REGIONAL MICROSCOPIC SIMULATION MODEL FOR STUDYING TRAFFIC CONTROL STRATEGIES AT A WORK ZONE

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Transportation Research Board 88th Annual Meeting,
January 11-15, 2009, Washington, DC

Submitted to consider for presentation and publication
Date of submission: August 01, 2008

Word Count: 4715 + 11*250 = 7465

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ABSTRACT

Work zones have significant negative impacts resulting from reduced capacity and speed, and increased accidents and delay. Thus, it is important to design a traffic control strategy that has minimum potential impact on the traffic at the work zone and the traffic in its vicinity. In this study, a regional microscopic model is used to evaluate different control strategies at a work zone on interstate I-89 in Vermont. The strategies are, i) no lane closure, but no shoulders, ii) one northbound lane closure, iii) one northbound and one southbound lane closure. The model predicted no significant traffic jam at any place in the work zone and surrounding area. Evaluation of strategy ii) for three different speed limits of 45, 35, 25 mph also resulted in a smooth traffic flow, but at reduced speed and increased density. However, a significant diversion of traffic to alternate routes was predicted. Data gathered during construction field observation and data fairly agree with the model prediction. The during-construction and before-construction analysis shows significant diversion of commuters on weekdays. But the traffic flow on a weekend during-construction is found similar to the flow on weekend before-construction.

KEY WORDS: Regional microscopic simulation, PARAMICS, Work zone

1. INTRODUCTION

Developing an efficient traffic control strategy at work zones and in its vicinity is a challenging task. The task is made more difficult when a work zone is on a major arterial requiring lane(s) closure. The potential negative impacts of traffic in work zones includes increased accidents *(1; 2*), reduced speed and capacity (*3; 4; 5*), and increased congestion and users cost (*6*). The control strategies usually adopted by traffic managers at a work zone include using shoulders, partial road closing, one directional traffic flow, constructing crossovers, and closing the road in both directions. Usually the impact of work zone is not limited to the traffic on the road being repaired, but the work zone also affects the traffic on nearby roads. Thus control strategies at work zone may necessitate additional control strategies on nearby roads. The selection of any particular strategy is a tradeoff between construction work difficulty and traffic impact. For example, using only road shoulders and not closing any lane might have least impact on traffic, but might increase construction cost by reducing contractor's staging areas. On the other hand, closing the entire road could make construction easier, but it can have significant impact on the traffic in terms of increased travel cost and discomfort/fatigue to travelers.

Ideally, the traffic manager should evaluate all feasible control strategies, taking into account both construction cost as well as users' discomfort and travel cost. The difficulty associated with evaluating control strategies, however, is that each work zone is unique. Work zones differ in terms of the number of lanes being closed, the length of the work zone, the duration of the work zone, allowable speed limits in and outside work zone, type of barricades in partial road closures, deployment of dynamic message signs (DMS) and other sign boards, road geometry at the work zone (gradient, curve, etc), type of the road, and the availability of the alternative routes. Although HCM2000 provides expressions for estimating capacity of freeway at work zones, it is not easy to develop standard analytical models to evaluate the overall performance of work zones. A microscopic simulation model is capable of modeling both traffic dynamics as well as travelers' complex routing logics (7*; 8; 9; 10*); thus it is an appropriate tool for conducting work zone analysis. For work zones, the ability of the simulation model to capture drivers' routing behavior is critical, because drivers encountering a work zone are likely to seek alternative routes especially if appropriate information is provided via strategically-located DMS. In this study we present a case study of a work zone on interstate I-89 in Vermont modeled using a PARAMICS based micro-simulation model. Additionally, we analyze the traffic characteristics (traffic counts and speed) observed during-construction and compare it with the before-construction and model predicted traffic characteristics.

The main purpose of this paper is to demonstrate the feasibility, and advantages, of using a regional microscopic traffic simulation model to evaluate various traffic control scenarios proposed for a work zone. This is accomplished by looking at a real-world case study from the State of Vermont, where a regional PARAMICS model, previously developed for Chittenden County in northwestern Vermont (*10*), was used to evaluate three suggested traffic control strategies for a major repaving/reconstruction project on Interstate 89. The paper uses real-world traffic data, collected before the beginning of the construction work and during the construction, in order to compare the traffic characteristics predicted by the model with actual traffic characteristics during construction.

The paper is organized into seven sections as follows. In the next section a brief literature review on work zones and simulation models is presented. Background information about the case study, and the PARAMICS regional microscopic simulation model used to evaluate the three different traffic control strategies, are provided in section 3. Section 4 describes how the PARAMICS model was first validated, and how the different scenarios were then modeled in PARAMICS. The modeling results for the three scenarios are also presented in this section. Additional analyses are performed to show the impact of different speed assumptions on the results in section 5. Finally, traffic data collected before and during construction are presented and contrasted against the model results in section 6. Section 7 concludes the paper by summarizing the important findings of the study.

