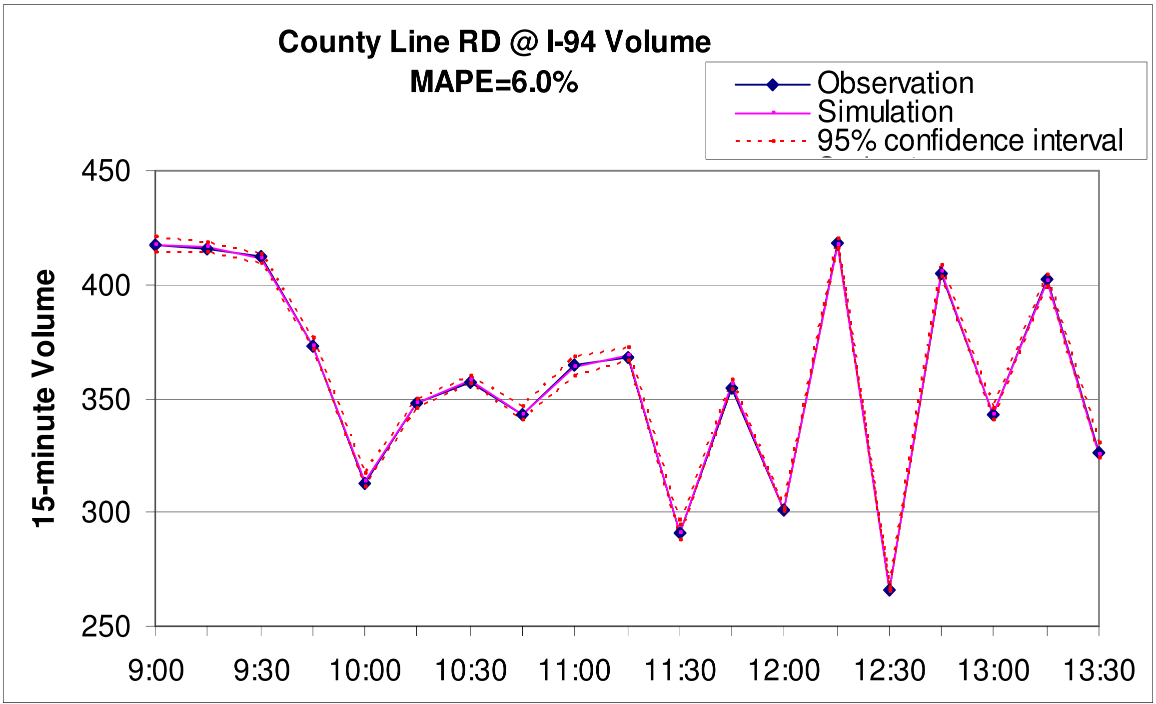


FIGURE 10 Validation for diversion algorithm (WZ4).

