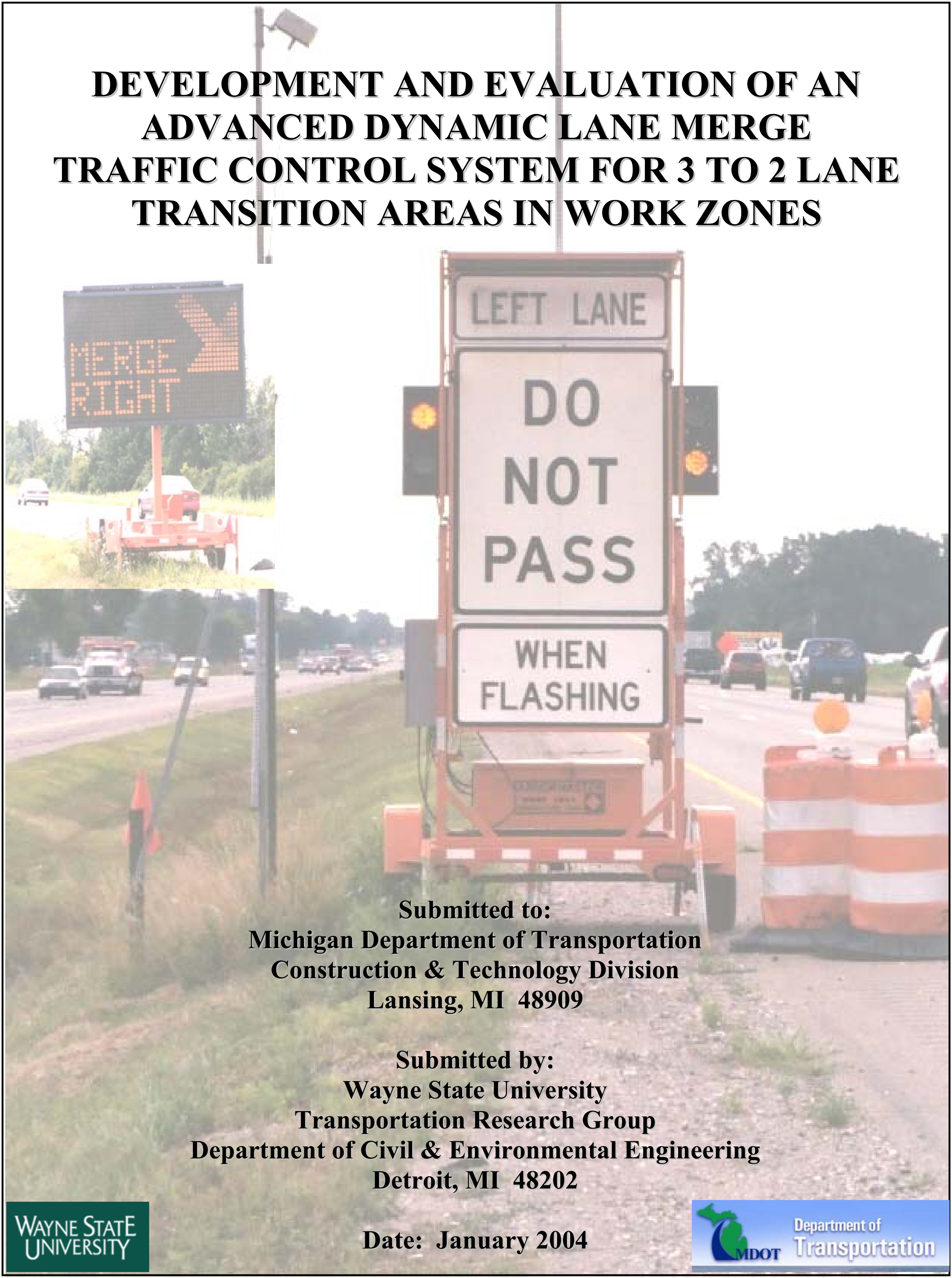
DEVELOPMENT AND EVALUATION OF AN ADVANCED DYNAMIC LANE MERGE TRAFFIC CONTROL SYSTEM FOR 3 TO 2 LANE TRANSITION AREAS IN WORK ZONES



Submitted to:
Michigan Department of Transportation
Construction & Technology Division
Lansing, MI 48909

Submitted by:
Wayne State University
Transportation Research Group
Department of Civil & Environmental Engineering
Detroit, MI 48202

Date: January 2004

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16. Abstract

The majority of safety hazards and resulting traffic crashes that occur in lane closure areas in work zone are often due to the aggressive behavior of some drivers. The late lane merge phenomenon occurs when some drivers try to avoid slow moving traffic by traveling in the lane that is about to end, and then attempt to force a merge in the through lane at the last moment. In an attempt to alleviate such aggressive driver behavior at work zones an innovative traffic control system was developed in Michigan for two (2) to one (1)-lane transition areas in work zones, which was found to be effective. In the current study, The Michigan Department of Transportation (MDOT) and Wayne State University Transportation Research Group have jointly developed a advanced dynamic early lane merge traffic control system (DELMTCS) for three (3) to two (2)-lane transition areas in work zones, creating an enforceable no passing zone to encourage motorists to make an early merge. During the year 2002, the system was designed for a right lane closure and in the year 2003 it was again set up for a left-lane closure. The effectiveness of the DELMTCS in terms of reducing delay, aggressive driver behavior and increasing average travel speed was evaluated using the field data collected at the study area before and after implementing the DELMTCS. Results of the evaluation study indicate that a smoother traffic flow is achieved by the installation of the DELMTCS. Also, the average delay per vehicle to pass through the work zone and the number of aggressive driving maneuvers decreased due to the installation of the DELMTCS in a work zone on the I-94 freeway in Michigan.

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Work zone, aggressive driver, dynamic early lane merge traffic control system (DELMTCS)

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INTRODUCTION

Safety at construction/work zones is a great concern to transportation officials and the motoring public. Safety hazards encountered in highway work zones are numerous. They encompass an area of the highway that mixes drivers, workers and unfamiliar objects, in a normally familiar setting. The majority of safety hazards and resulting traffic crashes in work zones occur in lane closure areas, often due to the aggressive behavior of some drivers. For example, 47.8 percent of all work zone accidents in Michigan occurred at lane closure areas in 2001. The total number of work zone crashes in 2001 in work zones was 6,331, which included 1,352 injury crashes and 17 fatal crashes. One situation that contributes to hazards commonly found in lane closure areas pertains to the 'forced late lane merge phenomenon'.

The 'forced lane merge phenomenon' occurs when some drivers try to avoid slow moving traffic by traveling in a lane that is about to end, and then attempting to force a merge at the last moment. This is a dangerous driving maneuver for the driver, other motorists, and workers in the construction zone. A forced lane merge of this type may cause hostility and "road rage" among the other patiently waiting drivers. It may also increase the delay to the motorists by creating this sudden interruption of traffic flow.

The Michigan Department of Transportation (MDOT) has used innovative technology in work zone traffic control during the past several years to improve traffic flow and to improve safety by minimizing aggressive driving behavior, typically observed in lane merge transition areas. Past initiatives included development, implementation and evaluation of the 'Dynamic Early Lane Merge Traffic Control System (DELMTCS)' on freeways with two travel lanes in each direction, reduced to one lane during construction. The evaluation results indicated that the DELMTCS is effective in reducing aggressive driver behavior, improving safety, and reducing delay at work zones with two (2)-lane to one (1)-lane transitions that experience moderate to high traffic volumes prior to construction.

The current study includes the evaluation of the DELMTCS installed on three lane freeways (each direction) reduced to two lanes during construction. During the 2002 and 2003 construction seasons, MDOT implemented the DELMTCS on a major suburban interstate freeway, on the Ford Freeway (I-94) in southeastern Michigan.

The Wayne State University – Transportation Research Group (WSU–TRG) was responsible for designing and developing the construction zone traffic control plan and operational parameters for the system, as well as evaluating the effectiveness of the system in improving safety and traffic flow on three-lane freeways (each direction) reduced to two lanes during construction. A 'before' and 'after' study of the operational and safety characteristics was performed as a part of this study.

SYSTEM DESCRIPTION

This system consists of dynamic "Do Not Pass/When Flashing" sign trailers that are equipped with detectors to capture speed, volume and lane occupancy data at the detection zone. A series of five signs dynamically communicate, with one another to create a variable length of no passing zone, by activating the signs in an on and off flashing mode based on the detected traffic volume and occupancies.

SITE DESCRIPTION

The construction site on the I-94 freeway between 23 Mile Road and 8 Mile Road in Macomb County was selected for the installation and testing of the DELMTCS. The I-94 freeway consists of three lanes in each direction with several interchanges. The construction project was scheduled for two consecutive construction seasons for the years 2002 and 2003 and included the reconstruction of all three lanes on EB and WB I-94, at several isolated locations, as well as bridge and ramp work at a few locations. This work zone had two crossovers, one of the crossovers was located near the Metropolitan Parkway and the other between 13 Mile Road and 15 Mile Road. The DELMTCS was installed in the advanced warning area on WB I-94 between M-59 and Crocker Boulevard in the two consecutive construction seasons. Figures showing the work zone characteristics and the traffic control plan for the DELMTCS are included in pages 12 through 18 of this report.

DATA COLLECTION

Travel time and delay studies were performed at the study site during the AM and PM peak periods on WB I-94 during the 2002 and 2003 construction seasons. These studies were conducted using the floating car method where a two-person survey team was used with one person driving through the study zone and the second person recording the travel time and delay data at specific locations. Travel time data was recorded at specified locations through the study work zone from just before the advanced warning area, through the transition area and partly through the work activity area. The location and duration of any stopped time delay through the study portion of the work zone was noted. Traffic volume data and driver behavioral characteristics, including aggressive driving maneuvers at the lane merge area were also recorded.

‘BEFORE’ AND ‘AFTER’ COMPARISON OF OPERATIONAL DATA

At the study sites in Macomb County on WB I-94, the data collection for the ‘before’ period began before the DELMTCS was operational in the selected work zone with ‘typical’ advanced warning area traffic control. This allowed for a baseline comparison to test the effects of the DELMTCS on the traffic conditions in the merge areas of a work zone. The traffic operations and driver behavior data were collected at the work zone with lane closure ‘after’ the DELMTCS was deployed on the same section of I-94.

The results of the ‘before’ and ‘after’ study of the operational characteristics on WB I-94 during the 2002 and 2003 construction seasons indicated the DELMTCS was effective in reducing travel time delays, number of stops and aggressive driving maneuvers for similar flow rates during the AM and PM peak periods.

ANALYSIS TO DETERMINE REQUIRED NUMBER OF TRAVEL TIME RUNS

In order to determine the minimum number of runs required during the peak period, a sample of travel time run data collected in the 2002 construction season on the I-94 study site in Macomb County for the ‘before’ AM and PM peak period were used. This sample data was used to calculate the minimum required number of runs needed to assess differences in the traffic characteristics for a ‘before’ and ‘after’ study, from a statistical standpoint. It should be noted that the actual number of runs conducted far exceeded the minimum required number of runs for both the AM and PM peak periods, and both construction seasons the DELMTCS was tested.

STATISTICAL ANALYSIS

The Students t-tests was used to determine if there are significant differences in the travel time 'before' and 'after' the installation of the DELMTCS on the selected work zone on I-94. A 95 percent level of confidence was used to test the statistical significance of the DELMTCS on traffic operations. The distribution of the travel time delay data (sec/veh/10,000 feet traveled) for 'before' and 'after' periods were compared for the 2002 and 2003 construction seasons, for the AM and PM peak periods.

The t-test compares the travel time delay data for the test site during the AM and PM peak periods, before and after the implementation of the DELMTCS to determine if there are significant benefits of the system in terms of reducing travel time delay, thus improving traffic operations through lane closure areas.

The mean and standard deviation of the delay rates, based on distance traveled during the runs were calculated for the before and after data sets for the AM and PM peak periods. The results of the statistical analysis of delay per vehicle 'before' and 'after' the installation of the DELMTCS indicated significant reductions in delay during the AM peak periods due to the DELMTCS.

FUEL CONSUMPTION AND VEHICLE EMISSIONS

The calculated fuel consumption and vehicle emissions for the 'before' and 'after' periods for all vehicles traveling on WB I-94 during the two (2)-hour AM and the two (2)-hour PM peak periods for the 2002 and 2003 construction seasons for 41 weekdays and 44 weekdays, respectively, for the 'before' and 'after' periods indicated a total fuel savings of 23,574 gallons, as a result of decreased number of stops and reduced travel time from the DELMTCS installation. Vehicular emissions were reduced by 10 to 28 percent in the AM peak period and

1 to 3 percent during the PM peak period for the 2002 and 2003 construction season respectively, as a result of the DELMTCS.

BENEFIT-COST ANALYSIS

An economic analysis was performed which considered travel time savings and fuel savings due to the DELMTCS. The results this analysis indicated that the DELMTCS was economically beneficial and achieved benefit to cost ratios greater than one, if a value of time of at least $3.33 per person hour, is assumed for travel time savings. Assuming a value of time of $8.00 per hour for travel time savings, which is a reasonable assumption, the benefit to cost ratio for the DELMTCS projects on I-94 is 1.96 to 1.0. This means that the measurable benefits of this system are approximately twice as compared to the cost to install and operate the system. From an economic standpoint, the DELMTCS will be most effective if installed for a duration of two (2) months or more.

TRAFFIC CRASH ANALYSIS

A 'before' and 'after' traffic crash analysis was performed for WB I-94 during the 2002 construction season for the following two locations:

- Through the work zone's advanced warning area to just after the lane merge transition (a distance of 3.6 miles)
- Within the critical lane merge area (a distance of 1.0 mile)

The results of this traffic crash analysis indicated that for the critical lane merge transition area, no crashes occurred after the DELMTCS was installed during the 2002 construction season. However, in the 'before' construction period, an average of 1.2 crashes per month, occurred in this area over a 4.3 month period in 2002. It should be noted that over the entire advanced warning area over a length of 3.6 miles, an average of 2.1 crashes per month, occurred in the 'before' period and an average of 3 crashes occurred in the 'after' period, for the 2002 construction season. Due to the small amount of crash data compiled for such a short period of time, it is difficult to attribute the changes in crash patterns to the installation of the DELMTCS.

CRITERIA FOR INSTALLATION OF THE DELMTCS

Criteria for the installation of the DELMTCS were developed, which include the following:

- The main criteria for the installation of the DELMTCS is that the lane closure must be in place and the DELMTCS must be planned to be operational during the higher volume periods of traffic on the highway facility.
- The DELMTCS is recommended for highway projects that experience moderate traffic volumes prior to construction. The DELMTCS should not be installed at locations where traffic volumes are low.
- The installation of the DELMTCS is recommended on three-lane highways (in each direction), reduced to two-lanes (in each direction) during construction, according to the following volume guidelines, based on the pre-construction traffic volume conditions:

Higher Volume Periods Observed Prior to Construction

- Range of Hourly Volume = **3,000 to 3,800 vehicles per hour** per direction (at least two hours per day on a typical weekday or 4 to 5 hours per day on the weekend)
- Average Daily Traffic Volumes = 34,500 to 45,000 vehicles per day per direction (Installation of the DELMTCS should not be based on ADT volumes alone)

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for the DELMTCS installation in Michigan for three (3)-lane freeways (in each direction) reduced to two (2) lanes during construction are as follows.

- The DELMTCS was found to be effective in reducing aggressive driver behavior which in turn improves safety, and reducing delay in the work zone on WB I-94 in Macomb County, Michigan. The study evaluated the effectiveness of three (3)-lane freeways (in each direction) reduced to two (2) lanes during construction. *The installation of the DELMTCS should be considered for future construction projects on three-lane freeways with one-lane closure.*

- The traffic control plan for the DELMTCS used on WB I-94 included traditional advanced work zone warning signs, a series of 3 static and up to 5 dynamic "Do Not Pass" signs, and a portable changeable message sign with text "Merge Right/Left" and an arrow symbol. With this traffic control plan, motorists seemed to understand the DELMTCS and take the proper driving action, as evidenced in this study. *The traffic control plans for the advanced warning area for future projects using the DELMTCS should be designed to take care of the entrance and exit ramps and other unique features of a freeway.*

- *The sensor settings for the DELMTCS included in this report may be used for future installations of the system on three (3)-lane freeways (each direction) with one-lane closures. The DELMTCS operation should be closely monitored during the first week of the system's installation in order to ensure the system is responding properly to traffic volumes and density. The activation and deactivation of the flashing mode of the "Do Not Pass/When Flashing" signs should follow driver expectancy.*

1.0 INTRODUCTION

Aggressive driver behavior in work zones involving speeding, frequent lane changing, late merging, following too close, etc. sometimes result in traffic crashes and injuries. The lane closures in work zones pose special problems to motorists. For example, 47.8 percent of all work zone crashes in Michigan occurred at lane closure areas in 2001. The total number of work zone crashes in 2001 was 6,331, which included 1,352 injury crashes and 17 fatal crashes *(1)*. If we consider the lane miles of construction zones in Michigan in any given year, the crash and injury rates will be extremely high as compared to the crash and injury rates for the rest of the freeway system. Safety hazards encountered in work zones are related to the fact that the drivers and workers are put into a highly vulnerable situation due to lack of adequate space and artificially lowered speed limits, all in a familiar setting. The transition to work zones create a critical scenario in terms of safety.

The situation that most often contributes to the occurrence of the safety hazards in the lane closure area of the work zones is the 'late lane merge phenomenon'. The 'late lane merge phenomena occurs when drivers, in an attempt to avoid slow moving traffic, continue to travel in the lane that will be closed and then are forced to merge into the adjacent continuous lane, at the last moment. This creates a dangerous situation for the driver, other motorists, and also the workers in the construction zone. This phenomenon causes turbulence in the traffic flow by creating sudden interruptions and excessive braking, which results in the increase in delay to motorists. This may also increase the risk of safety hazards to those drivers on the roadway who abide by traffic regulations.

The Michigan Department of Transportation (MDOT) has used innovative technology during the past several years to improve traffic flow and to improve safety by minimizing aggressive driving behavior typically observed in lane merge transition areas. The past initiatives included development, implementation and evaluation of the 'Dynamic Early Lane Merge Traffic Control System (DELMTCS)' on freeways with two travel lanes in each direction, reduced to one lane during construction. The evaluation results indicated that the DELMTCS is effective in reducing aggressive driver behavior, improving safety and reducing delay at work zones with two (2)-lane to one (1)-lane transitions that experience moderate to high traffic volumes prior to construction *(2)*.

The current study includes the evaluation of the DELMTCS installed on three lane freeways each way reduced to two lanes during construction. During the 2002 and 2003 construction seasons, MDOT implemented the DELMTCS on a major suburban interstate freeway (I-94 Ford Freeway) in Michigan.

The Wayne State University – Transportation Research Group (WSU–TRG) was responsible for designing and developing the construction zone traffic control plan and operational parameters for the system, as well as evaluating the effectiveness of the system in improving safety and traffic flow on three-lane freeways, each way reduced to two lanes during construction. The specific objectives of this study are as follows:

- Develop the traffic control plans and sensor settings for the DELMTCS on a three-lane freeway, each way reduced to two lanes during construction.
- Collect field data and quantify traffic operations and safety in the work zone 'Before' and 'After' installation of the DELMTCS.
- Evaluate the effectiveness of the DELMTCS using a 'Before and After' study.
- Assess the economic benefits of installing the DELMTCS on three-lane to two-lane work zone transition areas.

The data collection, analysis and results of this evaluation study are presented in the following sections.

2.0 BACKGROUND

Several studies have been performed in the United States to investigate aggressive driver behavior in work zones. Specifically, past-published literature has identified two systems used in lane closure areas in work zones that have been tested in the USA, an 'early' lane merge system and a 'late' lane merge system. These two systems are very different in that they operate under completely opposite assumptions. The concept of the dynamic 'early' lane merge system was initiated by the Indiana Department of Transportation (IDOT). A modified version of IDOT's system was also developed and tested by MDOT on two-lane freeways in Michigan. The Pennsylvania Department of Transportation (PennDOT) initiated and tested the 'late' lane merge system on two-lane freeways. A dynamic version of this system was deployed in Kansas. The following discusses the characteristics of these systems.

2.1 Early Lane Merge System

The lane merge traffic control system tested by IDOT *(3,4)* uses a series of "Do Not Pass/When Flashing" signs placed in advance of the taper area creating an enforceable no passing zone to encourage motorists to make an early merge. This traffic control system was designed to create a smooth and uniform flow of traffic as the vehicle proceeds through the lane closure area. The signs installed are equipped with sensors that monitor traffic density and congestion. When the density is high and congestion and traffic backups are detected, a signal is transmitted to the next upstream dynamic no passing sign to activate the sign's flashing signal. In this system, the primary warrant for the dynamic system's use is the anticipated or observed presence of congestion at the entry point of the work zone. The system's use is recommended if the congested segment is longer than approximately two miles. In this system, the minimum sign spacing between any two dynamic signs is 150 m (≈ 500') and is based on the time and distance necessary, for a driver to respond to any one of the signs. The signing system recommended by the Indiana DOT uses three static "Do Not Pass" signs with a range of two to six dynamic signs, based on the length of congestion, as shown in Figure 1.