2. LITERATURE REVIEW

As discussed above, each work zone has unique characteristics, thus no standard analytical models to evaluate overall work zone impact are not available in the literature. However, many empirical studies and experiences concerning the various aspects of work zones such as capacity, speed, user cost, and safety have been reported. Capacity, speed, and queue-discharge rate at work zones on a four-lane freeway in Indiana are studied in (*3*). The findings in the study indicate that sustained low vehicles speeds and fluctuating traffic flow rates are the characteristics of most work zones. The study reported traffic flow reductions of up to about 21% traffic flow and up to about 56% in speed. Dixon, et al., (*5*) determine work zone capacities for rural and urban freeways based on the traffic data from 24 work zones in North Carolina. The authors conclude that the intensity of work activity and the type of area (rural or urban) strongly affect work zone capacity. A procedure to determine speed limits that maximizes traffic safety in work zones is developed in (*11*)

Safety of workers and drivers in work zones is a primary concern, arguing for strong precautions to be taken while developing and implementing traffic control strategies. A study by Rouphall, et al. (*2*) documents the safety and operational aspects of 46 short term and long-term (construction lasted longer than 4 days) work zones in the Chicago metropolitan area. It is reported that long-term closures increased accidents by 88% during the existence of work zones. The analysis of accidents over a three year period from 1994 to 1996 in New York State is reported in (*1*).

An important observation from the literature review is that the majority of the past studies restrict the analysis to the work zone without giving much attention to the traffic and roads in the vicinity of the work zone. This is mainly because studying the impacts on the surrounding area would require modeling drivers' complex routing decisions including diversion to alternative routes. A static model such as user equilibrium traffic assignment cannot model work zones traffic dynamics realistically. Analytical approaches of modeling traffic dynamics suffer from many challenges such as simpler behavioral assumptions, complexity of analytical formulations, and other issues (*12; 13*). The difficulties with the analytical models have led researchers to develop simulation models to model traffic dynamics and drivers' behavior. Simulation models have become popular because of their ability to model various traffic flow conditions realistically therefore resulting in more accurate results (*14; 13*). For example, a large-scale micro-simulation model for the Salt Lake Area is developed by Rakha, et al., (*15*) and a micro-simulation is used to model freeway work zone traffic control in Mousa, et al., (*9*). The study integrates simulation and optimization submodels to determine optimum merging strategy.

Zhang, et al., (*7*) present systematic validation of a microscopic simulation model which involves animation comparison and quantitative/statistical analysis at macroscopic and microscopic levels. Numerous other studies are found in the literature where microscopic simulation tools have been used to model traffic dynamics and drivers' behavior from relatively small highway facilities such as traffic signals to large-scale regions involving traffic and highways in multiple cities and towns.

3. BACKGROUND

3.1 The case study

The Vermont Agency of Transportation (VTrans) undertook a major repaving/ reconstruction project over a significant segment of the northbound direction of Interstate 89 (I-89) in the summer of 2008. I-89, a two-lane freeway in Chittenden County, connects the Burlington metropolitan area—the biggest urban cluster in Vermont, to the surrounding towns and counties. The annual average daily traffic between Exit 11 and Exit 12 on I-89 in 2004 was 28,600 vehicles, which is one of the highest in Vermont (8). The Agency of Transportation expected to either partially or fully close the northbound roadway for two to four weeks under various proposed traffic control strategies to complete the reconstruction. Given the critical role that I-89 plays in accommodating travel throughout Chittenden County and the State of Vermont as a whole, VTrans was interested in understanding the impact that the project, along with its potential traffic control strategies, would have on travel characteristics. Obviously, the impact of a project of such magnitude on travel conditions is not likely to be limited to I-89 only, but is expected to affect the surrounding transportation network as drivers seek alternative routes. An analysis tool capable of evaluating the impact both on I-89 and the surrounding network and capable of capturing changes in travelers' routing behavior in response to the construction work, was required. This was especially true, given that VTrans, as a part of the repaving project, intended to provide travelers' with real-time information on the expected delay through the work zone, using a series of strategically-located DMS

VTrans asked the researcher to evaluate three traffic control strategies using microscopic traffic simulation to examine the effects on the morning and evening peak periods. There was considerable concern within VTrans about the impacts of lane closures on I-89 and surrounding roads. The three strategies were as follows:

- Strategy 1 (ST- 1): Under this strategy, two lanes would remain open in each direction (i.e. no lane closure was proposed) by opening the shoulder for traffic. The lanes, however, would be quite narrow, and traffic would move at a lower speed of 55 mph in the northbound direction of I-89. Traffic in the southbound direction would remain unaffected.
- Strategy 2 (ST-2): This strategy includes closing one northbound lane, thus leaving one lane open for traffic. The southbound traffic is unaffected thus two lanes carry the traffic. Since the work zone does not affect the southbound traffic the speed limit is not changed. However, the speed limit of northbound traffic is changed to 55 mph.
- Strategy 3 (ST-3): In this strategy, it is proposed to keep one lane open for traffic in each direction. This is achieved by closing both northbound lanes and using one southbound lane for the northbound traffic. Crossovers are proposed to be constructed to maneuver the traffic.

If the period of control strategies were the same for all strategies, ST-1 can be expected to result in a minimum impact on the traffic since no lane is closed in either direction. On the other had ST-3 will have the maximum impact on the traffic, because in this strategy only one lane is available for each of the northbound and southbound traffic. From the contractor's point of view, ST-3 would be the most convenient since traffic would not be interfering with the work zone, and ST-1 would be the most challenging. The estimated construction cost of each strategy was:

ST-1: $9,948,758.00
ST-2: $7,878,758.00
ST-3: $8,293,758.00

The cost of ST-1 is the highest, mainly because the construction period in this strategy was expected to be 30 days, whereas for the other two strategies, it would be only 15 days.

3.2 The Regional Microscopic Simulation Model

Many traffic simulation tools such as VISSIM (*17*) PARAMICS (*18*), DYNASMART (*19*) , and MITSIM (*20*) have been developed in recent years to model traffic dynamics and drivers' behavior. In this study, a regional microscopic traffic simulation model previously developed by one of the authors is used to evaluate the likely impacts of the suggested work zone traffic control strategies and to make recommendations to VTrans aimed at minimizing the impact of the construction work on the transportation network performance.