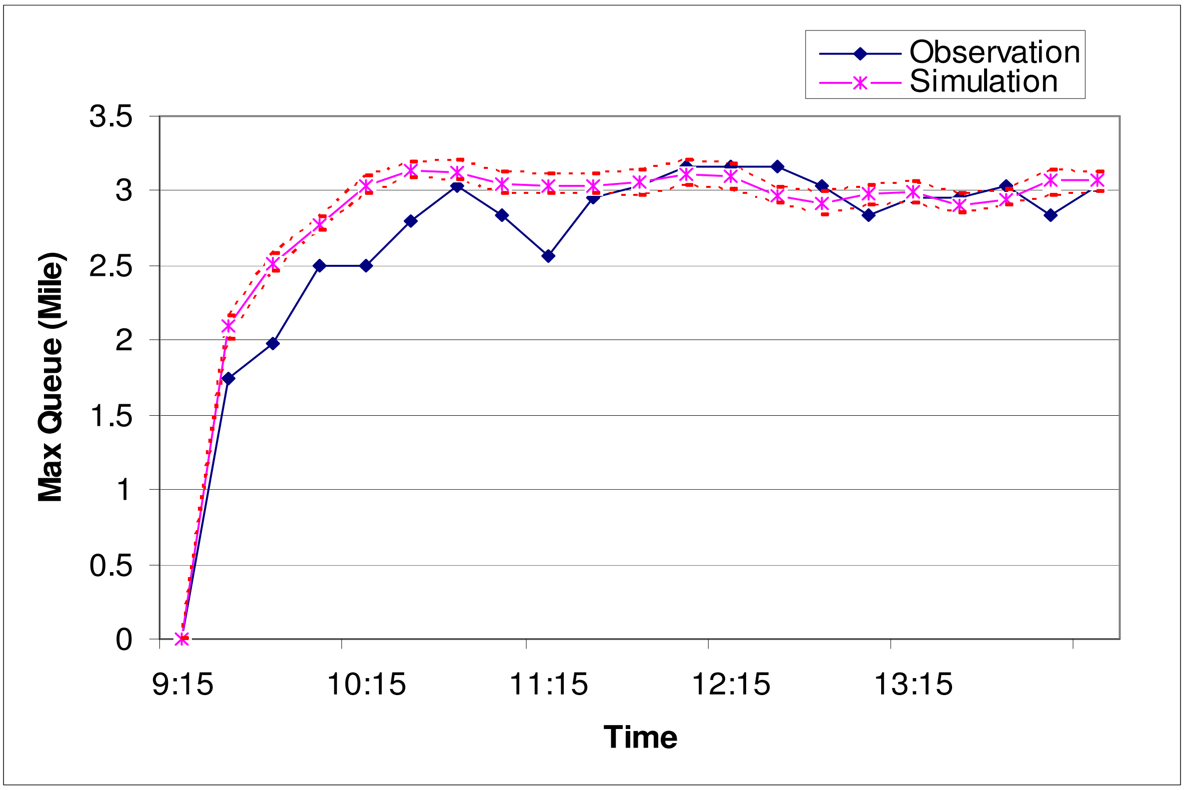


FIGURE 11 Queue length comparison (WZ4).