One advantage of the IDOT system which creates an enforceable no passing zone in construction areas, is that aggressive driver behavior can be altered through the work zone by citing the violators for improper driving actions. Alleviating aggressive driver behavior at work zones will provide a safer environment for motorists and construction workers.

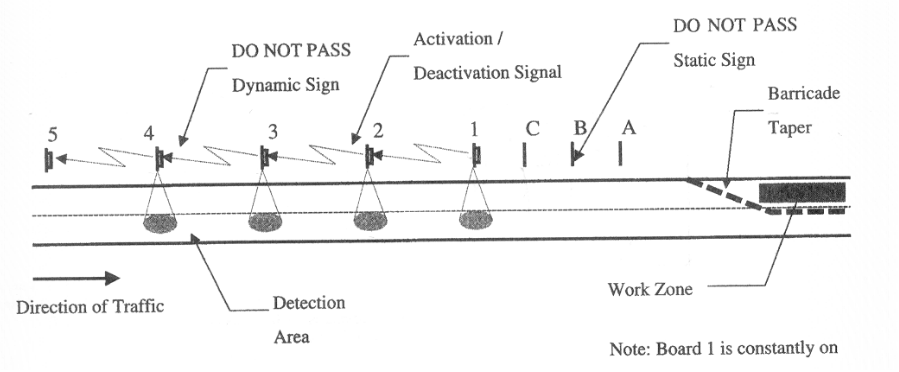


Figure 1. Lane Merge Traffic Control System Used by IDOT
[Source: Manual of the Indiana Lane Merge Control System- Final Report *(3)*]

The Michigan DELMTCS [two (2)-lane to one (1)-lane closures] is similar to IDOT's system and consists of traditional work zone traffic control devices along with a system of 3 static and 5 dynamic "Do Not Pass" signs, to create a no passing zone and minimize forced lane merges, aggressive driver behavior and delay at the taper area. The site layout developed and tested in Michigan [for the two (2)-lane to one (1)-lane closure] is shown in Figure 2.

Five dynamic "Do Not Pass/When Flashing" signs are mounted on trailers along with sensors that can detect and monitor traffic volumes and occupancy. Once traffic slowdowns are detected, the next upstream "Do Not Pass/When Flashing" signs are set to change into the flashing mode thus, increasing the length of the no passing zone when congestion on the freeway increases. This prompts drivers to change lanes even earlier, in comparison to the low traffic volume condition where only the sign trailer closest to the taper area is in the flashing mode, by default.

The spacing between the static traditional warning signs is 700 feet. A distance of 1,500 feet between the dynamic signs was determined desirable as a result of a driver behavior and human factor analysis. A changeable message sign with text 'Merge Right' (or 'Merge Left') with arrow symbol was also included in the traffic control plan.

2.2 'Late' Lane Merge System

The PennDOT system is based on directing motorists to merge late at lane closures, in order to increase the capacity in the work zones. This traffic control system is opposite of the 'early' lane merge systems used by IDOT and MDOT, in that it encourages drivers to merge late, near the taper, using a "Merge Here Take Your Turn" sign. *(5)*

In order to address issues associated with congestion in advance of the lane closure, the "late merge" concept was developed by PennDOT which uses the sign "Use Both Lanes to Merge Point" placed in advance of the lane closure on both sides of the roadway. These signs are followed by "Road Work Ahead" and advance lane-closed signs. Finally, "Merge Here Take Your Turn" signs were placed on both sides of the roadway near the beginning of the taper, as shown in Figure 3.

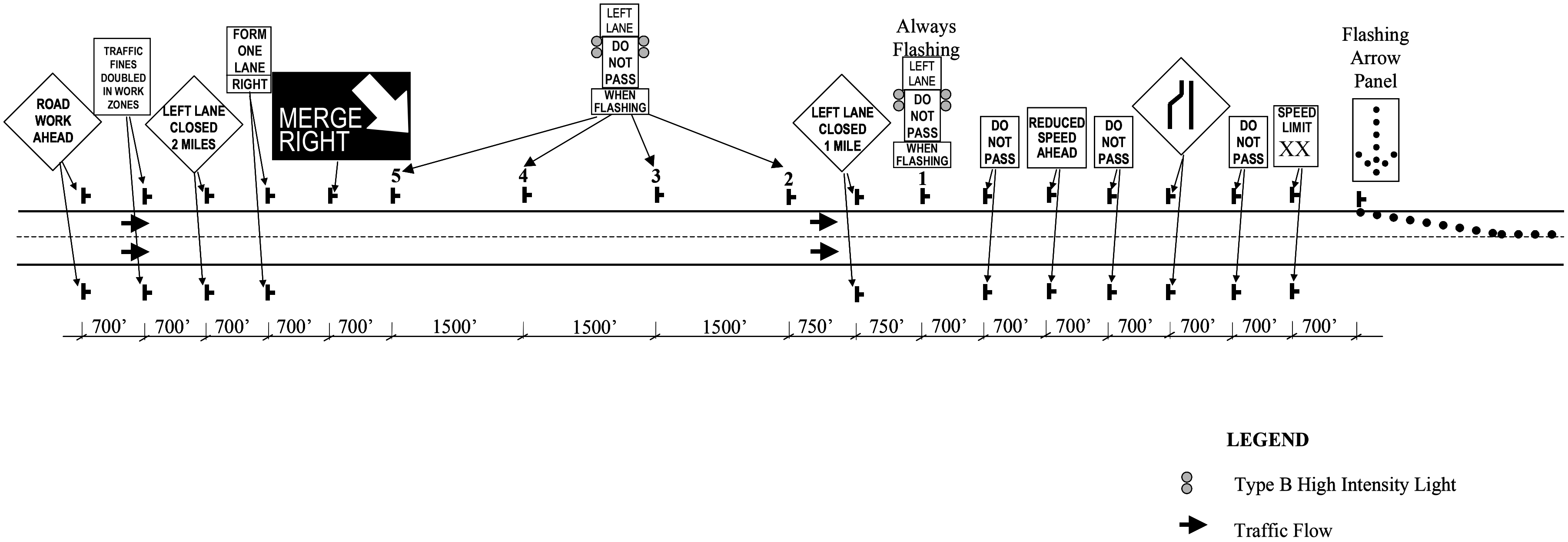


Figure 2. Michigan’s DELMTCS Implemented on Two Lane Freeways Each Way Reduced to One Lane During Construction

The results of field testing indicated that the late merge system has a higher capacity than the traditional lane merge system, and it also “produces fewer traffic conflicts associated with merging operations in advance of lane closures” *(5)*. However, the authors also noted that “the results of this field study indicate that the concept may not be working to its full potential” *(5)*. The authors concluded that “some motorists, especially truck drivers did not follow the directions given by the traffic control signs. Most of them tried to move into the open lane well before the merge point, except when very long queues were formed” *(5)*. This system may even violate some driver’s expectation by forcing drivers to merge late and thus, it may not operate as planned.

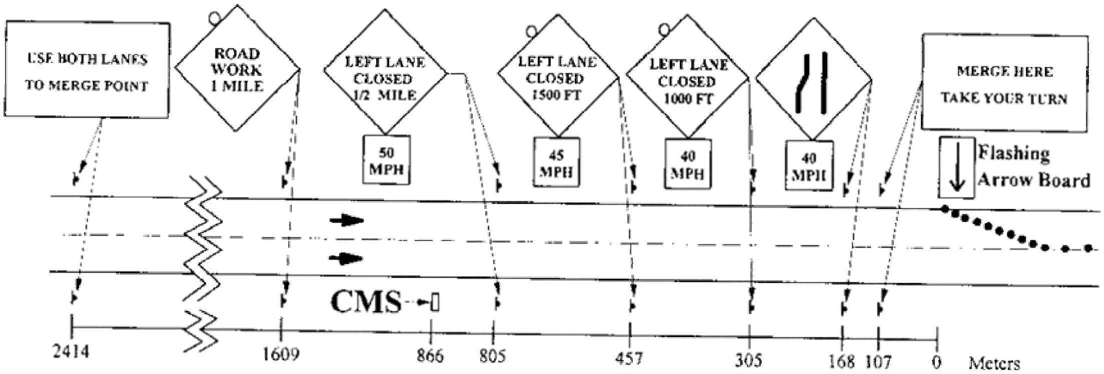


Figure 3. Late Merge Traffic Control System Used by PennDOT
[Source: Pesti, Jessen, Byrd and McCoy *(4)*]

In another paper, McCoy and Pesti *(6)* introduced a new concept, the ‘dynamic late merge’ which incorporates the late merge system with a traditional lane merge system.

The concept of a “dynamic late merge system” is intended to mitigate driver confusion at the taper area. With the static late merge system, there is potential for drivers to be confused at the merge point, especially during uncongested conditions where the travel speed is high, and the volume is low. The dynamic version of the system would switch from the ‘late merge’ system to a traditional lane merge system on the basis of real-time measurements of traffic flow. The authors state that the late merge system would be effective during the peak periods, while during the off-peak periods, a traditional system would be effective.

The ‘dynamic late merge system’ consists of a series of advanced signs that would be activated to advise the drivers to “Use Both Lanes to the Merge Point” when congestion is detected in the open lane. The detection and communication system seems similar to that used in the Indiana and Michigan dynamic lane merge systems. Signs are then placed at the merge area, advising drivers to "Merge and Take Your Turn". When congestion clears, the signs would be deactivated to inform drivers to travel through the area as a traditional system *(6)*.

In June 2003, the Scientex Corporation, deployed the **Construction Area Late Merge *(CALM)*** System in Kansas *(7)*. This system seems to be the dynamic version of the Late Merge Concept introduced by PennDOT. This system employs traffic detectors to sense congestion upstream of a construction lane closure. The traffic data is communicated in real-time to a central controller where proprietary software algorithms determine critical thresholds of traffic density and speed to activate real-time messages directing motorists to remain in their lanes until they approach the lane closure, where they merge alternately by taking turns. The CALM System is also used to sense incidents within and upstream of the work zone and to advice motorists of any opportunity to take alternate routes. During periods of steady traffic flow the CALM System provides real-time safety alerts to motorists. No published studies of the effectiveness of this system's application are available to date.

3.0 SYSTEM DESCRIPTION

The Michigan Dynamic Early Lane Merge Traffic Control System (DELMTCS) for three (3)-lane to two (2)-lane closure areas consists of traditional work zone traffic control devices, along with a system of 3 static and 5 dynamic "Do Not Pass" signs to create a no passing zone and minimize late lane merges, aggressive driver behavior, and delay at the taper area. The traffic control plan of the advanced warning area including the DELMTCS on three (3)-lane freeways reduced to two (2) lanes during construction is shown in Figure 4.

In this system, signs are placed in advance of the taper section for the lane closure. A series of "Do Not Pass/When Flashing" signs are placed near the lane merge area. The signs are mounted on trailers along with sensors that can detect and monitor traffic volumes and occupancy. Once traffic slowdowns are detected, the next upstream "Do Not Pass/When Flashing" signs are set to change into flashing mode in order to prompt drivers to change lanes even earlier, as compared to the low traffic volume condition. The sign including the trailer assembly for the DELMTCS is shown on Photograph 1. The "Do Not Pass/When Flashing" sign closest to the taper is always activated and in the flashing mode.

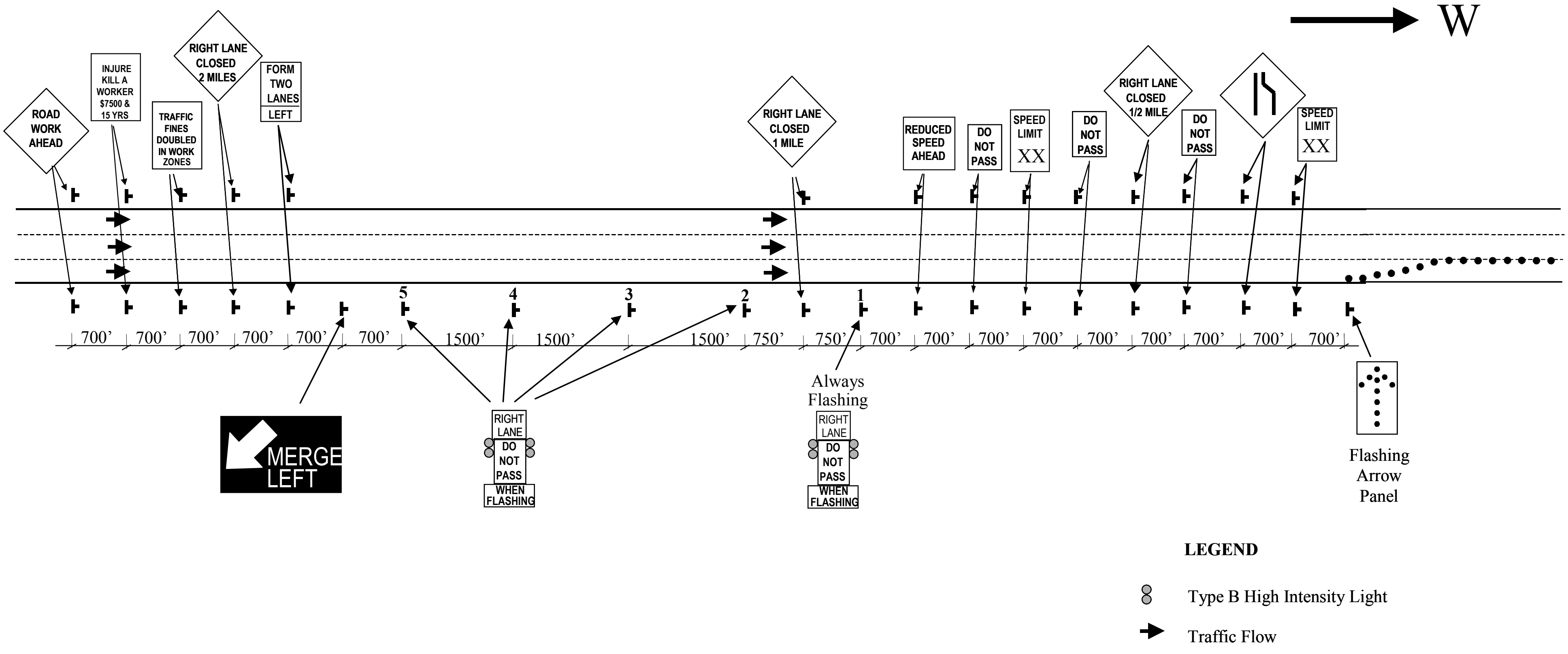


Figure 4. Dynamic Early Lane Merge Traffic Control System Used in Michigan for Three (3) to Two (2)-Lane Closure Areas in Work Zones

Photograph 1. Dynamic Early LMTCS Sign and Trailer Used in Michigan

Through the use of Non-intrusive Vehicle Presence Detectors (NVPD) and Microwave signals, the sensors on the dynamic signs detect speed and the traffic volume separately for each lane of the freeway and then the system automatically calculates an average 'activity index', which is a function of speed and volume, of all the lanes combined. In this way, it determines whether or not the signs should be in the flashing mode or not. When the sensor on this sign detects traffic beginning to back up, it sends a signal to the next upstream sign, based on a high and low threshold range of the 'activity index' to trigger the flashing mode of operation. If the average activity index measured is greater than the preset 'high activity index' value, then the signs will transmit messages to activate the lights of the next upstream dynamic sign to flashing mode. If the average activity index is less than the 'low activity index' value, then the signs will transmit messages to end the flashing mode. This activation system applies for all of the dynamic signs, except for the one closest to the taper, which is always in the flashing mode. When traffic in the upcoming closed lane encounters the "Do Not Pass/When Flashing" signs, drivers are not allowed to pass any vehicles in the adjacent through traffic lane as per the law.

The sensor detection time (or trailer update period) is the time increment, which is considered in the determination of the average ‘activity index’. The recommended ***update period*** in which messages are sent to the upstream trailers for sensors at all signs is **1 minute.**

Once the lights on a sign trailer become activated, it is recommended that they remain flashing for at least 5 minutes. This parameter may be referred to as ***minimum lamp ‘ON’ time*****,** which should be set to **5 minutes** for all the sign trailers. However, the lights on the sign closest to the taper (Sign No. 1, the base trailer) is always in the flashing mode.

Table 1 shows the sensor settings used for the DELMTCS installed on I-94 in Macomb County, Michigan.

Table 1. Sensor Settings for DELMTCS

SENSOR AT SIGN NO.	ACTIVITY INDEX THRESHOLD (%)		UPDATE PERIOD (MINUTES)	MIN LAMP ‘ON’ TIME (MINUTES)
	Low	High		
1 (Base Trailer) Closest to the Taper	10%	15%	1 minute	5 minutes
2	15%	20%	1 minute	5 minutes
3	20%	25%	1 minute	5 minutes
4	25%	30%	1 minute	5 minutes
5*	This sign does not transmit signals.			

4.0 SITE DESCRIPTION

The construction site on the I-94 freeway between 23 Mile Road and 8 Mile Road in Macomb County was selected for the installation of the DELMTCS. The I-94 freeway consists of three lanes in each direction with several interchanges. The construction project was scheduled for two consecutive construction seasons for the years 2002 and 2003 and included the reconstruction of all three lanes on EB and WB I-94, at several isolated locations, as well as bridge and ramp work at a few locations. The work zones had two crossovers located near the Metropolitan Parkway and the other between 13 Mile Road and 15 Mile Road. The DELMTCS was installed in the advanced warning area on WB I-94 between M-59 and Crocker Boulevard in two consecutive construction seasons. The lane merge traffic control system included five dynamic “Do Not Pass/When Flashing” signs, a changeable message sign with text “Merge Left/Right” and an arrow symbol (refer to Photographs 2 and 3), a “Form Two Lanes Left/Right” sign (refer to Photograph 4), and various traditional construction zone warning signs. In addition, new signage was installed on the North River Road entrance ramp to inform motorists that they were about to enter a no passing zone and thus, the sign text message was "No Passing Zone Ahead", as shown in Photograph 5.

Photograph 2. Changeable Message Sign - Phase I (2003 Construction Season)

Photograph 3. Changeable Message Sign - Phase II (2003 Construction Season)

Photograph 4. Regulatory Sign Used in the DELMTCS (2003 Construction Season)

Photograph 5. Sign Placed on Entrance Ramp within the DELMTCS

In the summer and fall of the year 2002, the DELMTCS was installed on westbound I-94 from M-59 to Crocker Boulevard. The average daily traffic (ADT) and peak hour traffic volumes northeast of the work zone, near 23 Mile Road, are shown in Table 2. These traffic volumes were obtained from the Michigan Department of Transportation (MDOT).