The simulation model used in this study was developed for Chittenden County, an area of about 540 sq miles, and population of 146,000, using PARAMICS 6.2. The PARAMICS suite consists of three basic tools: i) Modeller, the core network building tool, designed to operate at the microscopic level and integrates with the core PARAMICS tools, ii) Processor, a batch simulation management tool that reduces simulation run time, and iii) Analyser, a post simulation data analysis package.

The road network modeled includes all important roads including interstate, state highway, and other major routes. The trip matrices were obtained from the Chittenden County Metropolitan Planning Organization (CCMPO). The matrices were developed and calibrated for year 2000. The CCMPO model has a total of 367 traffic analysis zones (TAZs) including 17 external zones. The same zoning, used in the CCMPO model, is used in the micro-simulation model. More details of the model development and calibration are presented in (*10*). Originally the model was developed only for the evening peak period. Therefore, in order to develop the demand profile during the morning peak, the authors used a diurnal trip distribution derived from a 24-hour trip diary survey conducted by the CCMPO in 1998. For the morning peak, the period modeled extended from 6:30 AM to 8:45 AM.

4. TRAFFIC CONTROL STRATEGY EVALUATION

4.1 Model Validation

As discussed above the original PARAMICS model uses year 2000 trip matrices and was developed only for the evening peak. For the purpose of this study, new trip tables are developed assuming 1% annual growth rate in trips since 2000. Thus there is a need to validate the updated model with the existing traffic condition to assess the model's accuracy. The scope of the validation effort was limited to the area near the proposed road improvement, thus the model is validated with the morning and evening traffic counts on the segment of I-89 to be repaved and major arterials in its vicinity (US-2 and VT-2A). The traffic counter locations used in the study are shown in Figure 1.

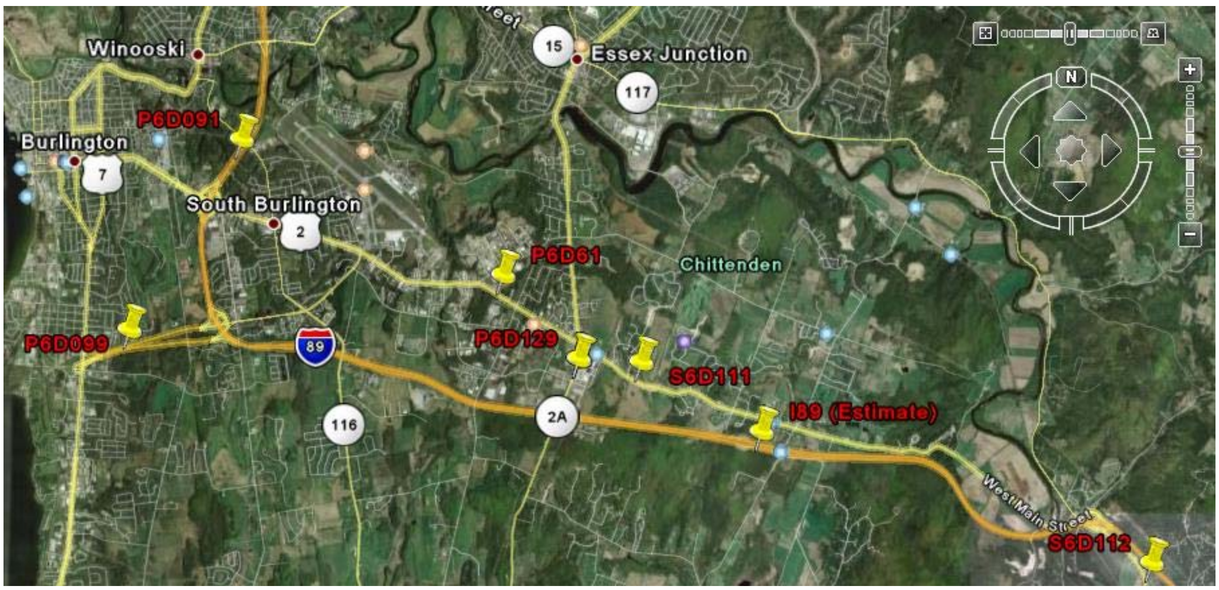

Figure 1 Observed traffic count locations

Table 1 compares the simulated traffic counts to the field counts at seven locations in the vicinity of the proposed project for both the morning peak period (6:30 AM to 8:45 AM), and the evening peak period (3:30 PM to 5:45 PM). The initial 30 minutes are assumed to be the warm-up period, thus the simulated link counts during that period are not compared with the observed counts.