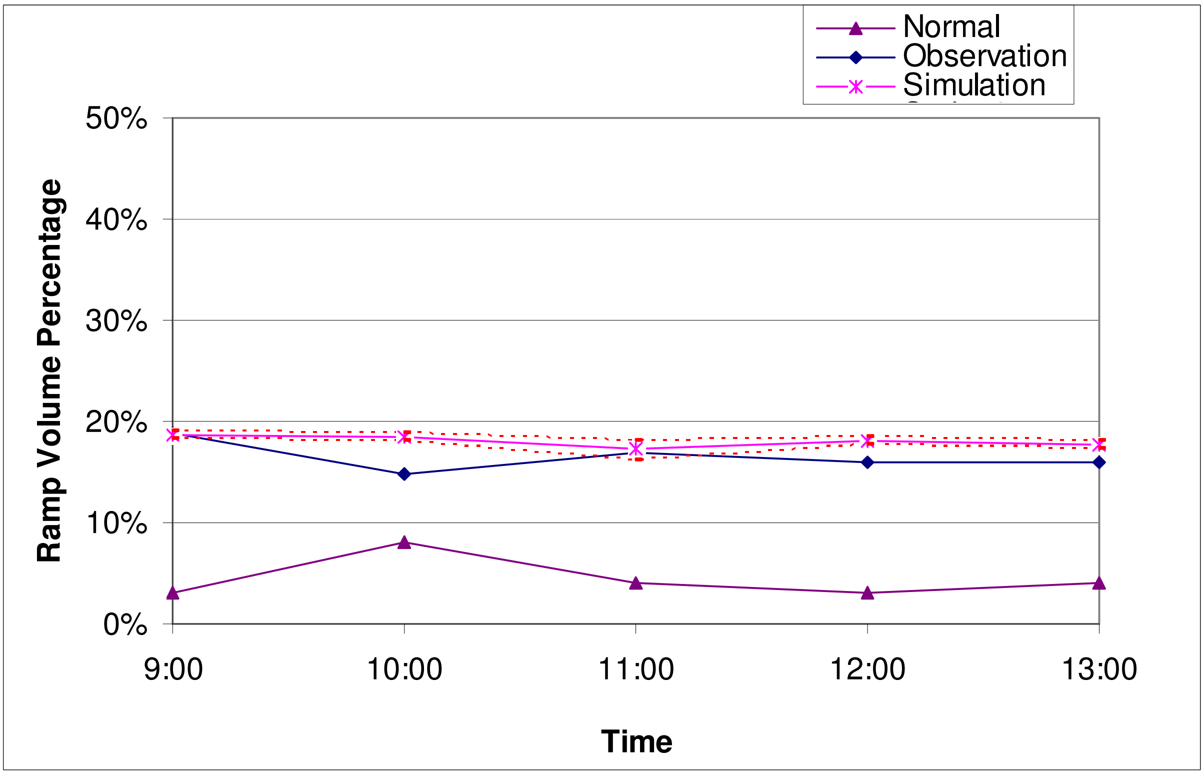


FIGURE 12 Ramp volume percentage comparison (WZ4).

CONCLUSIONS

A hybrid process combining micro-simulation and logistic regression was developed in this paper to replicate diversion behavior in work zone approaching area. It was an attempt to produce accurate work zone simulation models with consideration of the presence of entrance and exit ramps.

Field observations revealed a significant decrease in traffic volume on entrance ramps due to lane closure with the magnitude of decrease reaching over 40 percent. Additionally, it was also observed that volume on exit ramps increased by as much as 12 percent. Both the decrease in entering volume and increase in exiting volume contributed to the stabilization of queuing propagation upstream of the work zone after the initial development of queues. However, few work zone impact analysis tools reflect the diversion phenomenon in an effective and efficient manner, which often results in the overestimation of the queue length and delay due to lane closure. To yield more accurate estimations, it is necessary to incorporate diversion behavior into the work zone impact analysis. In response, a logistic regression analysis was applied to investigate the impact of the percentage of traffic on entrance/exit ramps under normal conditions, prevailing mainline volume, and queue length, on diversion behaviors. Furthermore, two logistic regression models for entrance and exit ramps were developed to estimate the percentage of ramp traffic with work zone presence.

A well-calibrated work zone micro-simulation model was created to implement the diversion algorithm. The integration between the work zone micro-simulation model and the logistic regression model was achieved via the development of two modules using COM interface provided by VISSIM, namely diversion calculation plug-in and routing decision plug-in. Specifically, the first module estimated the percentage of ramp traffic for each ramp according to simulated prevailing traffic conditions and fed it into the second module. The routing decision module accepted the percentage of ramp traffic and replaced the existing one. The simulation results suggested that the work zone simulation model with diversion control can represent the field observations in terms of the queuing propagation process and the traffic volume. Stated in another way, it was demonstrated that the diversion estimation algorithm based on a logistic analysis had good performance in the simulation environments and can be used to improve the work zone impact analysis by providing good estimates for diversion behavior under lane closure situations.

The main advantage of integrating the diversion algorithm and the simulation model is to provide an approach to estimate the ramp traffic reflecting potential diversion behavior due to lane closure based on the historical data under normal conditions. The interactive process allows dynamically determining the percentage of exiting/entering ramp traffic under work zone conditions, which improves the deterministic queuing approaches that do not take diversion into account. By implementing this approach into one or more of the work zone simulation models, this dynamic approach leads to an accurate prediction of the diversion phenomenon upstream of work zones and the corresponding impacts to work zone capacity.

Note that the diversion algorithm is one of the components in the work zone simulation model since work zones involve lane closure and speed reduction in addition to diversion phenomenon. The application of the diversion algorithm requires a simulation model that has been calibrated for work zone scenarios reflecting car following and lane changing behavior in work zones.

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