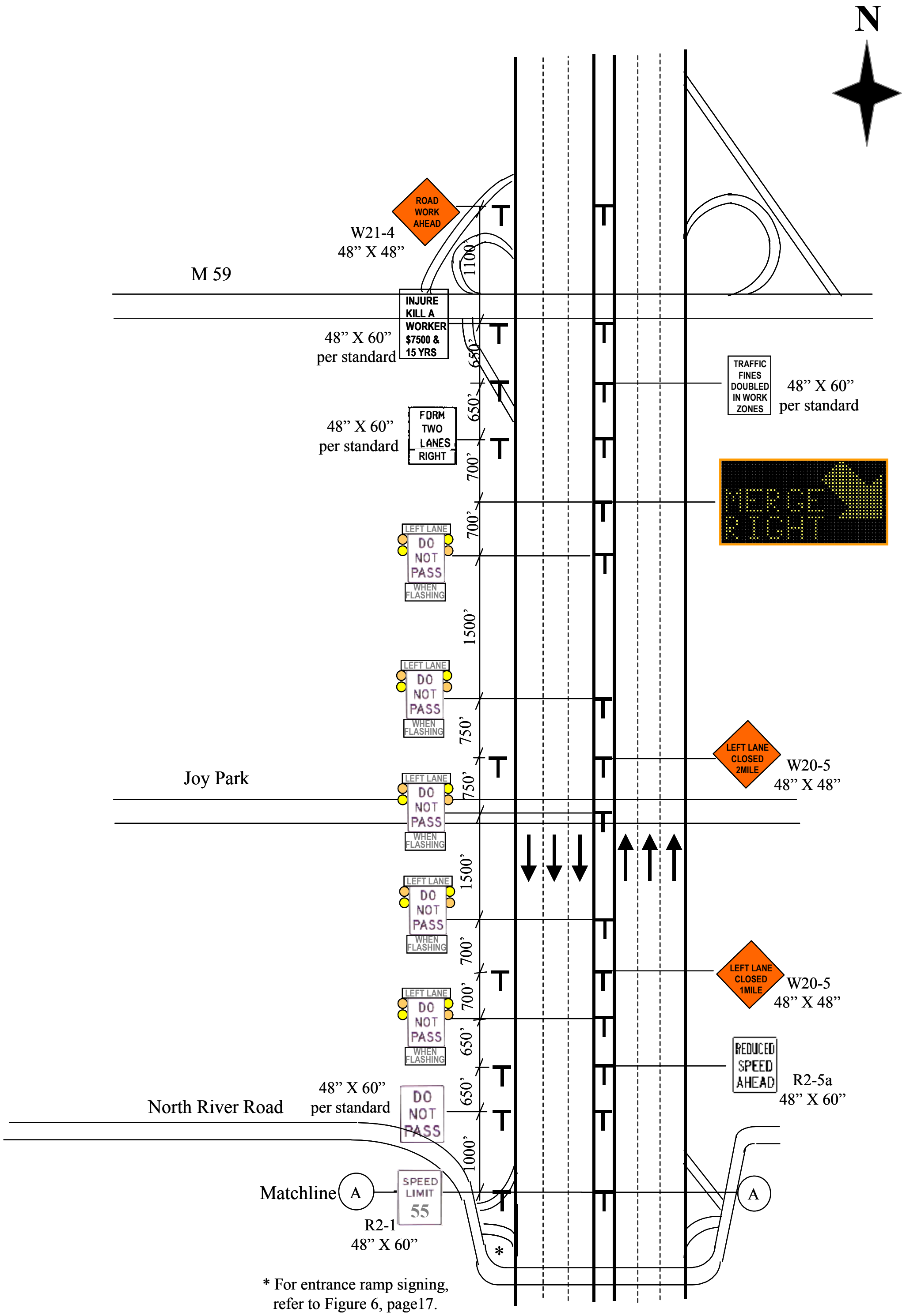
Table 2. Traffic Volumes on I-94 Near the Project Site

TIME PERIOD OF TRAFFIC VOLUMES	**TRAFFIC VOLUME COUNTS ON I-94 NORTHEAST OF 23 MILE ROAD (Source: MDOT)**			
	SEPTEMBER 2001 (No Construction) (MDOT Counts)		**OCTOBER 2002 (During Construction Season)**	
	EB	**WB**	**EB**	**WB**
ADT (vehicles per day)	33,736	34,244	35,982	37,203
AM Peak Hour (vehicles per hour)	1,603	3,805	1,648	3,707
PM Peak Hour (vehicles per hour)	4,194	1,948	3,696	2,066

As a part of the summer/fall 2002 construction season, the DELMTCS was implemented at the lane transition area on the northeast end of the project for westbound I-94 traffic.

During the 2002, the WB lanes were reconstructed between 13 Mile Road and Masonic Boulevard, and also near 14 Mile Road. In addition, the entrance and exit ramps at Little Mack Road were reconstructed. During the 2002 construction season, the right lanes were closed for the westbound direction of travel of I-94 freeway in the advanced warning area. The dynamic sign trailers were installed just beyond the right-hand shoulder on the west side of the I-94 freeway.

During the 2003 construction season the EB lanes were reconstructed between 13 Mile Road and Masonic Boulevard and also near 14 Mile Road. During this period, the left lane was closed for the westbound traffic. The dynamic sign trailers were installed within the median area on the left (east) side of the I-94 freeway. A sketch of the entire work zone, including the DELMTCS and advanced warning area for the 2003 construction project is shown in Figure 5. A close up of the traffic control plan for the DELMTCS for the 2003 construction season is shown in Figure 6.



* For entrance ramp signing, refer to Figure 6, page17.

Figure 5. I-94 - 2003 Construction Season

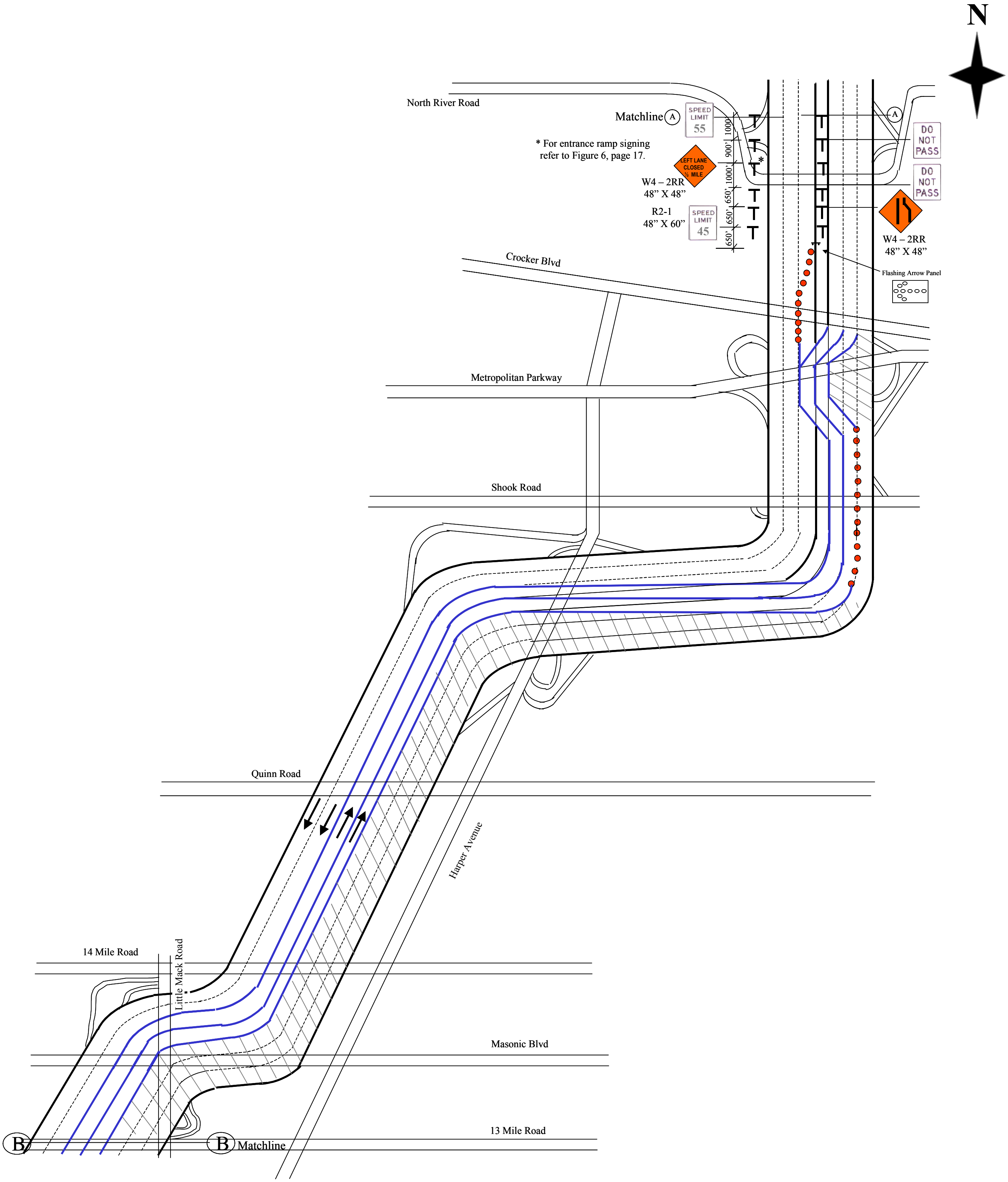


Figure 5. I-94 - 2003 Construction Season (Continued)

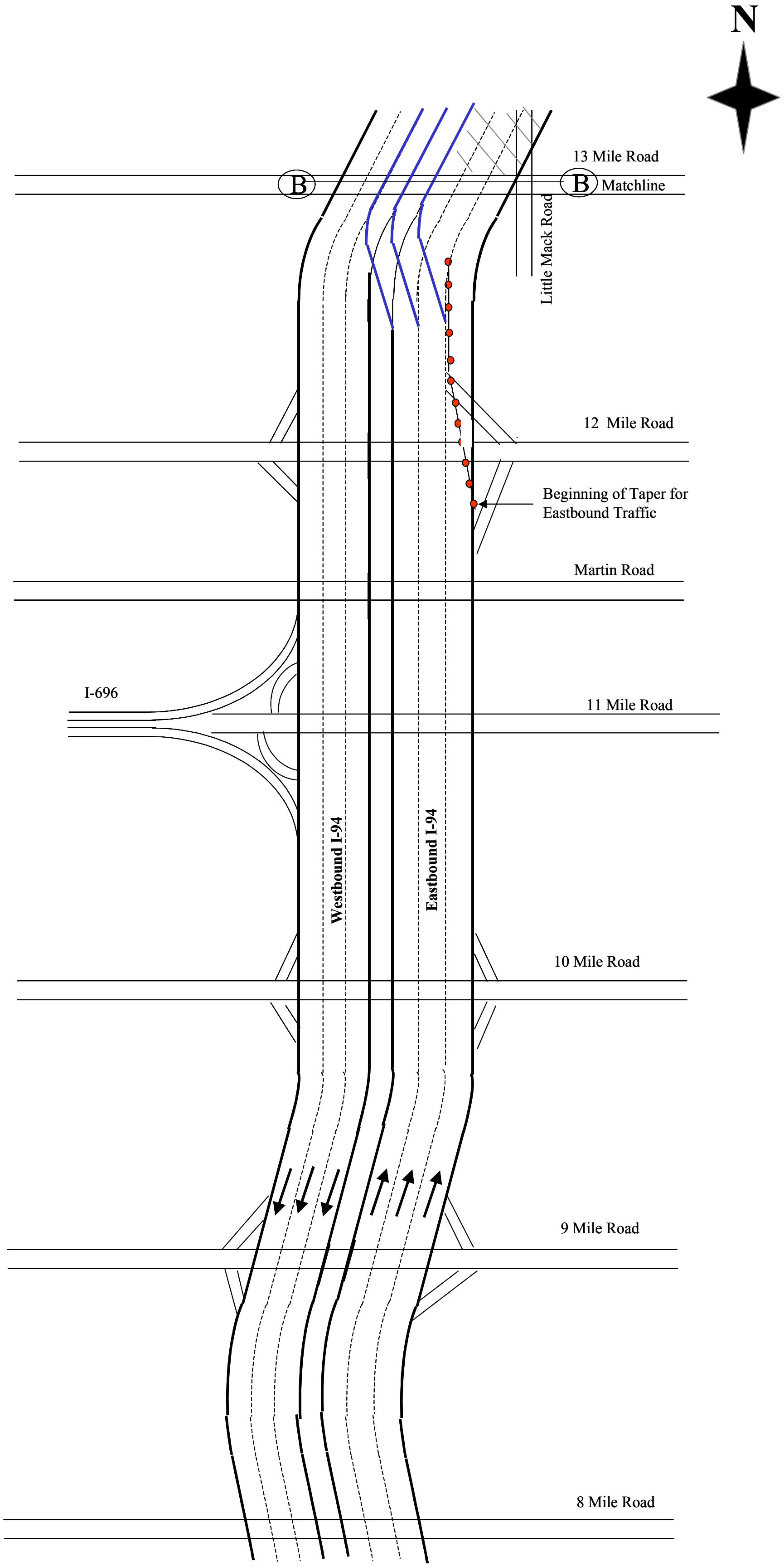


Figure 5. I-94 - 2003 Construction Season (Continued)

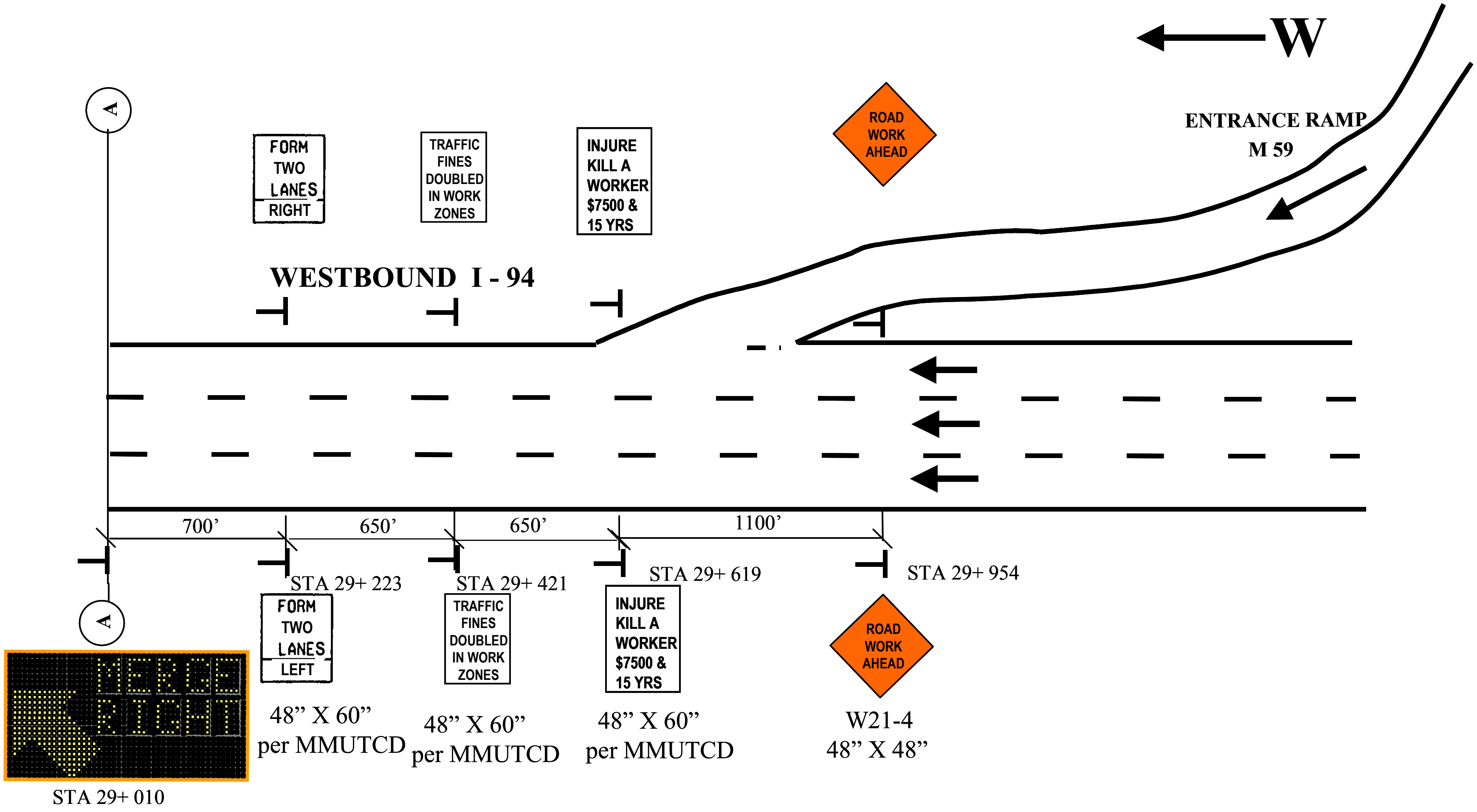


Figure 6. Dynamic Early Lane Merge Traffic Control System for Left Lane Closure on Westbound I-94 Implemented During the 2003 Construction Season

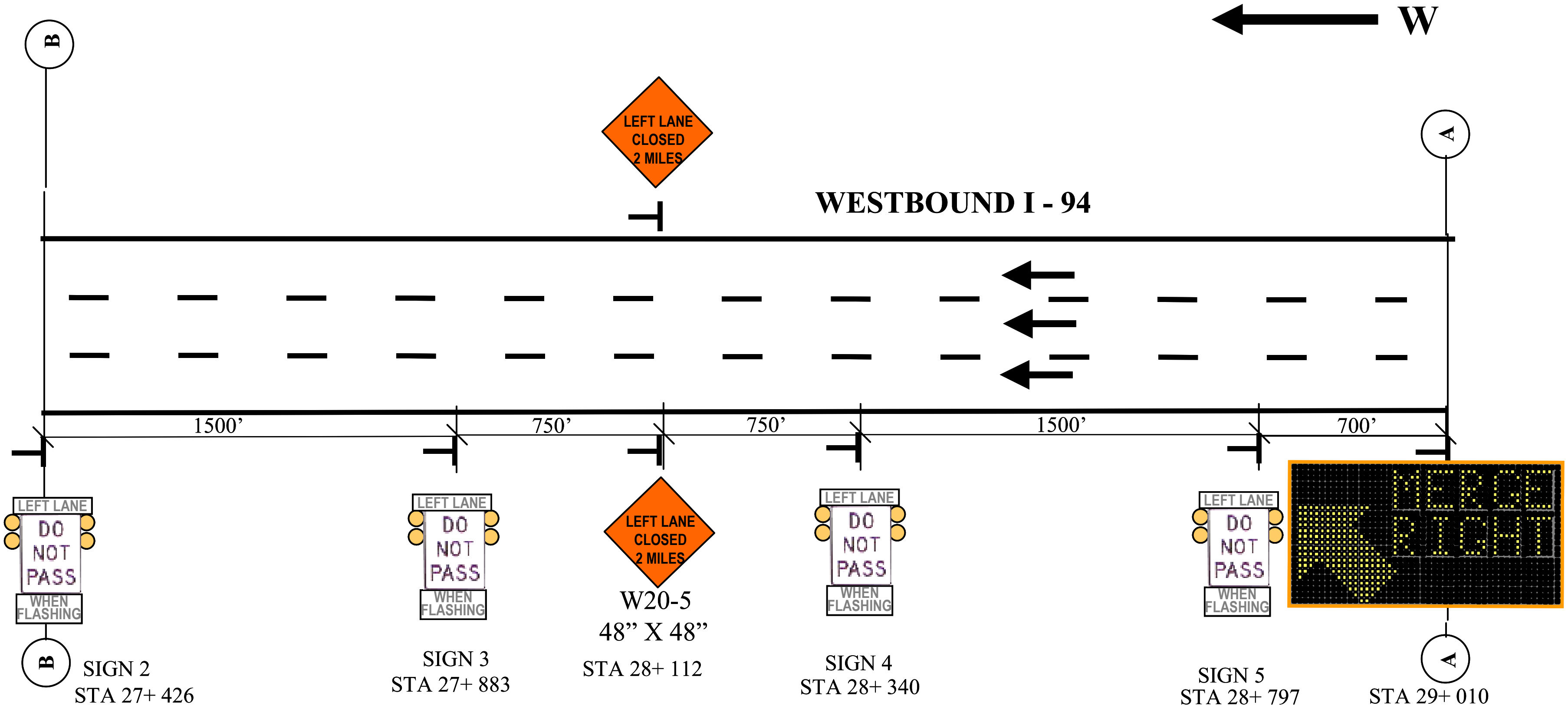


Figure 6. Dynamic Early Lane Merge Traffic Control System for Left Lane Closure on Westbound I-94 Implemented During the 2003 Construction Season (Continued)