Table 1 Comparison of Estimated Flows with Field Counts

Time		Simulation NB	Simulation SB	Simulation Total	Field observed	% difference
		I-89 between exit 11 and 12				
7:00 AM	8:00 AM	1344	360	1704	2323	-26.6%
8:00 AM	9:00 AM	1593	527	2120	2150	-1.4%
4:00 PM	5:00 PM	924	1074	1998	2642	-24.4%
5:00 PM	6:00 PM	913	1095	2008	2760	-27.2%
		P6D129 (Williston VT2A just N of Marshall Ave)				
7:00 AM	8:00 AM	388	805	1193	1223	-2.5%
8:00 AM	9:00 AM	459	708	1167	1309	-10.9%
4:00 PM	5:00 PM	570	1035	1605	1792	-10.4%
5:00 PM	6:00 PM	592	1025	1617	1654	-2.2%
		P6D061 (Williston US2 0.2 mi E of industrial ave)				
7:00 AM	8:00 AM	475	379	854	663	28.9%
8:00 AM	9:00 AM	500	489	989	766	29.2%
4:00 PM	5:00 PM	617	613	1230	1163	5.8%
5:00 PM	6:00 PM	624	673	1297	1033	25.6%
		P6D099 (S Burlington I-189 0.4 mi E of US7)				
7:00 AM	8:00 AM	923	1395	2318	3198	-27.5%
8:00 AM	9:00 AM	1145	1711	2856	3201	-10.8%
4:00 PM	5:00 PM	2472	1611	4083	3833	6.5%
5:00 PM	6:00 PM	2528	1560	4088	4032	1.4%
		P6D091 (S Burlington I-89 0.7 mi N of US2 (Ext14))				
7:00 AM	8:00 AM	1995	1388	3383	3014	12.2%
8:00 AM	9:00 AM	2412	1600	4012	4238	-5.3%
4:00 PM	5:00 PM	2188	2550	4738	5507	-14.0%
5:00 PM	6:00 PM	1996	2905	4901	5312	-7.7%
		S6D111 (Williston US2 0.8 mi E of VT2A)				
7:00 AM	8:00 AM	548	87	635	825	-23.0%
8:00 AM	9:00 AM	664	103	767	782	-2.0%
4:00 PM	5:00 PM	183	1050	1233	1002	23.1%
5:00 PM	6:00 PM	189	1128	1317	1080	22.0%
		S6D112 (Richmond: US2 W of Village Cemetery Ent)				
7:00 AM	8:00 AM	673	96	769	764	0.6%
8:00 AM	9:00 AM	841	144	985	782	26.0%
4:00 PM	5:00 PM	271	530	801	826	-3.0%
5:00 PM	6:00 PM	279	557	836	1038	-19.4%

The observed traffic counts are not available for 15 min intervals, thus simulation traffic counts for 8:45 AM to 9:00 AM and 5:45 PM to 6:00 PM are estimated by extrapolating the simulated traffic volume during the previous 45 minutes. In other words, the simulated traffic from 8:00 AM to 8:45 AM is assumed to be 75% of the traffic volume between 8:00AM to 9:00AM. Traffic between 5:00 PM to 6:00 PM is estimated similarly. With the exception of traffic counts on I-89, the observed traffic counts are not directional, thus the total volume is compared.

The percentage difference with the observed volume is given in the last column, where it can be seen that the absolute percent difference ranges from 1% at some locations to 29% at others. For I-89, the two observed traffic counts indicate that the micro-simulation model underestimated the traffic on I-89 except for the traffic between 7:00 to 8:00 AM at P6D091. Route US-2 is an alternative route that runs parallel to I-89 along the construction zone. At one location on US-2, the model overestimates the traffic during both morning and evening peak periods. The trend at other two locations varies from the morning to the evening peak. Given the stochastic nature of traffic, the authors felt that the micro-simulation model accuracy was adequate for the purposes of this project.

4.2 Evaluation of the three Traffic Control Strategies

The general trend of the traffic at the work zone is that the morning peak is more critical to northbound lanes since the residents of nearby towns (Williston, Jericho, Richmond, etc.) use the interstate for their morning commute north to Burlington. As a consequence, northbound lanes carry higher volumes during the morning peak, which means that closing the northbound lane(s) will affect the morning peak traffic the most, and closing the southbound lane(s) closure will affect the evening peak traffic the most.

The above three strategies are coded in the PARAMICS models individually and the model run for both morning and evening peak periods. In coding the different strategies, the following two assumptions are made: 1) the speed limit in work zone will be reduced from 65 MPH to 55 MPH 2) vehicles will be prohibited from passing in the work zone. An additional run of the base model without traffic control strategies was also conducted. The visual inspection during the simulation runs shows no indication of any serious traffic jam at any location in the vicinity of the project for any of the proposed control strategies. However, the model did indicate speed reduction and density increase in the work zone. Traffic diversion from I-89 to the alternative route US-2 was observed at Exit 11.

The outputs from the simulation runs of Modeller are processed with Analyser and reports are created to get information on traffic parameters (link counts, speed, delay etc). Two locations are selected at the work zone on I-89 and one on US-2 to compare the link count and speed under different control strategies.

The link counts and speed of the northbound traffic during morning and evening peak on I-89 at the construction site are presented in Table 2, while Table 3 shows the similar results for the northbound traffic on US-2. The results indicate that under all strategies the work zone will divert the traffic from I-89 to alternative routes, most likely US-2. The amount of diversion varies with the strategy. ST-1 is estimated to cause a minimal diversion (average 4.3%) followed by ST-2 and ST-3. The speed values in all three strategies indicated that lane closure has no severe impact on the traffic flow.