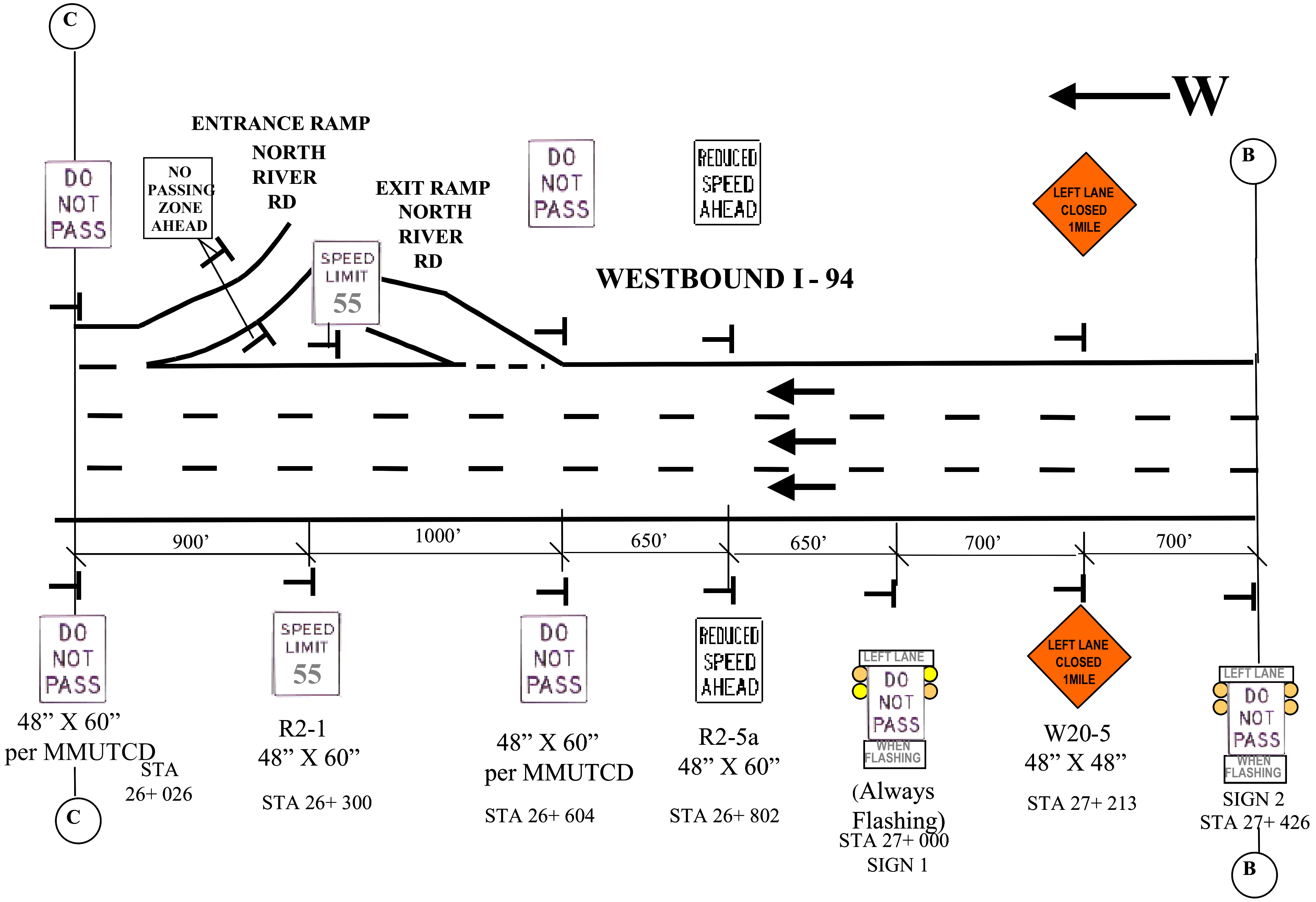


Figure 6. Dynamic Early Lane Merge Traffic Control System for Left Lane Closure on Westbound I-94 Implemented During the 2003 Construction Season (Continued)

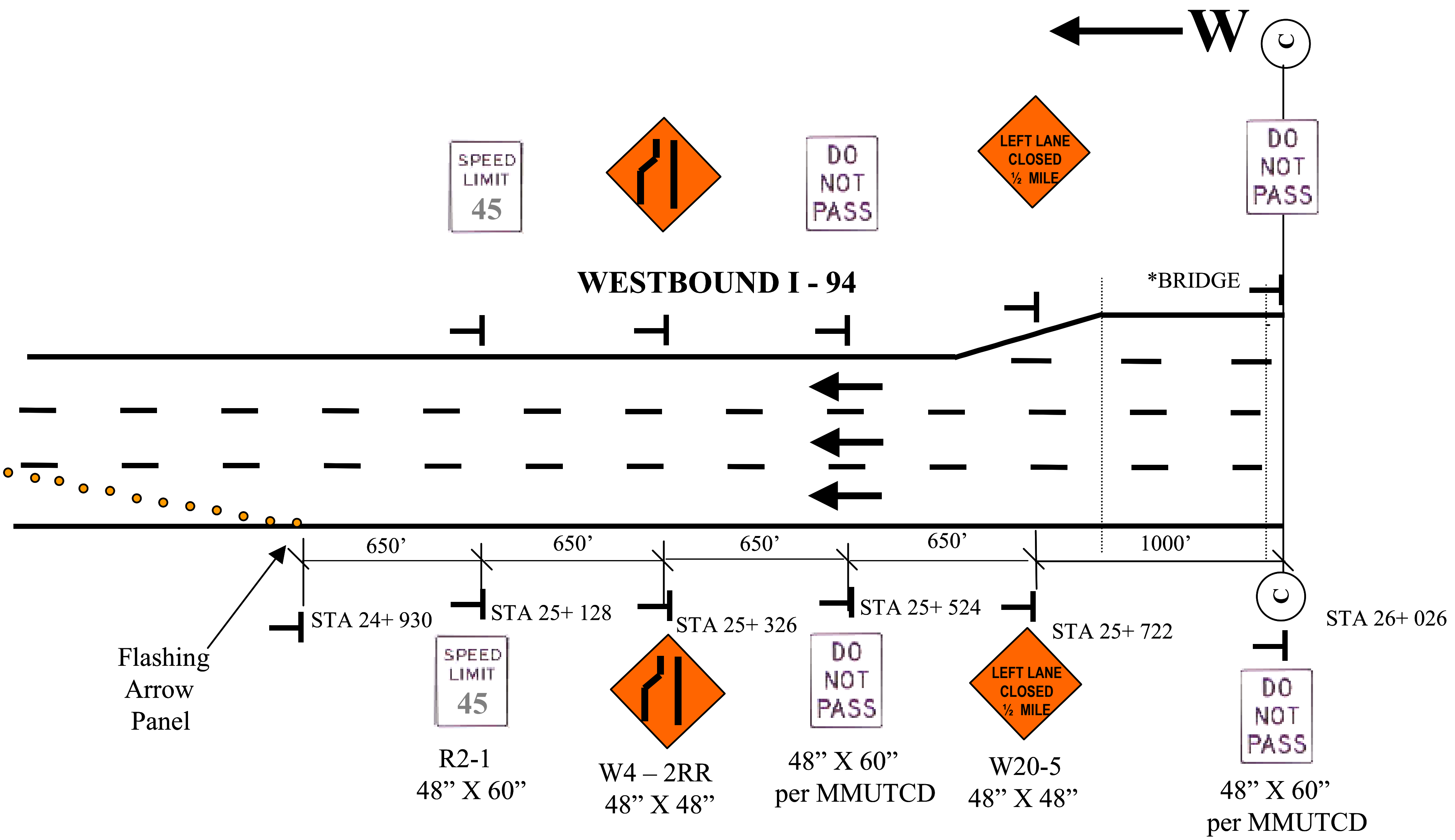


Figure 6. Dynamic Early Lane Merge Traffic Control System for Left Lane Closure on Westbound I-94 Implemented During the 2003 Construction Season (Continued)

It should be noted that the traffic control plans for the 2002 and 2003 construction seasons were similar, except for the "Left/Right" indications on the signs and the locations of the dynamic sign trailers. Additionally, in the 2002 construction season a solid white lane marking was installed to delineate the left-most continuous lane from dynamic sign trailer no. 1 to the flashing arrow panel. It was expected that this solid lane line would assist in minimizing lane change maneuvers in the through lanes. This pavement marking was not installed in the 2003 construction season. The effect of the solid white pavement marking could not be determined. However, based on observations during the field data collection, no appreciable differences in driver behavior in terms of the use of these were noticed between the 2002 and 2003 construction seasons through installations.

It should also be noted that some site specific challenges were encountered when determining how the system would be installed within the median area on the left side of the freeway for the 2003 construction season. As per the Operators Manual for the DELMTCS *(8),* the sensor should be located 13 feet away from the roadway, at a minimum height of 17 feet, in order to properly detect vehicular presence. However, the median on I-94 at the study location is a depressed median (28 feet wide). The sensors could not be mounted directly on the sign trailers since flat surface was not available due to drainage ditches located along side of the freeway. Thus, the sensors were assembled on a separate structure in order to meet the positioning requirements. Photographs 6 and 7 depict the dynamic sign trailer assembly with the sensors mounted on independent support systems.

Photograph 6. Modified Set Up of the Sign Trailer and Sensor in a Depressed Median (2003 Construction Season)

Photograph 7. Support Structure for Sensor When Installed in Depressed Medians (2003 Construction Season)

5.0 DATA COLLECTION

Travel time and delay studies were performed at the study site during the AM and PM peak periods on WB I-94. These studies were conducted using the floating car method where a two-person survey team was used with one person driving through the study zone and the second person recording the travel time at specific locations. Travel time data was recorded at specified locations through the study work zone from just before the advanced warning area, through the transition area and partly through the work activity area. The location and duration of any stopped time delay through the study portion of the work zone was noted. During part of the 2002 construction season, traffic operations near the lane closure areas were captured using a video camera mounted on the freeway shoulder. However, for safety and security reasons due to the site being located in close proximity to the Selfridge Air National Guard Base, this data collection approach was discontinued.

In the 2003 construction season, a digital video camera was set up inside the test vehicle to record driver behavioral characteristics of the vehicles surrounding the test vehicle while the travel time runs were conducted. These videos were later reviewed in the laboratory to obtain data on aggressive driver behavior and vehicle merge locations. These observations provided information on driver behavioral characteristics through the entire merge area for the vehicles in close proximity to the test car driver. The test car driver also observed the presence, or absence of police enforcement through each run, as well as the status of each of the dynamic signs (flashing or not flashing).

The total travel time through the study portion of the work zone was summarized and estimated delay values were calculated. Travel time delay is defined as the difference between the driver's desired total time to traverse a section of roadway and the actual time required to traverse it. *(9)* The total delay per run was determined by calculating the estimated travel time for an assumed travel speed, minus the actual travel time per run.

At the study sites in Macomb County on WB I-94, the data collection for the 'before' period began before the DELMTCS was operational in the selected work zone with 'typical' advanced warning area traffic control. This allowed for a baseline comparison to test the effects of the DELMTCS on the traffic conditions in the merge areas of a work zone. The traffic operations and driver behavior data were collected at the work zone with lane closure, 'after' the DELMTCS was deployed at the same section of I-94.

6.0 'BEFORE' AND 'AFTER' COMPARISON OF OPERATIONAL DATA

6.1 2002 Construction Season

The construction work zone was set up in May 2002 and was completed in the Fall, by November 2002. The DELMTCS was implemented in September 2002 and was operational during the Fall season for only a two-month time period. Thus, in the 'before' and 'after' periods, some seasonal variation of traffic volumes were observed. In the summer, the traffic flow was less concentrated during the peak periods due to flextime shifts, summer vacations and other activities. During the fall season, traffic was concentrated in the peak periods.

Field data collection for the 'before' period began at the end of June 2002 through September 2002, during both the summer and fall seasons. For the 'after' period, field data was collected during the fall season only (September-November 2002). A summary of the data collected in the AM and PM peak periods is presented in Table 3, both before and after the implementation of the DELMTCS. The 'before' data was collected on WB I-94 with a right lane closure in place, using traditional signage. The 'after' data was collected at the same site with the DELMTCS in place.

Table 3. Summary of 'Before' and 'After' Data for AM and PM Peak Period Traffic Operations for the 2002 Construction Season

OPERATIONAL AND DRIVER BEHAVIOR CHARACTERISTICS	**AM PEAK DATA COLLECTION**				**PM PEAK DATA COLLECTION**	
	Before Period June 2002 to September 10, 2002			**After Period September 11 to November 6, 2002 (Fall)**	**Before Period June 2002 to September 10, 2002**	**After Period September 11 to November 6, 2002**
	Summer 2002	Fall 2002	Summer and Fall 2002			
Average Travel Speed Based on Peak Period Travel Time Runs (mph)	53.3	29.7	51.3	47.8	54.7	55.9
Average Peak Hour Delay per 10,000 feet (sec/veh/10,000 feet)	39.4	128.4	48.2	58.6	31.6	20.7
Average Peak Hour Flow (vehicles per hour)	3,625	3,247	3,499	3,150	2,742	3,180
Average Number of Stops per Travel Time Run (stops/vehicle)	0.84	1.67	0.84	0.65	0.23	0.00
Average Stopped Time Delay per Travel Time Run (sec/veh)	24.1	27.9	24.1	20.30	25.48	0.00
Average Number of Aggressive Driving Maneuvers per hour during the peak hour	104			78	120	61
Average Length Traveled during Travel Time Runs (ft)	20,530			20,620	20,530	20,620

Details of the travel time data collected for the AM and PM peak periods on WB I-94 during the 2002 construction season is included in Appendix I.

A comparison of the before and after data at the study corridor indicated the following:

AM Peak Period

- For similar traffic flows during the Fall 2002 season, the average travel speeds observed during the travel time runs increased in the 'after' period.
- For similar traffic flows during the Fall 2002 season, the average peak period travel time delay decreased during the after period.
- For similar traffic flows during the Fall 2002 season, the average number of stops and the duration of stopped time decreased after the implementation of the DELMTCS based on the peak hour travel time runs.
- The number of aggressive driving maneuvers per hour decreased in the after period.

PM Peak Period

- The average travel speed based on the peak period travel time runs, increased slightly after the implementation of the DELMTCS.
- The average peak period travel time delay decreased in the after period.
- Based on the peak hour travel time runs, the average number of stops decreased after the implementation of the DELMTCS.
- The average duration of the stopped time per run decreased in the 'after' period.
- The number of aggressive driving maneuvers per hour decreased in the after period.

6.2 2003 Construction Season

A summary of the data collected in the AM peak period is presented in Table 4, both before and after the implementation of the DELMTCS. The 'before' data was collected at the site with a lane closure in place using traditional signage from May 2003 to August 5, 2003. The 'after' data was collected at the same site with the DELMTCS in place for a two-month period from August 6, 2003 to October 6, 2003.

Table 4. Summary of 'Before' and 'After' Data for AM and PM Peak Period Traffic Operations for the 2003 Construction Season

OPERATIONAL AND DRIVER BEHAVIOR CHARACTERISTICS	AM PEAK PERIOD		PM PEAK PERIOD	
	Before Period May 2003 to August 5, 2003	**After Period August 6 to October 6, 2003**	**Before Period May 2003 to August 5, 2003**	**After Period August 6 to October 6, 2003**
Average Travel Speed Based on Peak Period Travel Time Runs (mph)	40.04	45.52	57.91	58.15
Average Peak Hour Delay per 10,000 feet (sec/veh/10,000 feet)	95.10	69.33	6.33	1.59
Average Number of Stops per Travel Time Run (stops/vehicle)	1.75	0.96	0.10	0.00
Average Stopped Time Delay per Travel Time Run (sec/veh)	25.70	26.18	1.00	0.00
Average Number of Aggressive Driving Maneuvers per travel time run during the peak hours	0.89	0.95	2.88	0.55
Average Length Traveled during Travel Time Runs (ft)	25,760	25,760	25,760	25,760

Details of the travel time data collected for the AM and PM peak periods on WB I-94 during the 2003 construction season is included in Appendix II.

A comparison of the before and after data at the study corridor indicated the following:

AM Peak Period:

- The average travel speed based on the peak period travel time runs, slightly increased after the implementation of the DELMTCS.
- The average peak period travel time delay decreased during the after period.
- Based on the peak hour travel time runs, the average number of stops decreased after the implementation of the DELMTCS.

PM Peak Period:

- The average travel speed based on the peak period travel time runs, slightly increased after the implementation of the DELMTCS.
- The average peak period travel time delay decreased slightly during the after period.

- The average number of stops slightly decreased after the implementation of the DELMTCS.
- The average duration of the stopped time per run decreased slightly in the 'after' period.
- The number of aggressive driving maneuvers observed during the travel time runs decreased during the after period.

It should be noted that in the 2003 construction season, traffic volume data and aggressive driving maneuvers could not be collected in the same manner as in the 2002 construction season. This was mainly due to safety issues of collecting data on a freeway shoulder and also security reasons since the site was located near the Selfridge Air National Guard Base. The data for aggressive driving behavior was quantified during the travel time runs for motorists in the vicinity of the test vehicle. This was done for both the 'before' and 'after' periods for the 2003 construction season. The 'before' and 'after' comparison of aggressive driving behavior through the advanced warning area is therefore quantified, on a per run basis for the 2003 construction season, while for the 2002 construction season this data was quantified on a per hour basis.

7.0 ANALYSIS TO DETERMINE REQUIRED NUMBER OF TRAVEL TIME RUNS

Past literature has documented procedures to calculate the minimum sample size of number of travel time runs required for studies *(10,11)*. As with any study, as the sample size increases, the accuracy and reliability also increase. The limiting factor is typically the amount of resources needed to collect and analyze such data.

In order to determine the minimum number of required runs during the peak period, a sample of travel time run data collected in the 2002 construction season on the I-94 study site in Macomb County for the 'before' AM and PM peak periods were used.

The following equation was used to calculate the number of runs required *(12)*:

$$n = \left\{ \frac{\hat{\sigma} x Z}{\varepsilon} \right\}^2 \qquad \text{Equation 1}$$

Where,

n = Estimated sample size for number of runs at the desired precision and level of confidence

$\hat{\sigma}$ = Preliminary estimate of the population standard deviation for average travel speed among the sample runs

Z = Two-tailed value of the standardized normal deviate associated with the desired level of confidence (at a 95% level of confidence, $Z = 1.96$)

ε = Acceptable error (assumes as ± 3.0 mph)

The calculated sample size is based on the intended use of the travel time information. According to Oppenlander *(10)*, the range of permitted errors in the estimate of the mean travel speed (ε) is ± 1.0 mph to ± 3.0 mph for 'before and after' studies involving operational improvements of roadways. The allowable error used in this analysis was assumed to be ± 3.0 mph. According to Oppenlander, "If no travel time and delay studies have been conducted on the route under evaluation, an initial study of 4 to 5 test runs provides a sample of data for estimating the average range in travel speeds" *(10)*.

In order to calculate the number of runs required, a sample of travel time runs on westbound I-94 at the study site were taken on three typical weekdays during the AM and PM peak periods, representing the 'before' period of the 2002 construction season. The observed travel speeds during the AM peak hour for westbound I-94 ranged from 32 miles per hour (mph) to 63 mph with a standard deviation of 7.7 mph. Westbound I-94 experiences its highest traffic volumes during the AM peak period. During the PM peak period, the travel speeds ranged from 52 mph to 69 mph with a standard deviation of 4.1 mph. The traffic flows during the PM peak period are more uniform since the traffic volumes are moderate during this time period. The data used in this analysis is shown in Table 5.

Table 5. Data Used in the Calculation of Minimum Required Number of Travel Time Runs Westbound I-94 2002 Construction Season for the ‘Before’ Period (AM and PM Peak Periods)

AM Peak Period Sample Travel Time Data on I-94 for the 2002 'Before' Period

NO.	AVERAGE TRAVEL SPEED (MPH)	RECORDED TRAVEL TIME (SEC/VEH)
1	63.2	221
2	57.0	245
3	57.5	243
4	55.2	253
5	55.2	253
6	61.5	227
7	57.5	243
8	58.2	240
9	60.5	231
10	58.9	237
11	63.5	220
12	58.4	239
13	61.0	229
14	58.9	237
15	60.2	232
16	57.5	243
17	59.9	233
18	32.6	429
19	38.9	359
20	47.3	295
21	56.5	247
22	57.2	244
23	52.7	265
24	41.7	335
Average	**55.5**	
St. Dev	**7.7**	

PM Peak Period Sample Travel Time Data on I-94 for the 2002 'Before' Period

NO.	AVERAGE TRAVEL SPEED (MPH)	RECORDED TRAVEL TIME (SEC/VEH)
1	52.1	268
2	53.3	262
3	52.7	265
4	54.6	256
5	56.3	248
6	57.0	245
7	55.2	253
8	59.7	234
9	55.0	254
10	59.9	233
11	57.7	242
12	55.6	251
13	63.2	221
14	62.3	224
15	62.1	225
16	69.1	202
17	60.2	232
18	54.8	255
19	64.7	216
20	59.2	236
21	62.1	225
22	61.3	228
23	62.9	222
24	60.2	232
25	63.5	220
26	61.3	228
27	59.4	235
Average	**59.1**	
St. Dev.	**4.1**	

The calculation for the minimum number of runs required is shown below:

AM Peak Period

$$n = \left\{ \frac{\hat{\sigma} x Z}{\varepsilon} \right\}^2 = \left\{ \frac{7.7\, x 1.96}{3} \right\} = 25 \text{ runs for the AM peak period}$$

Where $\hat{\sigma}$ = 7.7 mph, Z = 1.96 and ε= 3 mph (assumed)

PM Peak Period

$$n = \left\{ \frac{4.1\,x1.96}{3} \right\}^2 = 7 \text{ runs for the PM peak period}$$

Where $\hat{\sigma}$ = 4.1 mph, Z = 1.96 and ε= 3 mph (assumed)

Thus, 25 runs are required for the AM peak period and 7 runs are needed during the PM peak period in order to quantify the operational characteristics of I-94 due to the DELMTCS.

A comparison of the total number of runs collected and the required number of runs for the AM and PM peak period are shown in Table 6.

Table 6. Comparison of the Required and Actual Number of Travel Time and Delay Runs Collected on I-94 During the 2002 and 2003 Construction Seasons for the AM and PM Peak Periods

PEAK	CONSTRUCTION SEASON	REQUIRED NUMBER OF RUNS	ACTUAL NUMBER OF TRAVEL TIME RUNS COLLECTED	
			Before	After
AM	2002	25	91	37
	2003	25	61	52
PM	2002	7	69	29
	2003	7	20	12

The actual number of runs made exceeds the minimum required number of runs for both the AM and PM peak periods, and both construction seasons the DELMTCS was tested.

8.0 STATISTICAL ANALYSIS

A statistical analysis was performed as a part of this study in order to quantify the differences in the measures of effectiveness (MOEs), which are attributable to the installation of the DELMTCS. The measure of effectiveness included in the evaluation was 'travel time delay per 10,000 feet traveled', which was normalized to account for slight variations in the distances traversed during the travel time runs.

The statistical analysis is based on a 'before and after' study of the data collected on WB I-94, during the AM peak period. In the 'before and after' study plan (Figure 7) only the project sites are used and data for the MOEs are compared 'before' and 'after' the implementation of the DELMTCS.

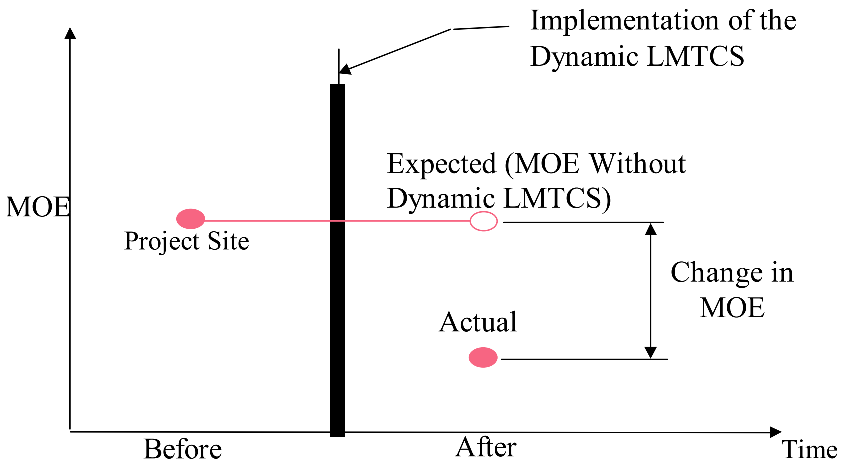


Figure 7. Before and After Evaluation Plan

The "Student's t-test" statistic *(13)*, derived by statistician W.S. Gossett under the pseudonym "Student", was used to determine if there are significant differences in the travel time 'before' and 'after' the installation of the DELMTCS on the selected work zone on I-94. The distribution of the travel time delay data (sec/veh/10,000 feet traveled) for 'before' and 'after' periods were compared for the 2002 and 2003 construction seasons, for the AM and PM peak periods.

The null and alternative hypotheses are as follows:

H_o: There is no difference in the mean travel time delay, before and after the implementation of the DELMTCS

H_a: The mean travel time delay before is greater than the mean after the implementation of the DELMTCS.

There are two general equations that can be applied for the "Student's t-test", based on whether or not the variance of the distributions of travel time observations for the 'before' and 'after' period could be assumed equal ($\sigma_A^2 = \sigma_B^2$) or unequal ($\sigma_A^2 \neq \sigma_B^2$). An analysis of the variance of the travel time observation for the 'before' and 'after' periods revealed that the variances were not equal. Thus, the following equations were used in performing the statistical analysis using the "Student's t-test" *(13)*:

"Student's t-test" Statistic ($t_{o\ calculated}$)

$$t_{o\ calculated} = \frac{\overline{X_B} - \overline{X_A}}{\sqrt{\frac{\hat{\sigma}_B^{\,2}}{N_B} + \frac{\hat{\sigma}_A^{\,2}}{N_A}}} \qquad \text{Equation 2}$$

Unbiased Estimate of Variance

$$\hat{\sigma}^2 = \frac{ns_X^{\,2}}{n-1} \qquad \text{Equation 3}$$

Calculated Degrees of Freedom

$$k' = \frac{\left[\hat{\sigma}_B^{\,2}/N_B + \hat{\sigma}_A^{\,2}/N_A\right]^2}{\frac{\left(\hat{\sigma}_B^{\,2}/N_B\right)^2}{N_B} + \frac{\left(\hat{\sigma}_A^{\,2}/N_A\right)^2}{N_A}}$$

Where:

t_o = "Student's t-test" statistic (calculated)

$\overline{X}_B$ = Mean of the 'before' travel time data

$\overline{X}_A$ = Mean of the 'after' travel time data

N_B = Number of travel time observations (number of runs) for the 'before' period

N_A = Number of travel time observations (number of runs) for the 'after' period

$\hat{\sigma}_B^2$ = Unbiased estimate of the variance of the travel time observations for the 'before' period = $(N_B\ S^2_B)/(N_B\text{-}1)$

$\hat{\sigma}_A^2$ = Unbiased estimate of the variance of the travel time observations for the 'after' period = $(N_A\ S^2_A)/(N_A\text{-}1)$

$S^2_{B,\ A}$ = Standard deviation of the travel time observations for the 'before'/'after' period, respectively.

k' = Degrees of freedom

It is important to note that in general, t_o does not exactly follow the t distribution; however by using k' as the degrees of freedom, the t distribution can be approximated by the "Student's" t_o distribution *(13)*.

The null hypothesis is rejected when the t_o (calculated) value is greater then the t_o (critical) value at $\alpha = 0.05$ (95% LOS), k' degrees of freedom.

The t-test compares the travel time delay data for the test site during the AM and PM peak periods, before and after the implementation of the DELMTCS to determine if there are significant benefits of the system in terms of reducing travel time delay, thus improving traffic operations through lane closure areas.

The mean and standard deviation of the delay rates, based on distance traveled during the runs, were calculated for the before and after data sets for the AM and PM peak periods. This data, as well as the results of the statistical analysis are shown in the Table 7.

Table 7. Results of Statistical Analysis of the DELMTCS Implemented on I-94 During the 2002 and 2003 Construction Season

Description	2002 Construction Season				2003 Construction Season			
	AM Peak Period (Fall Season Only)		PM Peak Period		AM Peak Period		PM Peak Period	
	Before	After	Before	After	Before	After	Before	After
Mean Delay per Vehicle (sec/veh/10,000 feet) ($\overline{X}$)	128.4	58.6	31.6	20.7	95.1	68.6	6.3	1.6
Standard Deviation of Delay per Vehicle (sec/veh/10,000 feet)	36.68	70.40	58.1	24.5	98.6	67.1	15.6	4.6
Variance (σ^2) of Delay per Vehicle (sec/veh/10,000 feet)	1,345.7	4,957.3	3,377.7	601.3	9,716.0	4,500.8	243.7	21.2
Unbiased Estimates of σ^2 ($\hat{\sigma}^2$) Calculated Using Equation 3	1,513.9	5,095.0	3,427.4	622.8	9,877.9	4,589.0	256.5	23.1
Sample Size (Number of Observations)	9	37	69	29	61	52	20	12

Results of the Statistical Tests

Description	2002 Construction Season		2003 Construction Season	
	AM Peak Period (Fall Season Only)	PM Peak Period	AM Peak Period	PM Peak Period
$t_{o\ calculated}$ Calculated Using Equation 2	3.992	1.292	1.678	1.236
Degrees of Freedom k′ Calculated Using Equation 4 for Unequal Sample Sizes	26	98	108	25
$t_{o\ critical}$ (one-tail test) at $\alpha = 0.05$ and k′	1.706	1.660	1.660	1.711
Significant Reduction?	Yes, since $t_{calculated} > t_{critical}$	No, Not Significant	Yes, since $t_{calculated} > t_{critical}$	No, Not Significant

The results of this analysis indicate that the DELMTCS significantly improved traffic flow through the lane merge transition area on the study freeway with three lanes (each way) reduced to two lanes during construction for the AM peak periods, both in the 2002 and 2003 construction seasons. The reductions in travel time were not significant during the PM peak periods in the 2002 and 2003 construction seasons. The traffic volumes during the PM peak period on WB I-94 are generally moderate, and thus traffic was able to merge smoothly.

9.0 FUEL CONSUMPTION AND VEHICLE EMISSIONS

The objective of the DELMTCS is to improve traffic flow through selected work zones, thus alleviating congestion through the advanced warning and lane merge area. Congestion is measured by increased travel time, delay and unnecessary stops along the travel route. These congestion parameters are directly related to fuel consumption and air pollution. Past research in traffic flow optimization has led to the development of various empirical and analytical relationships between congestion related traffic parameters such as delay, travel speed and vehicle stops with the dependent variables, such as fuel consumption, and undesirable emission parameters (Carbon Monoxide, Nitrogen Oxides and Volatile Oxygen Compounds). Many traffic flow optimization models include estimates of the system performance parameters (fuel consumption and vehicle emission).

The following relationships were identified in the literature *(14)* to estimate fuel consumption and emission characteristics.

Fuel Consumption:

$$F = (TTD * K_1) + (D * K_2) + (S * K_3) \qquad (14)$$

Where,

TTD = Total travel in vehicle miles of travel

$K_1 = 0.075 – 0.0016 * V + 0.000015 * V^2$

$K_2 = 0.73$

$K_3 = 0.0000061 * V^2$

F = Fuel Consumption in gallons

V = Operating Speed in mph

D = Total delay in vehicle-hours

S = Total stops per hour

Vehicular Emissions:

The main vehicular emissions being estimated here are Carbon Monoxide (CO), Nitrogen Oxides (NOx) and Volatile Oxygen Compounds (VOC).

$$\text{CO (in grams)} = F * (69.9 \text{ g/gal}) \quad (14)$$

$$\text{NOx (in grams)} = F * (13.6 \text{ g/gal}) \quad (14)$$

$$\text{VOC (in grams)} = F * (16.2 \text{ g/gal}) \quad (14)$$

Where F = fuel consumption in gallons

Travel time and delay runs have been made as a part of this study to test the effectiveness of the DELMTCS. These runs have been made in the field with test cars using the 'Floating Car Method' for both 'before' and 'after' periods. Based on the field data collected, including travel speed, delay and number of stops on WB I-94 for the 2002 and 2003 construction seasons, the system performance parameters such as fuel consumption and vehicle emission were calculated using the above noted formulae. It should be noted that analysis of vehicular fuel consumption characteristics are typically performed for peak traffic periods when volumes are high. On freeways, this typically occurs on weekday morning and afternoon periods and also on holiday weekends. When volumes are low, the operational impact of improvements on fuel consumptions may not be fully realized. Thus, as a part of this analysis, the fuel consumption characteristics of vehicles traveling along I-94 were analyzed during the weekday AM (7:00-9:00 AM) and PM (4:00-6:00 PM) periods, which are typically considered as the high traffic volume periods.

It should be noted that during the 4:00-6:00 PM time period, the traffic volumes on WB I-94 in the study area can be considered relatively moderate, and does not experience much congestion. Even though the 4:00-6:00 PM time period is still referenced to as the 'PM Peak Period' in this study.

Table 8 shows the 'before' and 'after' fuel consumption in gallons for all vehicles traveling through the work zone during the two (2) hour AM peak and two (2) hour PM peak periods for the 2002 and 2003 construction seasons. These estimates were based on a common length of time assumed as the number of weekdays in the 'after' period, which was 41 days for the 2002 construction season and 44 days for the 2003 construction season (total of 85 days).

Table 8. Comparison of the Fuel Consumption and Vehicle Emissions for the 'Before' and 'After' Periods for WB I-94 for the 2002 and 2003 Construction Seasons

Description	2002 Construction Season				2003 Construction Season			
	AM Peak Period (2 hour period)		PM Peak Period (2 Hour Period)		AM Peak Period (2 Hour Period)		PM Peak Period (2 Hour Period)	
	'Before' (Fall Season Only)	'After'	'Before'	'After'	'Before'	'After'	'Before'	'After'
Distance (feet)	20,575	20,575	20,575	20,575	25,760	25,760	25,760	25,760
Hourly Volume (Vehicles per hour)	3,200	3,200	3,000	3,000	3,200	3,200	3,000	3,000
No. of Weekdays DELMTCS was operational	41	41	41	41	44	44	44	44
No. of Hours in the Peak Period	2	2	2	2	2	2	2	2
TTD (Total travel time in vehicle miles of travel) =	**1,022,515**	**1,022,515**	**958,608**	**958,608**	**1,373,867**	**1,373,867**	**1,288,000**	**1,288,000**
Delay (seconds per vehicle per 10,000 feet)	128.38	58.60	31.57	20.67	95.10	69.33	6.33	1.59
D (Total delay in vehicle hours) =	**19,253**	**8,788**	**4,439**	**2,906**	**19,163**	**13,970**	**1,196**	**300**
No. stops per vehicle	1.67	0.65	0.23	0.00	1.75	0.96	0.10	0.00
S (Total stops per hour) =	**5,344.00**	**2,080.00**	**690.00**	**0.00**	**5,600.00**	**3,072.00**	**300.00**	**0.00**
V (Operating speed in MPH) =	29.73	47.75	54.73	55.94	40.04	45.52	57.91	58.15
Fuel Consumption in gallons for all vehicles traveling on WB I-94 during the peak period	**55,690**	**39,984**	**34,276**	**33,214**	**62,107**	**55,917**	**42,929**	**42,313**
Fuel Savings in gallons	**15,706 gallons**		**1,062 gallons**		**6,190 gallons**		**616 gallons**	
Carbon Monoxide Emissions in grams produced by all vehicles traveling on WB I-94 during the peak periods	**3,892,713**	**2,794,864**	**2,395,881**	**2,321,670**	**4,341,273**	**3,908,579**	**3,000,742**	**2,957,667**
Nitrogen Oxide Emissions in grams produced by all vehicles traveling on WB I-94 during the peak periods	**757,381**	**543,779**	**466,151**	**451,713**	**844,654**	**760,467**	**583,835**	**575,454**
Volatile Oxygen Emissions in grams produced by all vehicles traveling on WB I-94 during the peak periods	**902,174**	**647,737**	**555,268**	**538,069**	**1,006,132**	**905,851**	**695,451**	**685,468**
Total Emissions in grams produced by all vehicles traveling on WB I-94 during the peak periods	**5,552,268**	**3,986,380**	**3,417,301**	**3,311,451**	**6,192,059**	**5,574,897**	**4,280,028**	**4,218,589**
Percent Reduction in Total Vehicle Emissions	**28.20%**		**3.10%**		**9.97%**		**1.44%**	

Table 8 also shows the vehicle emissions, such as Carbon Monoxide, Nitrogen Oxides and Volatile Oxygen Compounds in grams for all vehicles traveling on WB I-94 during the AM and PM peak periods for the same 85 day duration of time.

The results of this analysis indicated that vehicles traveling on WB I-94 consumed less fuel due to the installation of the DELMTCS as a result of smoother traffic flow, reduced delay through the lane merge transition area and reduced number of stops. For the same length of time (assumed as the duration of the 'after' period), a total of 23,574 gallons of fuel were saved due to the DELMTCS for all vehicles traveling on WB I-94 during the AM and PM peak periods over a total of 85 days for the 2002 and 2003 construction seasons combined. This in turn reduced the amount of pollutants produced by vehicle emissions by 28 to 10 percent during the AM peak period and 3 to 1 percent during the PM peak period.

10.0 BENEFIT-COST ANALYSIS

A benefit-cost (B/C) analysis was performed as a part of this study in order to determine the economic effectiveness of the DELMTCS installed on three lane freeways each way reduced to two lanes during construction.

The purpose of the DELMTCS is to reduce the number of aggressive driving maneuvers, improve safety and improve traffic flow by encouraging drivers to merge 'early' in the traffic stream. The sensors on the dynamic sign trailers detect traffic flows, speed and occupancy, in order to create a dynamic no passing zone. Under high traffic volume conditions, the no passing zone will encourage drivers to merge well in advance of the lane taper where larger gaps are available in the traffic stream, and will provide safe and smooth merging of traffic. This system also induces a lower differential in vehicle speeds between the lanes, which also contributes to safety benefits. Thus, the total benefits of the DELMTCS include both tangible measures such as reduced travel time, reduced vehicular fuel consumption due to smoother traffic flow, reduced number of stops and delay, as well as intangible measures, such as benefits due to reduced air pollution from vehicle emissions, safety benefits related to a reduction in aggressive driver maneuvers, potential traffic crashes and associated risk due to road rage.

In the economic analysis, the benefit was considered as the travel time savings and fuel consumption savings due to the installation of the DELMTCS. The travel time savings were calculated as the difference between the delay recorded from the travel time runs from the 'before' and 'after' periods. The travel time saving is then converted to a monetary value by assuming a monetary equivalence for 'value of time'. The 'value of time' may be estimated according to the 'willingness to pay' or 'cost of time' concepts *(15)*. The willingness to pay concept considers what monetary value motorists would be willing to pay for travel time savings. The cost of time concept is the actual cost of providing time savings for a project. In this analysis, various values of time were used to determine the benefits due to travel time savings.

The fuel consumed (in gallons) by vehicles traveling on WB I-94 during the two (2)-hour AM peak and two (2)-hour PM peak periods from M-59 to just past the lane merge area (past Metropolitan Parkway), for the 2002 and 2003 construction seasons were calculated. The same length of time was used for the 'before' and 'after' periods in order to normalize the duration of time, which was assumed as the length of time for the 'after' period (41 weekdays for the 2002 construction season and 44 weekdays for the 2003 construction season). The difference in the vehicular fuel consumption for the 'before' and 'after' periods was then included in the economic analyses as a savings in vehicular fuel consumption on a per gallon basis for road users, which is attributable to the DELMTCS. An average cost of fuel of $1.50 per gallon was used to quantify the benefits due to the fuel savings.

The cost of the system was considered as the cost of the system's implementation, operation and relocation, if necessary. The resulting benefit to cost ratios were then calculated. Travel time savings were calculated for the AM and PM peak periods for the 2002 and 2003 construction seasons in which the DELMTCS was implemented.

10.1 Calculation of the Benefits

Travel Time Savings

The travel time savings in vehicle-hours is calculated as follows:

= (Delay $_{\text{before}}$ – Delay $_{\text{after}}$) (sec/veh/10,000 feet traveled) * (1/3600) (hr/sec) * (Average flow) (veh/hr) * (no. of peak hours/day) * (No. week days during the period DELMTCS was installed) * (average length of advanced warning area in which the DELMTCS is deployed, in feet)

For the 2002 construction season, the DELMTCS was operational for 41 weekdays from September 11, 2003 to November 6, 2003. For the 2003 construction season there were 44 week days between August 6th and October 6th in which the DELMTCS was operational. The travel time savings in vehicle hours for the 2002 and 2003 construction seasons for the AM and PM peak periods is calculated as follows:

2002 Construction Season – AM Peak Period

= (128.4 – 58.6) (sec/veh/10,000 feet traveled) * (1/3,600) (hr/sec) * [3,200] (veh/hr) * (2 peak hours/day) * (41 week days during the period dynamic LMTCS was installed) * (20,575 feet for the advanced warning area in which the DELMTCS was deployed) * (1/10,000 feet)

= 10,467 total vehicle-hours of travel time savings (based on the peak period for the entire period during which the DELMTCS was installed)

The average vehicle occupancy is considered to be 1.25 persons per vehicle. So, total person hours of travel time saved during installation of DELMTCS in the 2002 construction season during the AM peak period is

= 10,467*1.25 = **13,084 person hours.**

2002 Construction Season – PM Peak Period

= (31.6 – 20.7) (sec/veh/10,000 feet traveled) * (1/3,600) (hr/sec) * [3,000] (veh/hr) * (2 peak hours/day) * (41 week days during the period dynamic LMTCS was installed) * (20,575 feet for the advanced warning area in which the DELMTCS was deployed) * (1/10,000 feet)

= 1,532 total vehicle-hours of travel time savings (based on the peak period for the entire period during which the DELMTCS was installed)

The average vehicle occupancy is considered to be 1.25 persons per vehicle. So, total person hours of travel time saved during installation of DELMTCS in the 2002 construction season during the PM peak period is

= 1,532*1.25 = **1,915 person hours.**

2003 Construction Season – AM Peak Period

= (95.10 – 68.6) (sec/veh/10,000 feet traveled) * (1/3,600) (hr/sec) * [3,200] (veh/hr) * (2 peak hours/day) * (44 week days during the period dynamic LMTCS was installed) * (25,760 feet for the advanced warning area in which the DELMTCS was deployed) * (1/10,000 feet)

= 5,340 total vehicle-hours of travel time savings (based on the peak period for the entire period during which the DELMTCS was installed)

The average vehicle occupancy is considered to be 1.25 persons per vehicle. So, total person hours of travel time saved during installation of DELMTCS in the 2003 construction season during the AM peak period is = 5,340*1.25 = **6,675 person hours.**

2003 Construction Season – PM Peak Period

= (6.3 - 1.6) (sec/veh/10,000 feet traveled) * (1/3,600) (hr/sec) * [3,000] (veh/hr) * (2 peak hours/day) * (44 week days during the period dynamic LMTCS was installed) * (25,760 feet for the advanced warning area in which the DELMTCS was deployed) * (1/10,000 feet)

= 888 total vehicle-hours of travel time savings (based on the peak period for the entire period during which the DELMTCS was installed)

The average vehicle occupancy is considered to be 1.25 persons per vehicle. So, total person hours of travel time saved during installation of DELMTCS in the 2003 construction season during the PM peak period is

= 888*1.25 = **1,110 person hours**.