Table 2 Link Flow and Speed on I-89 (NB) for Three Control Strategies

Start Interval	End Interval	Link Count							Link Speed (mph)			
		Base	ST-1		ST-2		ST-3		Base	ST-1	ST-2	ST-3
7:15	7:30	285	275	-3.5%	267	-6.3%	249	-12.6%	68.79	57.79	60.66	60.78
7:30	7:45	391	342	-12.5%	341	-12.8%	331	-15.3%	68.89	56.29	59.91	59.20
7:45	8:00	358	358	0.0%	340	-5.0%	356	-0.6%	69.45	56.57	59.33	59.55
8:00	8:15	409	393	-3.9%	397	-2.9%	388	-5.1%	68.63	56.12	59.48	59.28
8:15	8:30	393	408	3.8%	392	-0.3%	387	-1.5%	68.41	55.99	58.62	59.17
8:30	8:45	490	450	-8.2%	456	-6.9%	445	-9.2%	68.91	55.90	59.72	60.03
(7:15 to 8:45)		2326	2226	-4.3%	2193	-5.7%	2156	-7.3%				
(vehicles/hour)		387.7	371	-4.3%	365.5	-5.7%	359.333	-7.3%				

Since US-2 is an alternative route to I-89 in the area of the project, reduction in the traffic on I-89 is expected to increase the traffic on US-2. This effect is clearly visible from the results of ST-2 and ST-3 in Table 3. ST-1 shows a small reduction in traffic, but this might be due to the randomness associated with PARAMICS model. The increase in traffic under strategies ST-2 is about 7% and ST-3 is about 12%; this increase can be attributed to the diverted traffic from I-89.

Table 3 Link Flow and Speed on US-2 (NB) for Three Control Strategies

Start Interval	End Interval	Link Count							Link Speed (mph)			
		Base	ST-1		ST-2		ST-3		Base	ST-1	ST-2	ST-3
7:15	7:30	45	51	13.3%	51	13.3%	73	62.2%	42.74	42.25	43.09	43.03
7:30	7:45	46	52	13.0%	60	30.4%	64	39.1%	41.64	41.72	41.57	41.67
7:45	8:00	68	69	1.5%	92	35.3%	72	5.9%	41.91	42.57	41.96	42.40
8:00	8:15	76	78	2.6%	69	-9.2%	83	9.2%	42.66	41.79	42.08	41.79
8:15	8:30	136	100	-26.5%	112	-17.6%	100	-26.5%	41.53	42.64	42.87	42.62
8:30	8:45	48	63	31.3%	64	33.3%	76	58.3%	41.38	42.40	41.67	41.34
Total link counts		419	413	-1.4%	448	6.9%	468	11.7%				
Average link		69.83	68.83	-1.4%	74.67	6.9%	78	11.7%				

ST-2 has the minimum estimated cost and the traffic impact is not expected to be significantly higher than ST-1 (ST-2 is better than ST-2 if there are equal number of days of closure), VTrans decided to implement ST-2. Thus, further analyses are conducted for ST-2.

5. SPEED SCENARIOS FOR STRATEGY ST-2

The results in the previous section conclude ST-2 is not expected to severely impact traffic in the project impact area if the free flow speed is 55 mph. However, the past experience on traffic condition in work zones in Vermont indicates that the free flow speed of 55 mph is very optimistic. Additionally, the location of the project is on a hill with 5% upward slope for the northbound traffic. A further complication is that the work zone is on a long curve. Three additional speed scenarios were developed for ST-2. The outputs of the ST-2 simulation model are analyzed for the speed of 45, 35 and 25 mph. The results (link flow and speed) at the location shown in at two locations (one in the work zone and other on alternative route US-2) are presented in Table 4 and Table 5.

The results in Table 4 show that the reduced speed in work zone discourage drivers from using I-89. The average percentage of diversion during peak hours with the free flow speed of 25 mph is about 34%. The speed values indicate that the traffic would move without any significant queue formation. The large percentage of diversion from I-89 has resulted in a significant increase in the volume on US-2 (Table 5). When the speed in work zone is 45 mph the increase in peak hour traffic is about 26% and when the speed is reduced to 25 mph, the increase in traffic is about 76%. Nevertheless, it appears that even with these more conservative estimates for traffic speed in the work zone, the network performance would still be acceptable, although a significant percentage of drivers would have to divert to US-2 to maintain acceptable flow conditions.

Table 4 Link Flow and Speed on I-89 (NB) for Speed Scenarios (Morning Peak)

Start Interval	End Interval	Link Flow (vehicles/hour)							Link Speed (mph)			
		Base	SP-I (45 mph)		SP-II (35 mph)		SP-III (25 mph)		Base	SP-I	SP-II	SP-III
7:15	7:30	1176	972	-17.3%	884	-24.8%	648	-44.9%	70.83	49.72	39.00	27.76
7:30	7:45	1344	1264	-6.0%	976	-27.4%	804	-40.2%	69.46	48.97	38.18	27.40
7:45	8:00	1496	1188	-20.6%	1268	-15.2%	968	-35.3%	68.35	48.71	37.64	27.43
8:00	8:15	1672	1568	-6.2%	1260	-24.6%	1040	-37.8%	68.51	48.80	38.02	26.97
8:15	8:30	1504	1168	-22.3%	1124	-25.3%	1144	-23.9%	68.97	50.07	38.36	27.00
8:30	8:45	1712	1680	-1.9%	1364	-20.3%	1300	-24.1%	67.92	48.08	37.52	26.74
Total link counts (7:15 to 8:45)		2226	1960	-11.9%	1719	-22.8%	1476	-33.7%				
Average link flow (vehicles/hour)		1484	1306.7	-11.9%	1146	-22.8%	984	-33.7%				
		Note: The flow is per hour and not per 15 minutes										

Table 5 Link Flow and Speed on US-2 (NB) for Speed Scenarios (Morning Peak)