Total Travel Time Savings for the 2002 and 2003 Construction Season AM and PM Peak Periods on I-94 with the DELMTCS

= 13,084 person hours + 1,915 person hours + 6,675 person hours + 1,110 person hours

= 22,774 person hours of travel time savings due to the DELMTCS implemented on a three (3)-lane freeway each way (I-94) reduced to two (2) lanes during construction

A comparison of the total travel time savings in the 2002 and 2003 construction season indicates that the travel time savings in the 2002 construction season were higher as compared to the 2003 construction season. Potential reasons for such differences may be attributable to ‘spill-over’ effects of the systems from one season to the next and differences in police enforcement strategies.

In the ‘before’ period, of the 2003 construction season, even though the DELMTCS was not installed, police officers were issuing citations and/or warnings for aggressive driving behavior through the advanced warning area of the work zone. This resulted in drivers making smooth and early merges, which may have impacted the traffic operations. Additionally, having the system implemented one year prior, may have impacted drivers’ actions while driving through the work zone on WB I-94 in the 2003 construction season, even though the DELMTCS had not been installed.

Fuel Savings

As shown in Table 8, page 33, a total of 23,574 gallons of fuel (=15,706 + 1,062 + 6,190 + 616 gallons) were saved for all vehicles traveling on WB I-94 during the AM and PM peak periods while the DELMTCS was operational in the 2002 and 2003 construction seasons combined.

Assuming an average cost of $1.50 per gallon of gasoline, this translates into a monetary savings of $35,361.00 for both 2002 and 2003 construction seasons combined.

10.2 Calculation of the Costs

The total cost of installing and operating the DELMTCS for both the 2002 and 2003 construction seasons was considered as the cost in the economic analysis. The total cost for the installation and operation of the DELMTCS for the 2002 and 2003 construction seasons combined was $111,134.50, which consists of the following cost items:

ITEM	COST
Dynamic Lane Merge Trailer Furnished (2002)	$47,250.00
Dynamic Lane Merge Trailer Operation (2002)	$23,635.00
Dynamic Lane Merge Trailer Furnished (2003)	$5,250.00
Dynamic Lane Merge Trailer Operation (2003)	$2,625.00
Trailer Relocate	$5,250.00
Dynamic Lane System Remobilization	$8,295.00
Portable Changeable Message Board (2002) Operation	$1,785.00
Portable Changeable Message Board (2003) Operation	$1,785.00
Portable Changeable Message Board (2002) Furnished	$3,459.75
Portable Changeable Message Board (2003) Furnished	$3,459.75
Police Enforcement	$8,350.00
TOTAL	**$111,134.50**

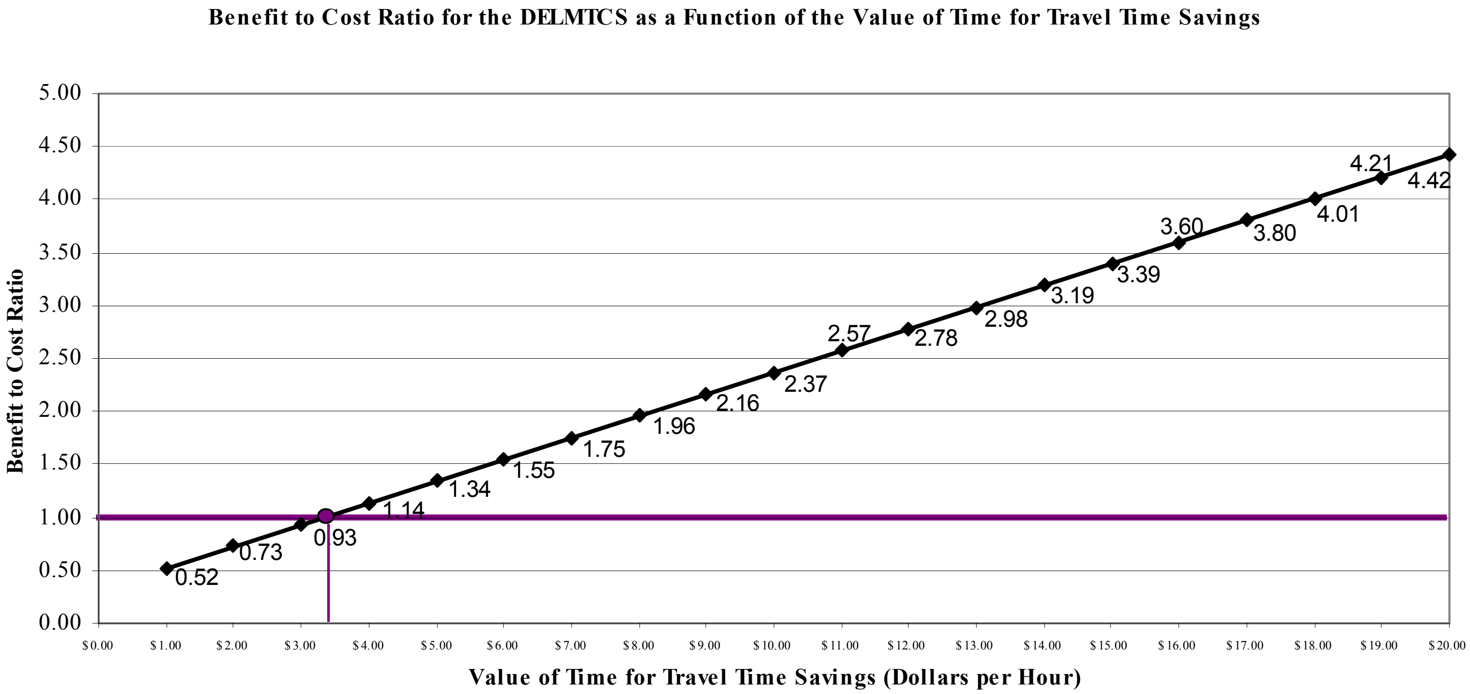
10.3 Benefit to Cost Analysis

The following table shows the monetary benefits of the DELMTCS, based on various amounts of value of travel time savings in person hours, plus the monetary value of the fuel savings.

VALUE OF TRAVEL TIME SAVINGS ($ PER HOUR PER PERSON)	MONETARY BENEFITS OF THE DELMTCS		
	Due to Travel Time Savings	Due to Vehicular Fuel Savings	Total Tangible Benefits
$1.00	$22,774.00	$35,361.00	$58,135.00
$2.00	$45,548.00	$35,361.00	$80,909.00
$3.00	$68,322.00	$35,361.00	$103,683.00
$4.00	$91,096.00	$35,361.00	$126,457.00
$5.00	$113,870.00	$35,361.00	$149,231.00
$6.00	$136,644.00	$35,361.00	$172,005.00
$7.00	$159,418.00	$35,361.00	$194,779.00
$8.00	$182,192.00	$35,361.00	$217,553.00
$9.00	$204,966.00	$35,361.00	$240,327.00
$10.00	$227,740.00	$35,361.00	$263,101.00
$11.00	$250,514.00	$35,361.00	$285,875.00
$12.00	$273,288.00	$35,361.00	$308,649.00
$13.00	$296,062.00	$35,361.00	$331,423.00
$14.00	$318,836.00	$35,361.00	$354,197.00
$15.00	$341,610.00	$35,361.00	$376,971.00
$16.00	$364,384.00	$35,361.00	$399,745.00
$17.00	$387,158.00	$35,361.00	$422,519.00
$18.00	$409,932.00	$35,361.00	$445,293.00
$19.00	$432,706.00	$35,361.00	$468,067.00
$20.00	$455,480.00	$35,361.00	$490,841.00

The B/C ratios were then calculated based on these values of the benefits. It is important to note that since the dynamic LMTCS was implemented for a short duration of time, the economic analysis was calculated as the direct ratio of the benefits over the costs.

The results of the B/C analysis were then plotted on a graph showing the B/C ratios versus the various values of time, as shown below:



This graph shows that for a value of time for travel time savings greater than approximately \$3.33, the benefit to cost ratio will be greater than one, indicating that the monetary benefits of the DELMTCS outweigh the cost of the system.

In a study conducted by Purdue University for the Indiana Department of Transportation regarding the safety benefits of the LMTCS suggested the use of “a delay cost of \$8/hour and an average occupancy of 1.25 persons/vehicle *(16)*”. When these values are used, the B/C ratio is 1.96 to 1.0.

It is important to note that there are other intangible benefits of the DELMTCS which were not included in the economic analysis because there is not a precise way to quantify them in monetary terms. Such benefits include the reduction of air pollutants of vehicular emissions as a result of a reduced number of stops and associated acceleration/deceleration cycles, delay and congestion on the freeway. In addition, there are significant safety benefits which could not be quantified in this analysis related to the reduction in observed aggressive driving maneuvers at the lane merge transition area. If these factors could be quantified in monetary terms, the economic analysis would result in much higher benefit to cost ratios than reported here.

11.0 TRAFFIC CRASH ANALYSIS

As a part of this study, two types of traffic crash analyses were conducted. A traffic crash analysis was conducted for the years 2000 and 2001 for the pre-construction period in order to assess the general traffic crash experience on WB I-94. A second analysis is presented for the 'before' and 'after' crash experience due to the installation of the DELMTCS for the 2002 construction season. The traffic crash analyses conducted as a part of this study are presented below.

11.1 Pre-Construction Traffic Crash Analysis

As a part of this study, a traffic crash analysis was performed for westbound I-94 from M-59 to Metropolitan Parkway for the years 2000 and 2001 when no construction projects were in place. This analysis was performed in order to present the crash experience on westbound I-94 without any construction in order to assess if any hazardous conditions existed which may have impacted the installation of the DELMTCS.

Traffic crash data for I-94 from M-59 to Metropolitan Parkway was obtained from SEMCOG's Transportation Data Management (on-line) Tool for the years 2000 and 2001. The traffic crashes were then plotted on a collision diagram in order to visually display potential crash patterns. The resulting collision diagrams are shown on Figures 8 and 9.

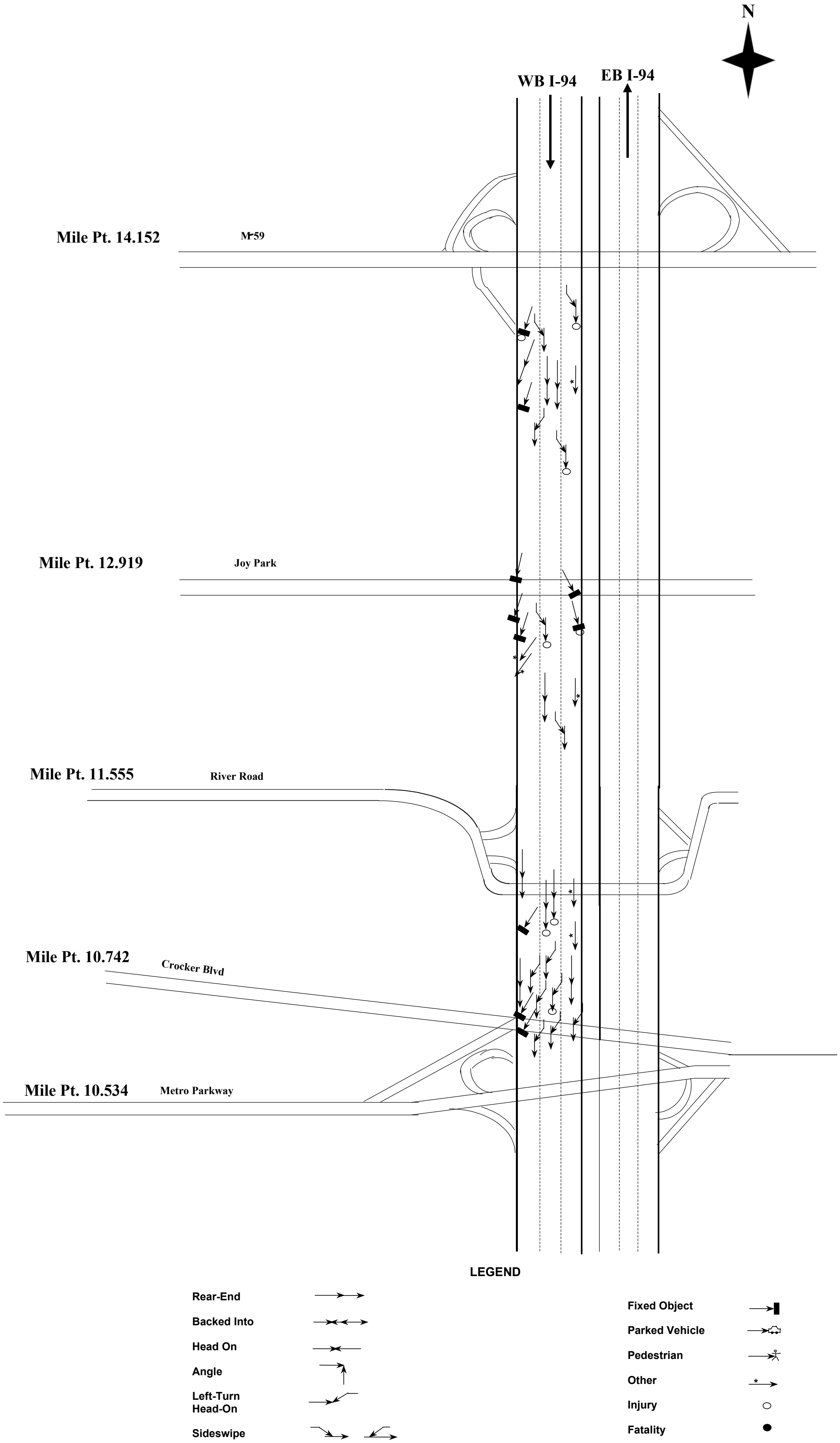


Figure 8. Collision Diagram for the Year 2000 for Westbound I-94 (With No Construction)

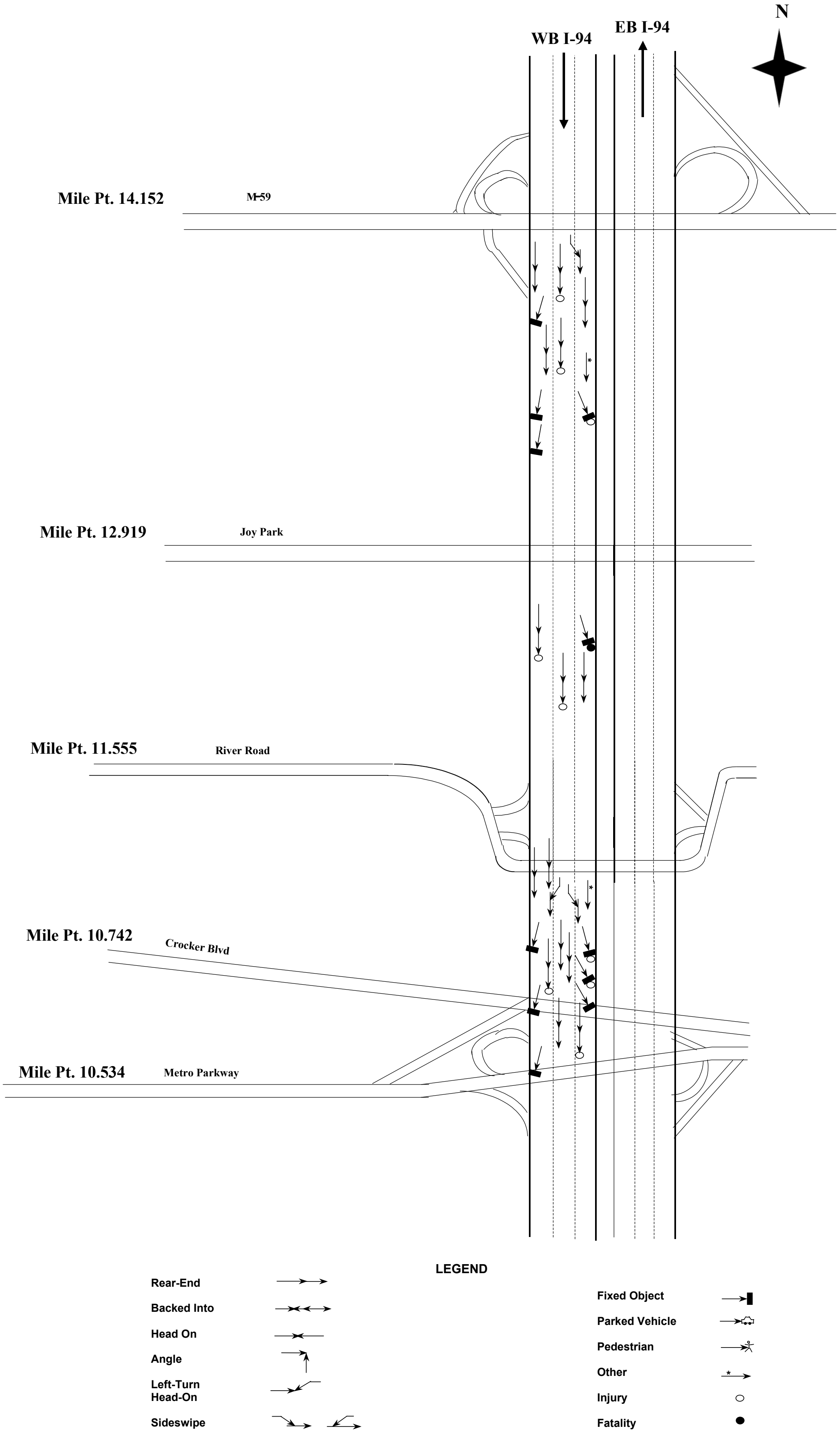


Figure 9. Collision Diagram for the Year 2001 for Westbound I-94 (With No Construction)

The results of the crash analysis indicate that in the year 2000, a total of 39 crashes with 7 injury crashes occurred on westbound I-94 over a distance of 3.6 miles and in the year 2001, a total of 32 crashes with 11 injury crashes occurred along this same segment. Crash rates were calculated to account for exposure using the average daily traffic (ADT) volumes. In the year 2001, the ADT on WB I-94 was 34,244 vehicles per day. Assuming the ADT was similar in the year 2000, the crash rates are as follows:

$$\text{Crash Rate} = \frac{\text{(Number of crashes per year) * (10\^{}6)}}{\text{(ADT) * (365) * (Length of segment in miles)}}$$

(crashes per million
entering vehicles per mile)

Crash Rate for WB I-94 for the Year 2000 = 0.89 crashes per million vehicle miles of travel (from M-59 to Metropolitan Parkway)

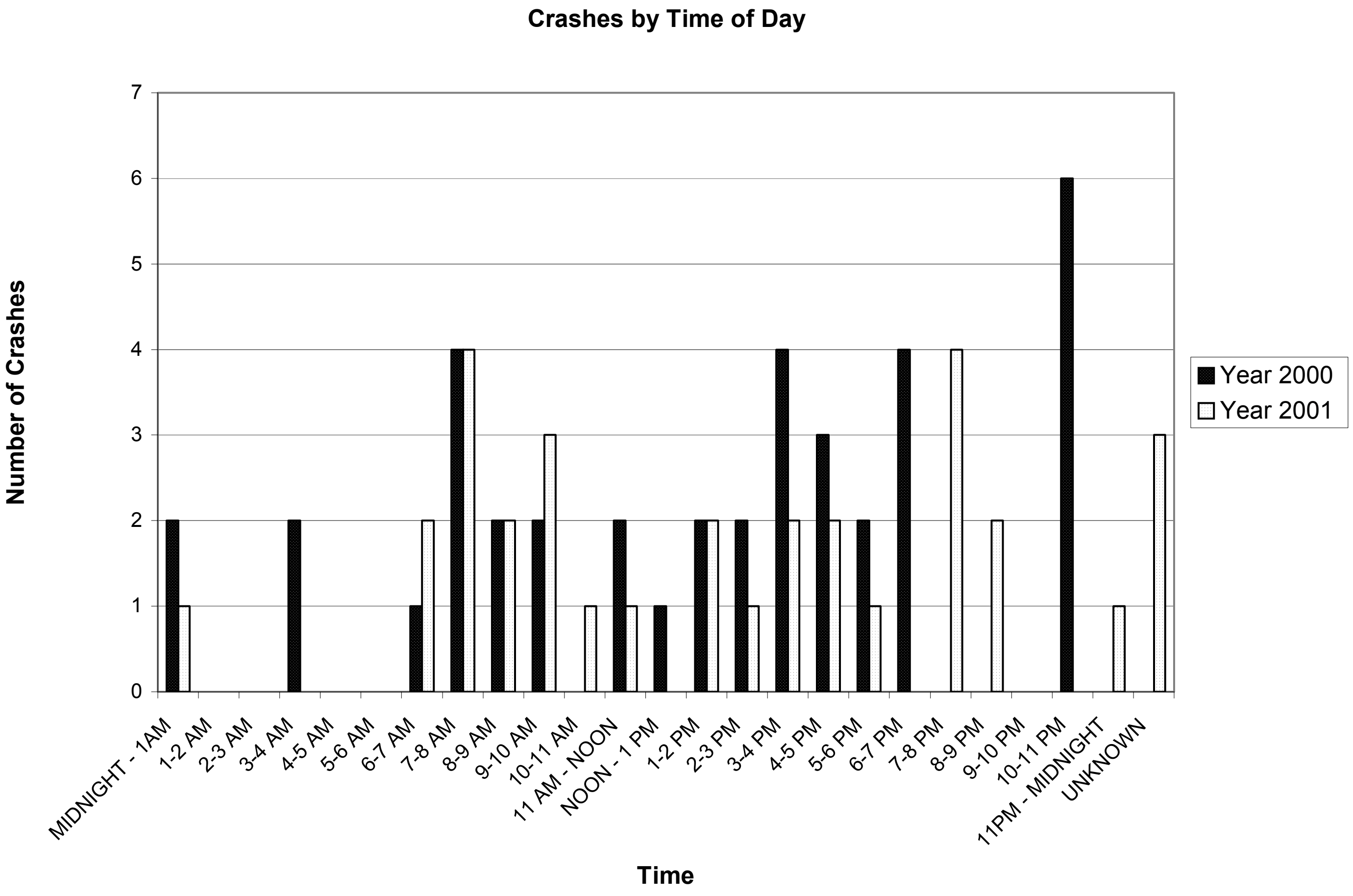
Crash Rate for WB I-94 for the Year 2001 = 0.71 crashes per million vehicle miles of travel (from M-59 to Metropolitan Parkway)

The crash experience on WB I-94 seems reasonable for this type of facility.