Start Interval	End Interval	Link Flow (vehicles/hour)							Link Speed (mph)			
		Base ca	SP-I (45 mph)		SP-II (35 mph)		SP-III (25 mph)		Base	SP-I	SP-II	SP-III
7:15	7:30	204	272	33.3%	400	96.1%	472	131.4%	43.26	41.51	43.08	43.24
7:30	7:45	216	296	37.0%	384	77.8%	592	174.1%	42.62	42.82	42.57	43.22
7:45	8:00	284	376	32.4%	304	7.0%	476	67.6%	42.92	42.06	42.51	42.72
8:00	8:15	328	448	36.6%	604	84.1%	700	113.4%	42.26	42.26	42.68	41.99
8:15	8:30	516	620	20.2%	656	27.1%	540	4.7%	41.38	42.84	42.15	42.38
8:30	8:45	396	436	10.1%	652	64.6%	644	62.6%	43.09	41.87	41.83	41.84
Total link counts (7:15 to 8:45 AM)		486	612	25.9%	750	54.3%	856	76.1%				
Average link flow (vehicles/hour)		324.00	408.00	25.9%	500.00	54.3%	570.67	76.1%				
		Note: The flow is per hour and not per 15 minutes										

6. FIELD OBSERVED TRAFFIC DATA DURING CONSTRUCTION

The reconstruction work started on May 15, 2008 and the northbound lane was closed from Thursday May 15, 2008 to Sunday May 25, 2008. In order to analyze and compare the traffic characteristics during the construction period, VTrans collected traffic volume and speed at the work site both before and after construction. Before construction hourly traffic volumes were collected on northbound lanes starting from 1:00 PM on Tuesday May 06, 2008 to Monday, May 12, 2008. The during construction traffic data collection started on 11:00 AM on Thursday May 15, 2008 and ended 10 AM on Tuesday May 20, 2008.

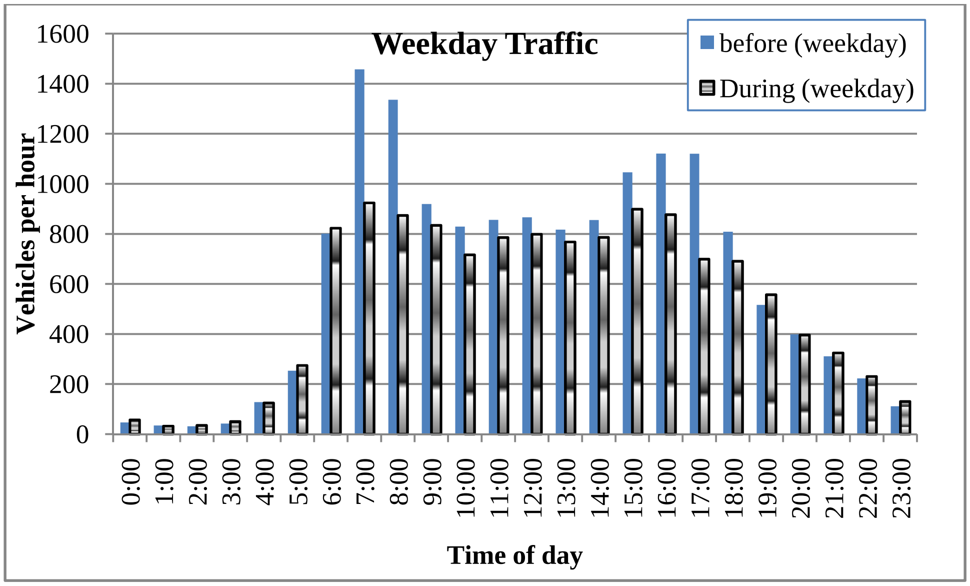

Figure 2 Comparison of before and after traffic volumes on weekdays

Figure 2 compares traffic volumes on I-89 at the work zone before and after the beginning of construction. As can be seen, traffic volume on I-89 at the work zone has two distinct peak periods and the volume during morning peak is higher than in the evening peak. The plot shows that during construction traffic volume is significantly less than the before construction traffic volume, especially during peak hours. The average reduction in volume during 7:00 to 9:00 AM is about 35%. The percentage of diversion estimated by the micro-simulation models was about 34% for the speed of 25 mph. Therefore at the reduced speed assumption the model predicted traffic diversion volume accurately. Unlike the weekday the hourly traffic on a weekend shows a single peak spread over several hours of a day (Figure 3). Additionally, there is no significant diversion of traffic from I-89 to other routes.

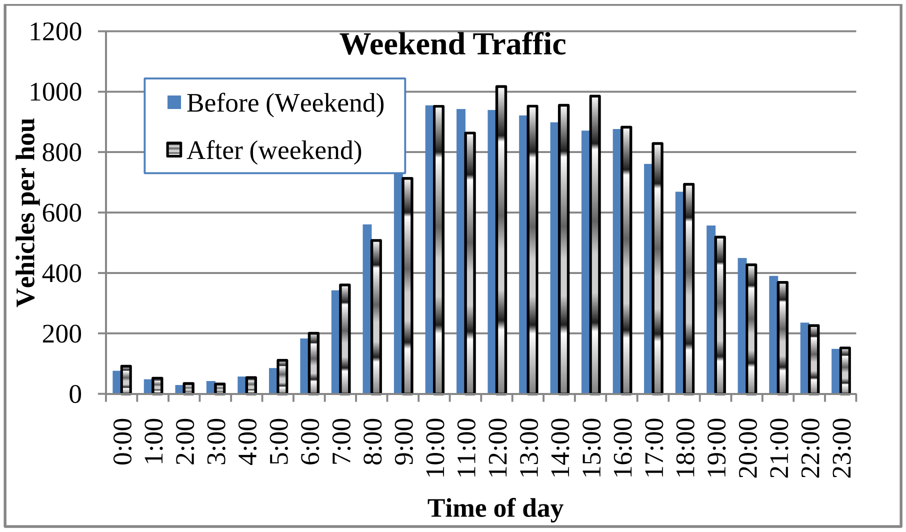

Figure 3 Comparison of before and during traffic volumes on weekends

It should be noted that, on the second day of the lane closure (Friday May 16, 2008) between 7:00 to 9:00 AM there was about 50% traffic diversion. However, the diversion decreased during the later part of the day (Figure 4). The reduction in traffic volume decreased significantly after 4:00 AM, this we believe is mainly due to the drivers returning to Burlington for a weekend.