A pattern analysis of the crashes on WB I-94 by crash type are as follows:

CRASH TYPE	**ANNUAL CRASH FREQUENCY**		**AVERAGE ANNUAL CRASH FREQUENCY**
	2000	**2001**	
Rear End	9	12	10
Sideswipe	13	3	8
Single Vehicle	11	13	12
Other	6	4	5
Total	**39**	**32**	**35**
Injury	7	11	9

The results of the pattern analysis indicate that there are a predominance of single vehicle and rear end crashes which occurred on WB I-94 prior to any construction. Rear end and single vehicle crashes are typically predominant for any freeway facility.



A pattern analysis was also conducted for the time of day in which the crashes occurred in order to identify any predominant crash trends.

The majority of the crashes in the years 2000 and 2001 occurred between 6 AM and 11 PM. Approximately one-fourth of the crashes occurred during the AM (7-9 AM) and PM (4-6 PM) peak periods.

Since the crash experience on WB I-94 in the years 2000 and 2001 are typical of a suburban freeway, and no unusual crash patterns were identified, the installation of the DELMTCS on WB

I-94 was appropriate. It should be noted that anytime a fixed object is placed on a roadside, the probability of a fixed object crash increases. However, the safety and operational benefits attributable to the DELMTCS exceed any potential risk of placing additional fixed objects on the roadside.

11.2 'Before' and 'After' Traffic Crash Analysis

As a part of this study, a traffic crash analysis was conducted 'before' and 'after' the installation of the DELMTCS. This analysis was conducted using traffic crash data for the 2002 construction season, since 2003 data was not available at the time of this study. Traffic crash data for the year 2002 was obtained from SEMCOG's Transportation Data Management Tool (on-line) for WB I-94 from M-59 to Metropolitan Parkway. The 'before' period considered in this analysis was from May 2002 to September 10, 2002 (4.3 months) while the construction work zone was in place on WB I-94, but 'before' the DELMTCS was operational. The 'after' period was from September 11 to November 6, 2002 (2 months) while the DELMTCS was operational from the work zone traffic control.

Comparisons of the 'before' and 'after' crash data were made for the following segments on WB I-94:

- Throughout the Advanced Warning Area until just after the lane merge area, from M-59 to Metropolitan Parkway (a distance of 3.6 miles)
- Just before and just after the critical lane merge area from North River Road to Metropolitan Parkway (a distance of 1.0 miles)

Table 9 shows the results of the 'before' and 'after' comparisons on WB I-94 for the 2002 construction season.

Table 9. 'Before' and 'After' Traffic Crash Comparison on WB I-94 for the 2002 Construction Season

LOCATION	NUMBER OF CRASHES IN THE 'BEFORE' PERIOD		NUMBER OF CRASHES IN THE 'AFTER' PERIOD	
	May 2002 to September 10, 2002 (4.3 months)	**Average Number of Crashes per Month**	**September 11 to November 6, 2002 (2 months)**	**Average Number of Crashes per Month**
WB I-94 from beginning of Advanced Warning Area to just after the lane merge area (M-59 to Metropolitan Parkway, 3.6 miles)	Total Crashes 11.0 crashes in 4.3 months Injury Crashes 2 injury crashes in 4.3 months	Total Crashes 2.1 crashes per month Injury Crashes 0.47 injury crashes per month	Total Crashes 6.0 crashes in 2 months Injury Crashes 3 injury crashes in 2 months	Total Crashes 3.0 crashes per month Injury Crashes 1.5 injury crashes per month
WB I-94 before and after the critical lane merge area (North River Road to Metropolitan Parkway, 1 mile)	Total Crashes 5.0 crashes in 4.3 months Injury Crashes 0 injury crashes in 4.3 months	Total Crashes 1.2 crashes per month Injury Crashes 0 injury crashes per month	Total Crashes 0 crashes in 2 months Injury Crashes 0 injury crashes in 2 months	Total Crashes 0 crashes per month Injury Crashes 0 injury crashes per month

Details of the traffic crash data used in this analysis are included in Appendix III.

The results of this traffic crash analysis indicated that for the critical lane merge transition area no crashes occurred after the DELMTCS was installed, while in the 'before' construction period, an average of 1.2 crashes per month occurred in this area from May 2002 to September 10, 2002 for a 4.3 month period.

It should be noted that 4 of the 5 crashes in the critical lane merge area for the 'before' period occurred in the morning peak period from 6:00 AM to 10:00 AM, while in the 'after' period, no crashes at all occurred on this segment of WB I-94. This indicates that the DELMTCS helped improve safety during the peak targeted time periods in which the system was installed to improve safety and traffic flow.

However, the entire advanced warning area over a length of 3.6 miles, an average of 2.1 crashes per month occurred in the 'before' period and an average of 3.0 crashes occurred in the 'after' period.

Due to the small amount of crash data compiled for such a short period of time, it is difficult to attribute the changes in the crash patterns to the installation of the DELMTCS. As such, data for surrogate measures, which included the quantification of the number of aggressive driver maneuvers, was collected in order to assess the safety benefits of the DELMTCS (refer to Tables 3 and 4, pages 20 and 22, respectively).

The data for aggressive driving maneuvers indicated significant reductions during the peak periods after the DELMTCS was implemented, especially during the 2002 construction season. This, coupled with the reduced number of crashes in the critical lane merge area indicate that the DELMTCS is useful in improving safety in construction work zones on three (3)-lane freeways each way reduced to two (2) lanes during construction.

12.0 CRITERIA FOR INSTALLATION OF THE DELMTCS

In order to install the DELMTCS, certain criteria should be met for the system to reach optimal efficiency and achieve the maximum benefits. The criteria for the installation of the DELMTCS on three (3)-lane freeways (each way) reduced to two (2) lanes during construction are as follows:

The main criteria for the installation of the DELMTCS is that the construction zone must be in place and the DELMTCS must be planned to be operational during the peak hours of travel. The DELMTCS is recommended for highway projects that experience moderate traffic volumes prior to construction. It is obvious that the DELMTCS should not be installed at locations where traffic volumes are low. This is because when the traffic volumes are low, drivers do not need any assistance for merging to the next lane to avoid lane closure; they can easily do it without any problem. Thus, guidelines related to traffic volumes (hourly volumes and average daily traffic volumes) were developed for the installation of the DELMTCS. These guidelines were developed based on analyses of expected delay using the Highway Capacity Software (HCS-2000) *(17)*, as well as the traffic flow and system performance observed at the test sites.

Sets of capacity analyses were performed in order to evaluate the traffic volume ranges that a freeway can handle when a three-lane freeway is reduced to two lanes during construction using HCS-2000. The level of service for freeways is based on the operating speed, traffic volumes and number of lanes, as shown below *(17)*:

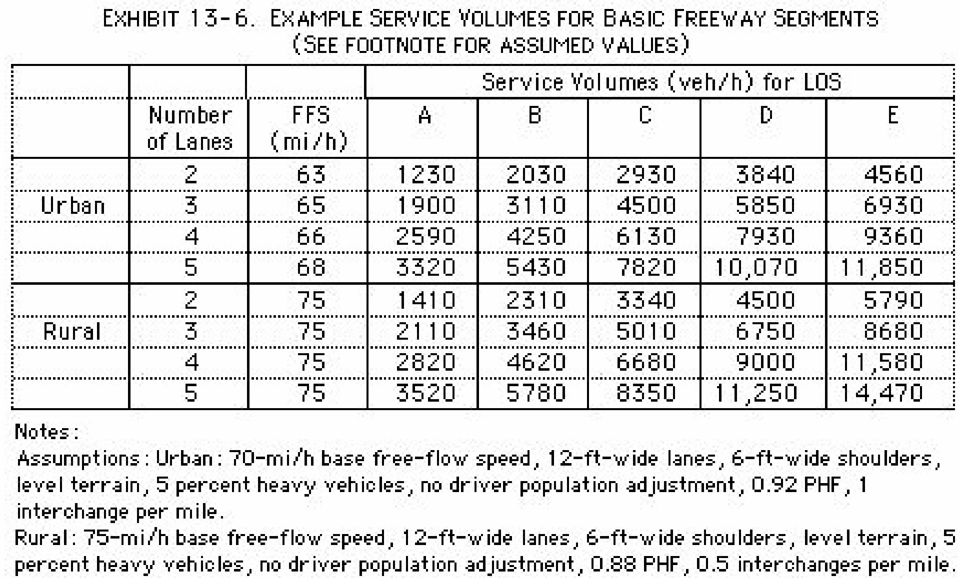


EXHIBIT 13-6. EXAMPLE SERVICE VOLUMES FOR BASIC FREEWAY SEGMENTS
(SEE FOOTNOTE FOR ASSUMED VALUES)

			Service Volumes (veh/h) for LOS				
	Number of Lanes	FFS (mi/h)	A	B	C	D	E
	2	63	1230	2030	2930	3840	4560
Urban	3	65	1900	3110	4500	5850	6930
	4	66	2590	4250	6130	7930	9360
	5	68	3320	5430	7820	10,070	11,850
	2	75	1410	2310	3340	4500	5790
Rural	3	75	2110	3460	5010	6750	8680
	4	75	2820	4620	6680	9000	11,580
	5	75	3520	5780	8350	11,250	14,470

Notes:
Assumptions: Urban: 70-mi/h base free-flow speed, 12-ft-wide lanes, 6-ft-wide shoulders, level terrain, 5 percent heavy vehicles, no driver population adjustment, 0.92 PHF, 1 interchange per mile.
Rural: 75-mi/h base free-flow speed, 12-ft-wide lanes, 6-ft-wide shoulders, level terrain, 5 percent heavy vehicles, no driver population adjustment, 0.88 PHF, 0.5 interchanges per mile.

[Source: Highway Capacity Manual – 2000 Version *(17)*]

The capacity of a highway facility can be evaluated based on six levels of service (LOS) ranging from LOS "A" to LOS "F". The following describes each level of service as per the Highway Capacity Manual *(17)*:

- LOS "A" describes completely free-flow conditions where the operation of vehicles is virtually unaffected by the presence of other vehicles.
- LOS "B" also indicates free-flow conditions, however the presence of other vehicles becomes noticeable. Drivers have slightly less freedom to maneuver as compared to the LOS "A" condition.
- In LOS "C", the influence of traffic density on operations is apparent. The ability to maneuver within the traffic stream is clearly affected by other vehicles.
- At LOS "D", the ability to maneuver is severely restricted due to traffic congestion.
- LOS "E" represents operations at or near capacity, which is an unstable level.
- LOS "F" represents forced or breakdown flow.

The table below shows the results of capacity analyses for various traffic volume ranges, considering two lanes of moving traffic and assuming a 65 mph operating speed.

Capacity Analysis for Traffic Volume Ranges (Two-Lane Freeway)

TRAFFIC VOLUME (VPH)	NUMBER OF LANES OF TRAFFIC	LEVEL OF SERVICE	DENSITY (VEH/MILE/LANE)
2,500 VPH	2	C	24.5
2,800 VPH	2	D	27.4
3,000 VPH	2	D	29.5
3,500 VPH	2	E	36.2
3,800 VPH	2	E	42.4
4,000 VPH	2	F	*
4,500 VPH	2	F	*

* Overall results are not computed when free-flow speed is less than 55 mph.

The DELMTICS will operate efficiently during medium to moderately high density levels, (LOS "D" to LOS "E"). Based on the traffic characteristics observed on westbound I-94, the DELMTCS could efficiently handle traffic volumes of approximately 3,000 vph to 3,500 vph without experiencing extreme levels of congestion. It was assumed that the traffic volumes on a given freeway before construction would be slightly higher than during the construction period, due to some motorists choosing alternative routes. Thus, the installation of the DELMTCS is recommended on three-lane highways (in each direction), reduced to two-lanes (each direction) during construction according to the following volume guidelines, based on the pre-construction traffic volume conditions:

Higher Volume Periods Observed Prior to Construction

- Range of Hourly Volume = **3,000 to 3,800 vehicles per hour** per direction (at least two hours per day on a typical weekday or 4 to 5 hours per day on the weekend)
- Average Daily Traffic Volumes = 34,500 to 45,000 vehicles per day per direction (Installation of the DELMTCS should not be based on ADT volumes alone)

13.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions for the DELMTCS as tested in Michigan on three (3)-lane freeways (each direction) reduced to two (2) lanes during construction are as follows. Specific recommendations for the future use of the system are also provided and italicized for emphasis.

1. The DELMTCS was found to be effective in reducing aggressive driver behavior, increasing safety and reducing delay in the work zone on WB I-94 in Macomb County, Michigan, which consists of a three (3)-lane freeways (each direction) reduced to two (2) lanes during construction. *The installation of the DELMTCS should be considered for future construction projects on three lane freeways reduced to two lanes in Michigan.*

2. The traffic control plan for the DELMTCS used on WB I-94 included traditional advanced work zone warning signs, a series of 3 static and up to 5 dynamic "Do Not Pass" signs, and a portable changeable message sign with text "Merge Right/Left" and an arrow symbol. With this traffic control plan, motorists seemed to understand the DELMTCS and take the proper driving action, as evidenced in this study. *The traffic control plans for the advanced warning area for future projects using the DELMTCS should be designed to take care of the entrance and exit ramps and other unique features of a freeway.*

3. *The sensor settings for the DELMTCS included in this report may be used for future installations of the system on three lane freeways (each direction) with one lane closures. The DELMTCS operation should be closely monitored during the first week of the system's installation in order to ensure the system is responding properly to the traffic volumes and density. The activation and deactivation of the flashing mode of the "Do Not Pass/When Flashing" signs should follow the drivers expectancies. For example, all the signs should be activated in flashing mode during congested conditions where drivers need the most assistance in determining the appropriate location to merge. If gaps in the traffic stream are available, which is usually the case in low traffic volume conditions, the signs should not be activated into the flashing mode.*

4. The results of the 'before' and 'after' study of the operational characteristics on WB I-94 during the 2002 and 2003 construction seasons indicated the DELMTCS was effective in reducing travel time delays, number of stops and aggressive driving maneuvers for similar flow rates during the AM peak period. The results of the statistical analysis of delay per vehicle 'before' and 'after' the installation of the DELMTCS indicated significant reductions in delay during the AM peak periods due to the DELMTCS. This analysis was conducted using the Student's t-test at a 95 percent level of confidence.

5. The calculated fuel consumption and vehicle emissions for the 'before' and 'after' periods for all vehicles traveling on WB I-94 during the two (2)-hour AM and two (2)-hour PM peak periods for the 2002 and 2003 construction seasons for 41 weekdays and 44 weekdays, respectively for the 'before' and 'after' periods indicated a total fuel savings of 23,574 gallons as a result of decreased number of stops and reduced travel time from the installation of the DELMTCS. Vehicular emissions were reduced by 10 to 28 percent in the AM peak period and 1 to 3 percent during the PM peak period for the 2002 and 2003 construction season respectively, as a result of the DELMTCS.

6. An economic analysis was performed which considered travel time savings and fuel savings due to the DELMTCS. The results this analysis indicated that the DELMTCS was economically beneficial and achieved benefit to cost ratios greater than one, if a value of time of $3.33 per person hour is assumed for travel time savings. Assuming a value of time of $8.00 per hour for travel time savings, which is a reasonable assumption, the benefit to cost ratio for the DELMTCS installation on I-94 was 1.96 to 1.0. *From an economic standpoint, the DELMTCS will be most effective if installed for a duration of 2 months or more.*

7. A 'before' and 'after' traffic crash analysis was performed for WB I-94 during the 2002 construction season for the following two locations:
    - Through the work zone's advanced warning area to just after the lane merge transition (a distance of 3.6 miles)
    - Within the critical lane merge area (a distance of 1.0 mile)

The results of this traffic crash analysis indicated that for the critical lane merge transition area no crashes occurred after the DELMTCS was installed during the 2002 construction season, while in the 'before' construction period, an average of 1.2 crashes per month occurred in this area over a 4.3 month period in 2002. However, the entire advanced warning area over a length of 3.6 miles, an average of 2.1 crashes per month occurred in the 'before' period and an average of 3.0 crashes occurred in the 'after' period for the 2002 construction season. Due to the small amount of crash data compiled for such a short period of time, it is difficult to attribute the changes in the crash patterns to the installation of the DELMTCS.