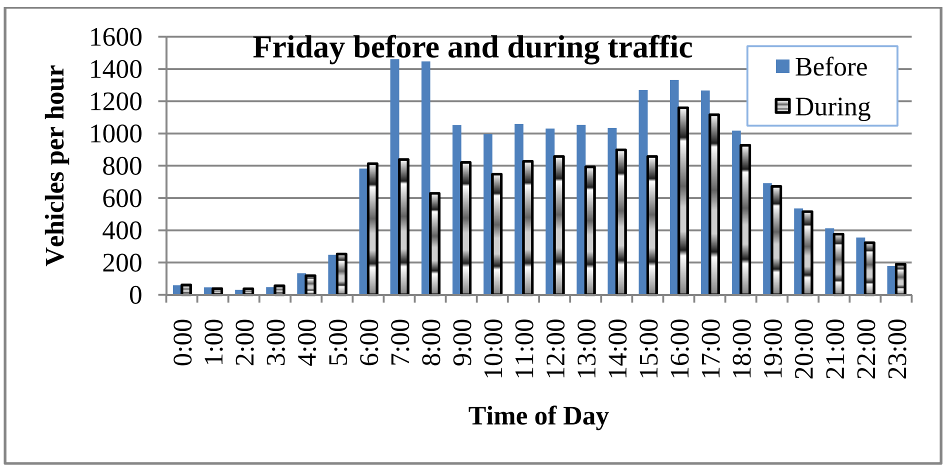

Figure 4 Traffic comparison on the second day of lane closure

The before construction speed data is collected for both passing and through northbound lanes. During construction the passing lane was closed. For the purpose of comparison, we combine both passing lane and through lane speed data. The speed is not available in absolute values but in ranges, as shown on the horizontal axis of Figure 5 and Figure 6. The plots show that there are not significant differences in the vehicles speed on weekdays and weekends. In the absence of the work zone, on a weekday about 83% of vehicles moved at a speed between 61 to 75 mph. During the construction activities about 72% of the vehicles moved at a speed between 41 to 45 mph. The speed during construction is much higher than the speed anticipated by VTrans officials.

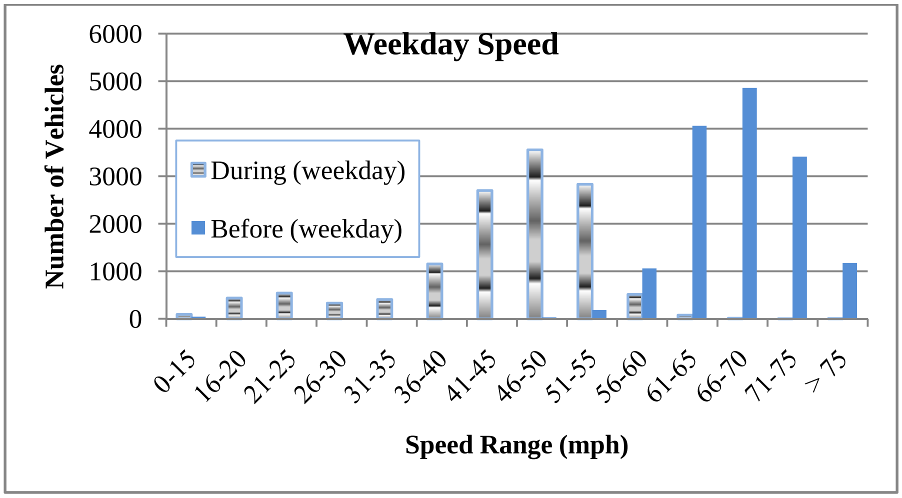

Figure 5 Comparison of before and during speed on weekends

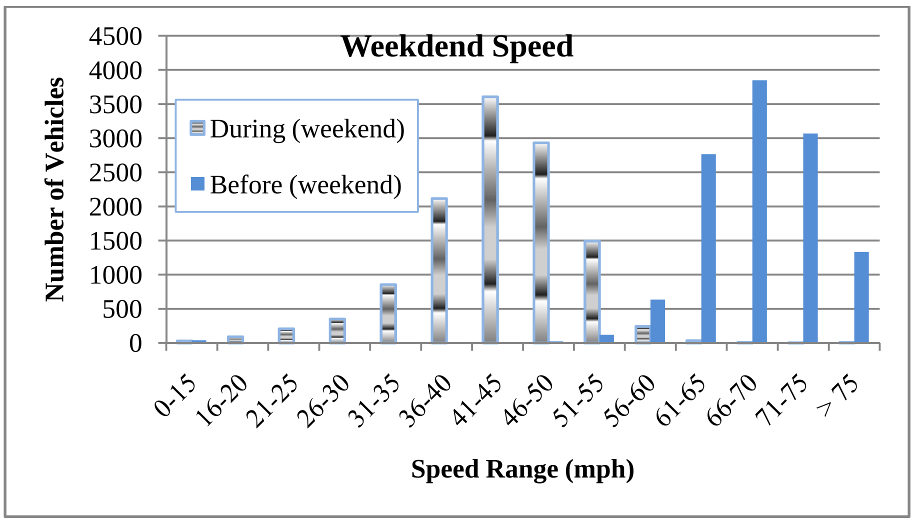

Figure 6 Comparison of before and during speed on weekday

7. CONCLUSIONS

In this study a regional PARAMICS based microscopic simulation model is used to model and evaluate different traffic control strategies at a work zone on interstate I-89 in Vermont. I-89 has two lanes each in northbound and southbound directions; the work zone is in the northbound direction. The simulation model is validated with the traffic counts collected at 7 locations on I-89 and arterials in nearby area. The three control strategies evaluated for morning and evening peak periods are, i) no lane closures in either direction, but not shoulders for northbound traffic, ii) one northbound lane closure, and iii) one northbound and one southbound lane closure. The model predicts 4.3, 5.7, and 7.3 percent traffic diversion from northbound lanes during morning peak in the first, second, and third strategies respectively assuming the speed limit in northbound is 55 mph. The model predicts smooth flow for the second strategy for speed values of 45, 35 and 25 mph. A higher diversion of up to about 34% was observed in the second strategy for a lower speed of 25 mph. The reduction in the traffic at work zone resulted in the increased traffic on US-2, an alternative route to I-89 for the traffic in surrounding area. No reduction in the speed because of congestion is predicted on any route. During construction, data show about 50% traffic diverted from I-89 to other routes during morning peak hours.

The results presented in the study and our own experience from this exercise demonstrate the regional microscopic simulation models such as the one used in this study are capable modeling the complex traffic conditions and drivers behavior at a work zone and its vicinity. The models help in understanding the capacity, speed, flow, etc under various control strategies. Thus, it is an appropriate tool for agencies interested in evaluating traffic impacts of work zones, especially the ones which require lane(s) closure for a longer period.

8. REFERENCES

(1). Bryden, J. E., Andrew, L. B., & Fortuniewicz, J. S. (1998). Work zone traffic accidents involving traffic control devices, safety features, and construction operations. *Transportation Research Record , 1650*, 71-81.

(2). Rouphall, N. M., Yang, Z. S., & Fazio, J. (1988). Comparative study of short- and long-term urban freeway work zones. *Transportation Research Record , 1163*, 4-14.

(3). Jiang, Y. (1999). Traffic capacity, speed, and queue-discharge rate of Indiana's four-lane freeway work zones. *Transportation Research Record , 1657*, 10-17.

(4). Al-Kaisy, A., Z, M., & Hall, F. (2000). New insights into freeway capacity at work zones. *Transportation Research Record* (1710), 154-160.

(5). Dixon, K. K., Hummer, J. E., & Lorscheider, A. R. (1996). Capacity for North Carolina freeway work zones. *Transportation Research Record , 1529*, 27-31.

(6). Jiang, Y. (1999). A model for estimating excess user costs at highway work zones. *Transportation Research Record , 1657*, 31-41.

(7). Zhang, Y., & E, O. L. (2004). Systematic validation of a microscopic traffic simulation program. *Transportation Research Record , 1876*, 112-120.

(8). Toledo, T., & Koutsopoulos, H. N. (2004). Statistical validation of traffic simulation models. *Transportation Reseach Record , 1876*, 142-150.

(9). Mousa, R. M., Rouphal, N. M., & Azadiva, F. (1990). Integrating microscopic simulation and optimization: application to freeway work zone traffic control. (1254), 14-25.

(10). Smith, M., Sadek, A. W., & Huang, S. (2008). Large-scale microscopic simulation: toward an increasing resolution of transportation models. *ASCE Journal of Transportation Engineering , In press*.

(11). Migletz, J., Graham, J. L., Anderson, I. B., Harwood, D. W., & Bauer, K. M. (1999). Work zone speed limit procedure. *Transportation Research Record* (1657), 24-30.

(12). Boyce, D., D, L., & Ran, B. (2001). Analytical models of the dynamic traffic assignment problem. *Networks and Spatial Economics , 1*, 377-390.

(13). Peeta, S., & Ziliaskopoulos, A. (2001). Foundation of dynamic traffic assignment: the past, the present and the future. *1*, 235-265.

(14). Ben-Akiva, M., Bierlaire, M., Koutsopoulos, H. N., & Mishalani, R. (1998). DynaMIT: a simulation based system for traffic prediction and guidance generation. *Proceedings of the 3rd Triennial Symposium on Transportation Systems.* San Juan, Puerto Rico.

(15). Rakha, H., V, A. M., Bloomer, L., & Huang, X. (1998). Construnction and calibration of a large-scale microsimulation model of the Salt Lake area. *Transportation Research Record* (1644), 93-102.

(16). Vermont Agency of Transportation. (2007). *2006 (Route Log) AADTs State Highways.* Retrieved July 2008, from Traffic Data Electronic Publication: http://www.aot.state.vt.us/Planning/Documents/TrafResearch/Publications/pub.htm

(17). PTV-AG. (2004). *Vissim microscopic traffic and transit simulation user manual - V .3.70.* Karlshruhe, Germany.

(18). Quadstone, L. *Quadstone Paramics V6 Modeller user guide.* Scotland, UK.

(19). Jayakrishnan, R., Mahmassani, H. S., & Hu, T. (1994). An evaluation tool for advanced traffic information and management systems in urban networks. *Transportation Research , 2C*, 129-147.

(20). Massachusetts Institute of Technology (MIT). *Developing of a deployable real-time dynamic traffic assignment system - user guide, DynaMIT & DynaMIT-P, Version 0.9.* Cambridge, Massachusetts.