8. Criteria for the installation of the DELMTCS were developed, which include the following guidelines:
   - *The main criteria for the installation of the DELMTCS is that the lane closure must be in place and the DELMTCS must be planned to be operational during the higher volume periods of travel on the highway facility.*
   - *The DELMTCS is recommended for highway projects that experience moderate traffic volumes prior to construction. The DELMTCS should not be installed at locations where traffic volumes are low or too high.*
   - *The installation of the DELMTCS is recommended on three-lane highways (in each direction), reduced to two-lanes (each direction) during construction according to the following volume guidelines, based on the pre-construction traffic volume conditions:*

Higher Volume Periods Observed Prior to Construction

- *Range of Hourly Volume =* ***3,000 to 3,800 vehicles per hour*** *per direction (at least two hours per day on a typical weekday or 4 to 5 hours per day on the weekend)*
- *Average Daily Traffic Volumes = 34,500 to 45,000 vehicles per day per direction (Installation of the DELMTCS should not be based on ADT volumes alone)*

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APPENDIX I – TRAVEL TIME DATA COLLECTED FOR THE ‘BEFORE’ AND ‘AFTER’ PERIODS DURING THE 2002 CONSTRUCTION SEASON FOR THE AM AND PM PEAK PERIODS

TRAVEL TIME DATA FOR THE 'BEFORE' PERIOD FOR THE 2002 CONSTRUCTION SEASON FOR THE AM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	July 2, 2002	6:47:11-6:50:55 AM	0	224	20530	62.3	0	215	9	4.38
2	July 2, 2002	6:57:09-7:01:09 AM	0	240	20530	58.2	0	215	25	12.18
3	July 2, 2002	7:07:26-7:11:23 AM	0	237	20530	58.9	0	215	22	10.72
4	July 2, 2002	7:17:39-7:21:44 AM	0	245	20530	57.0	0	215	30	14.61
5	July 2, 2002	7:50:14-7:54:18 AM	0	244	20530	57.2	0	215	29	14.13
6	July 2, 2002	8:00:44-8:05:09 AM	0	265	20530	52.7	0	215	50	24.35
7	July 2, 2002	8:12:23-8:21:38 AM	89	555	20530	25.2	6	215	340	165.61
8	July 2, 2002	8:28:56-8:46:18 AM	517	1042	20530	13.4	13	215	827	402.83
9	July 2, 2002	8:53:00-9:00:36 AM	48	456	20530	30.6	3	215	241	117.39
10	July 8, 2002	7:21:02-7:24:43 AM	0	221	20530	63.2	0	215	6	2.92
11	July 8, 2002	7:30:44-7:34:49 AM	0	245	20530	57.0	0	215	30	14.61
12	July 8, 2002	7:41:20-7:45:23 AM	0	243	20530	57.5	0	215	28	13.64
13	July 8, 2002	7:52:41-7:56:54 AM	0	253	20530	55.2	0	215	38	18.51
14	July 8, 2002	8:03:55-8:08:08 AM	0	253	20530	55.2	0	215	38	18.51
15	July 8, 2002	8:14:29-8:18:16 AM	0	227	20530	61.5	0	215	12	5.85
16	July 8, 2002	8:24:28-8:28:31 AM	0	243	20530	57.5	0	215	28	13.64
17	July 8, 2002	8:35:55-8:39:55 AM	0	240	20530	58.2	0	215	25	12.18
18	July 8, 2002	8:46:06-8:49:57 AM	0	231	20530	60.5	0	215	16	7.79
19	July 9, 2002	7:26:28-7:30:25 AM	0	237	20530	58.9	0	215	22	10.72
20	July 9, 2002	7:37:17-7:40:57 AM	0	220	20530	63.5	0	215	5	2.44
21	July 9, 2002	7:47:08-7:51:07 AM	0	239	20530	58.4	0	215	24	11.69
22	July 9, 2002	8:14:18-8:18:07 AM	0	229	20530	61.0	0	215	14	6.82
23	July 9, 2002	8:24:26-8:28:23 AM	0	237	20530	58.9	0	215	22	10.72
24	July 9, 2002	8:34:20-8:38:12 AM	0	232	20530	60.2	0	215	17	8.28
25	July 9, 2002	8:44:25-8:48:28 AM	0	243	20530	57.5	0	215	28	13.64
26	July 9, 2002	9:00:04-9:03:57 AM	0	233	20530	59.9	0	215	18	8.77
27	July 10, 2002	7:47:24-7:54:33 AM	49	429	20530	32.6	2	215	214	104.24
28	July 10, 2002	8:01:33-8:07:32 AM	11	359	20530	38.9	1	215	144	70.14
29	July 10, 2002	8:14:31-8:19:26 AM	0	295	20530	47.3	0	215	80	38.97
30	July 10, 2002	8:26:00-8:30:07 AM	0	247	20530	56.5	0	215	32	15.59
31	July 10, 2002	8:37:32-8:41:36 AM	0	244	20530	57.2	0	215	29	14.13
32	July 10, 2002	8:47:54-8:52:19 AM	0	265	20530	52.7	0	215	50	24.35
33	July 10, 2002	8:59:13-9:04:48 AM	0	335	20530	41.7	0	215	120	58.45
34	July 11, 2002	7:11:43-7:15:23 AM	0	220	20530	63.5	0	215	5	2.44
35	July 11, 2002	7:22:27-7:26:29 AM	0	242	20530	57.7	0	215	27	13.15
36	July 11, 2002	7:32:29-7:37:00 AM	0	271	20530	51.5	0	215	56	27.28
37	July 11, 2002	7:44:00-7:48:38 AM	0	278	20530	50.2	0	215	63	30.69
38	July 11, 2002	7:55:52-7:59:52 AM	0	240	20530	58.2	0	215	25	12.18
39	July 11, 2002	8:05:59-8:09:52 AM	0	233	20530	59.9	0	215	18	8.77
40	July 11, 2002	8:15:56-8:20:08 AM	0	252	20530	55.4	0	215	37	18.02
41	July 11, 2002	8:27:11-8:31:17 AM	0	246	20530	56.8	0	215	31	15.10
42	July 11, 2002	8:37:48-8:41:58 AM	0	250	20530	55.9	0	215	35	17.05
43	July 11, 2002	9:02:18-9:06:43 AM	0	265	20530	52.7	0	215	50	24.35
44	July 12, 2002	7:05:54-7:09:30 AM	0	216	20530	64.7	0	215	1	0.49
45	July 12, 2002	7:15:37-7:19:23 AM	0	226	20530	61.8	0	215	11	5.36
46	July 12, 2002	7:25:51-7:29:34 AM	0	223	20530	62.6	0	215	8	3.90
47	July 12, 2002	7:35:46-7:40:15 AM	0	269	20530	51.9	0	215	54	26.30
48	July 12, 2002	7:46:52-7:51:17 AM	0	265	20530	52.7	0	215	50	24.35
49	July 12, 2002	7:57:19-8:01:38 AM	0	259	20530	53.9	0	215	44	21.43
50	July 12, 2002	8:22:27-8:26:13 AM	0	226	20530	61.8	0	215	11	5.36
51	July 12, 2002	8:32:30-8:35:59 AM	0	209	20530	66.8	0	215	0	0.00
52	July 12, 2002	8:42:31-8:46:31 AM	0	240	20530	58.2	0	215	25	12.18
53	July 12, 2002	8:53:17-8:57:01 AM	0	224	20530	62.3	0	215	9	4.38
54	July 15, 2002	7:12:46-7:17:13 AM	0	267	20530	52.3	0	215	52	25.33
55	July 15, 2002	7:23:53-7:31:04 AM	75	431	20530	32.4	3	215	216	105.21
56	July 15, 2002	7:37:31-7:44:19 AM	36	408	20530	34.2	3	215	193	94.01
57	July 15, 2002	7:50:44-7:58:00 AM	62	436	20530	32.0	1	215	221	107.65
58	July 15, 2002	8:04:21-8:18:36 AM	347	856	20530	16.3	6	215	641	312.23
59	July 15, 2002	8:25:49-8:46:31 AM	581	1242	20530	11.2	8	215	1027	500.24
60	August 6, 2002	6:56:57-7:01:59 AM	9	302	20530	46.2	2	215	87	42.38
61	August 6, 2002	7:08:08-7:15:35 AM	35	447	20530	31.2	5	215	232	113.01
62	August 6, 2002	7:21:52-7:28:42 AM	30	410	20530	34.1	3	215	195	94.98
63	August 6, 2002	7:34:56-7:41:47 AM	3	411	20530	34.0	1	215	196	95.47
64	August 6, 2002	7:48:13-7:54:31 AM	38	378	20530	36.9	3	215	163	79.40
65	August 6, 2002	8:01:24-8:05:48 AM	0	264	20530	52.9	0	215	49	23.87
66	August 6, 2002	8:13:14-8:17:02 AM	0	228	20530	61.3	0	215	13	6.33
67	August 6, 2002	8:23:18-8:26:45 AM	0	207	20530	67.5	0	215	0	0.00
68	August 6, 2002	8:32:55-8:36:38 AM	0	223	20530	62.6	0	215	8	3.90
69	August 6, 2002	8:43:01-8:46:14 AM	0	193	20530	72.4	0	215	0	0.00
70	August 6, 2002	8:52:58-8:56:32 AM	0	214	20530	65.3	0	215	0	0.00
71	August 7, 2002	6:52:14-6:55:46 AM	0	212	20530	65.9	0	215	0	0.00
72	August 7, 2002	7:02:22-7:06:15 AM	0	233	20530	59.9	0	215	18	8.77
73	August 7, 2002	7:12:14-7:15:55 AM	0	221	20530	63.2	0	215	6	2.92
74	August 7, 2002	7:22:17-7:26:36 AM	0	259	20530	53.9	0	215	44	21.43
75	August 7, 2002	7:32:45-7:36:43 AM	0	238	20530	58.7	0	215	23	11.20
76	August 7, 2002	7:43:50-7:48:30 AM	16	280	20530	49.9	1	215	65	31.66
77	August 7, 2002	7:55:39-7:59:00 AM	0	201	20530	69.5	0	215	0	0.00
78	August 7, 2002	8:05:42-8:09:11 AM	0	209	20530	66.8	0	215	0	0.00
79	August 7, 2002	8:15:46-8:19:12 AM	0	206	20530	67.8	0	215	0	0.00
80	August 7, 2002	8:25:44-8:29:11 AM	0	207	20530	67.5	0	215	0	0.00
81	August 7, 2002	8:35:40-8:39:12 AM	0	212	20530	65.9	0	215	0	0.00
82	August 7, 2002	8:45:29-8:49:09 AM	0	220	20530	63.5	0	215	5	2.44
83	September 9, 2002	7:15:32-7:26:29 AM	83	657	20530	21.3	2	215	442	215.29
84	September 9, 2002	7:38:17 - 7:46:03 AM	11	466	20530	30.0	1	215	251	122.26
85	September 9, 2002	7:55:20 - 8:03:50 AM	26	510	20530	27.4	4	215	295	143.69
86	September 9, 2002	8:13:18 - 8:20:41 AM	11	443	20530	31.5	1	215	228	111.06
87	September 9, 2002	8:42:51 - 8:50:44 AM	0	473	20530	29.5	0	215	258	125.67
88	September 10, 2002	7:26:38 - 7:33:48 AM	0	430	20530	32.5	0	215	215	104.72
89	September 10, 2002	7:44:30 - 7:51:07 AM	12	397	20530	35.2	1	215	182	88.65
90	September 10, 2002	7:59:55 - 8:08:10 AM	94	495	20530	28.2	3	215	280	136.39
91	September 10, 2002	8:16:26 - 8:23:42 AM	14	436	20530	32.0	3	215	221	107.65
					AVERAGES					
		Average- Summer Only (7/2/02 to 8/7/02)	**24.14**	**313.01**	**20530.00**	**53.28**	**0.84**	**215.00**	**80.82**	**39.37**
		Average- Fall Only (9/9/02 to 9/10/02)	**27.89**	**478.56**	**20530.00**	**29.73**	**1.67**	**215.00**	**263.56**	**128.38**
		Average - Summer and Fall Combined (7/2/02 to 9/10/02)	**24.14**	**313.01**	**20530.00**	**51.30**	**0.84**	**215.00**	**98.89**	**48.17**

TRAVEL TIME DATA FOR THE 'AFTER' PERIOD FOR THE 2002 CONSTRUCTION SEASON FOR THE AM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	September 19, 2002	7:01:46-7:11:12 AM	41	566	20620	24.8	3	216.24	350	169.6
2	September 19, 2002	7:20:09-7:29:30 AM	26	561	20620	25.0	1	216.24	345	167.2
3	September 19, 2002	7:38:27-7:45:12 AM	34	405	20620	34.6	2	216.24	189	91.5
4	September 19, 2002	7:53:11-7:57:46 AM	0	375	20620	37.4	0	216.24	159	77.0
5	September 19, 2002	8:08:22-8:12:26 AM	0	244	20620	57.5	0	216.24	28	13.5
6	September 19, 2002	8:21:25-8:25:03 AM	0	218	20620	64.3	0	216.24	2	0.9
7	September 19, 2002	8:33:12-8:36:57 AM	0	225	20620	62.3	0	216.24	9	4.2
8	September 19, 2002	8:46:42-8:50:30 AM	0	228	20620	61.5	0	216.24	12	5.7
9	October 11, 2002	7:20:24-7:26:59 AM	58	395	20620	35.5	1	216.24	179	86.7
10	October 11, 2002	7:40:19-7:46:37 AM	28	378	20620	37.1	1	216.24	162	78.4
11	October 11, 2002	7:55:38-8:00:48 AM	0	310	20620	45.2	0	216.24	94	45.5
12	October 11, 2002	8:09:11-8:13:29 AM	0	258	20620	54.4	0	216.24	42	20.3
13	October 11, 2002	8:22:14-8:26:06 AM	0	232	20620	60.5	0	216.24	16	7.6
14	October 11, 2002	8:35:20-8:38:59 AM	0	219	20620	64.1	0	216.24	3	1.3
15	October 16, 2002	7:16:57-7:27:24 AM	66	627	20620	22.4	2	216.24	411	199.2
16	October 16, 2002	7:44:12-7:55:15 AM	124	663	20620	21.2	5	216.24	447	216.7
17	October 16, 2002	8:01:37-8:08:45 AM	35	428	20620	32.8	2	216.24	212	102.7
18	October 16, 2002	8:15:33-8:19:28 AM	0	235	20620	59.7	0	216.24	19	9.1
19	October 16, 2002	8:40:53-8:44:46 AM	0	233	20620	60.2	0	216.24	17	8.1
20	October 16, 2002	8:52:19-8:56:09 AM	0	230	20620	61.0	0	216.24	14	6.7
21	October 21, 2002	7:27:33-7:39:36 AM	96	723	20620	19.4	2	216.24	507	245.8
22	October 21, 2002	8:46:21-8:56:12 AM	168	591	20620	23.7	2	216.24	375	181.7
23	October 22, 2002	7:19:57-7:24:56 AM	0	299	20620	46.9	0	216.24	83	40.1
24	October 22, 2002	7:40:14-7:46:53 AM	18	399	20620	35.2	1	216.24	183	88.6
25	October 22, 2002	7:53:38-7:57:30 AM	0	232	20620	60.5	0	216.24	16	7.6
26	October 22, 2002	8:03:51-8:07:52 AM	0	241	20620	58.2	0	216.24	25	12.0
27	October 22, 2002	8:14:58-8:18:32 AM	0	214	20620	65.5	0	216.24	0	0.0
28	October 22, 2002	8:25:15-8:29:08 AM	0	233	20620	60.2	0	216.24	17	8.1
29	October 22, 2002	8:35:32-8:41:53 AM	0	381	20620	36.8	0	216.24	165	79.9
30	October 23, 2002	7:06:16-7:12:55 AM	57	399	20620	35.2	2	216.24	183	88.6
31	October 23, 2002	7:20:22-7:25:33 AM	0	311	20620	45.1	0	216.24	95	46.0
32	October 23, 2002	7:38:35-7:42:44 AM	0	249	20620	56.3	0	216.24	33	15.9
33	October 23, 2002	8:01:45-8:06:10 AM	0	265	20620	52.9	0	216.24	49	23.6
34	October 23, 2002	8:13:24-8:17:08 AM	0	224	20620	62.6	0	216.24	8	3.8
35	October 23, 2002	8:23:31-8:27:06 AM	0	215	20620	65.2	0	216.24	0	0.0
36	October 23, 2002	8:33:31-8:37:15 AM	0	224	20620	62.6	0	216.24	8	3.8
37	October 23, 2002	8:43:28-8:47:26 AM	0	238	20620	58.9	0	216.24	22	10.6
		Average	**20.30**	**336.97**	**20620.00**	**47.75**	**0.65**	**216.24**	**120.83**	**58.60**

TRAVEL TIME DATA FOR THE 'BEFORE' PERIOD FOR THE 2002 CONSTRUCTION SEASON FOR THE PM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	June 28, 2002	3:31:38-3:36:06 PM	0	268	20530	52.1	0	215	53	25.82
2	June 28, 2002	3:43:28-3:47:50 PM	0	262	20530	53.3	0	215	47	22.89
3	June 28, 2002	3:55:04-3:59:29 PM	0	265	20530	52.7	0	215	50	24.35
4	June 28, 2002	4:20:21-4:24:37 PM	0	256	20530	54.6	0	215	41	19.97
5	June 28, 2002	4:31:50-4:35:58 PM	0	248	20530	56.3	0	215	33	16.07
6	June 28, 2002	4:43:34-4:47:39 PM	0	245	20530	57.0	0	215	30	14.61
7	June 28, 2002	4:55:23-4:59:36 PM	0	253	20530	55.2	0	215	38	18.51
8	June 28, 2002	5:07:24-5:11:18 PM	0	234	20530	59.7	0	215	19	9.25
9	June 28, 2002	5:19:36-5:23:50 PM	0	254	20530	55.0	0	215	39	19.00
10	June 28, 2002	5:30:56-5:34:49 PM	0	233	20530	59.9	0	215	18	8.77
11	June 28, 2002	5:42:03 -5:46:05 PM	0	242	20530	57.7	0	215	27	13.15
12	June 28, 2002	5:53:04-5:57:15 PM	0	251	20530	55.6	0	215	36	17.54
13	July 2, 2002	4:23:19-4:27:00 PM	0	221	20530	63.2	0	215	6	2.92
14	July 2, 2002	4:33:03-4:36:47 PM	0	224	20530	62.3	0	215	9	4.38
15	July 2, 2002	4:42:26-4:46:11 PM	0	225	20530	62.1	0	215	10	4.87
16	July 2, 2002	4:52:57-4:56:19 PM	0	202	20530	69.1	0	215	0	0.00
17	July 2, 2002	5:02:55-5:06:47 PM	0	232	20530	60.2	0	215	17	8.28
18	July 2, 2002	5:15:37-5:19:52 PM	0	255	20530	54.8	0	215	40	19.48
19	July 2, 2002	5:26:25-5:30:01 PM	0	216	20530	64.7	0	215	1	0.49
20	July 2, 2002	5:40:51-5:44:47 PM	0	236	20530	59.2	0	215	21	10.23
21	July 2, 2002	5:51:21-5:55:06 PM	0	225	20530	62.1	0	215	10	4.87
22	July 8, 2002	4:02:15-4:06:03 PM	0	228	20530	61.3	0	215	13	6.33
23	July 8, 2002	4:12:28-4:16:10 PM	0	222	20530	62.9	0	215	7	3.41
24	July 8, 2002	4:23:04-4:26:56 PM	0	232	20530	60.2	0	215	17	8.28
25	July 8, 2002	4:33:19-4:36:59 PM	0	220	20530	63.5	0	215	5	2.44
26	July 8, 2002	4:43:15-4:47:03 PM	0	228	20530	61.3	0	215	13	6.33
27	July 8, 2002	4:53:42-4:57:37 PM	0	235	20530	59.4	0	215	20	9.74
28	July 10, 2002	4:19:34-4:23:52 PM	0	258	20530	54.1	0	215	43	20.94
29	July 10, 2002	4:50:29-4:54:29 PM	0	240	20530	58.2	0	215	25	12.18
30	July 10, 2002	5:01:36-5:05:29 PM	0	233	20530	59.9	0	215	18	8.77
31	July 10, 2002	5:13:11-5:17:20 PM	0	249	20530	56.1	0	215	34	16.56
32	July 10, 2002	5:24:07-5:27:56 PM	0	229	20530	61.0	0	215	14	6.82
33	July 10, 2002	5:34:38-5:38:46 PM	0	248	20530	56.3	0	215	33	16.07
34	July 10, 2002	5:47:00-5:51:04 PM	0	244	20530	57.2	0	215	29	14.13
35	July 10, 2002	6:14:18-6:18:20 PM	0	242	20530	57.7	0	215	27	13.15
36	July 10, 2002	5:51:21-5:55:06 PM	0	225	20530	62.1	0	215	10	4.87
37	July 11, 2002	3:48:01-3:51:46 PM	0	225	20530	62.1	0	215	10	4.87
38	July 11, 2002	3:57:44-4:01:37 PM	0	233	20530	59.9	0	215	18	8.77
39	July 11, 2002	4:24:25-4:28:26 PM	0	241	20530	58.0	0	215	26	12.66
40	July 11, 2002	4:35:02-4:38:50 PM	0	228	20530	61.3	0	215	13	6.33
41	July 11, 2002	4:45:26-4:49:23 PM	0	237	20530	58.9	0	215	22	10.72
42	July 11, 2002	4:58:54-5:02:39 PM	0	225	20530	62.1	0	215	10	4.87
43	July 11, 2002	5:08:43-5:12:29 PM	0	226	20530	61.8	0	215	11	5.36
44	July 11, 2002	5:18:58-5:22:54 PM	0	236	20530	59.2	0	215	21	10.23
45	July 11, 2002	5:29:55-5:33:55 PM	0	240	20530	58.2	0	215	25	12.18
46	July 11, 2002	5:40:40-5:44:33 PM	0	233	20530	59.9	0	215	18	8.77
47	July 12, 2002	4:15:42-4:19:44 PM	0	242	20530	57.7	0	215	27	13.15
48	July 12, 2002	4:27:28-4:31:43 PM	0	255	20530	54.8	0	215	40	19.48
49	July 12, 2002	4:39:01-4:43:01 PM	0	240	20530	58.2	0	215	25	12.18
50	July 12, 2002	5:06:31-5:10:32 PM	0	241	20530	58.0	0	215	26	12.66
51	July 12, 2002	5:17:12-5:21:16 PM	0	244	20530	57.2	0	215	29	14.13
52	July 12, 2002	5:27:26-5:31:15 PM	0	229	20530	61.0	0	215	14	6.82
53	July 12, 2002	5:37:27-5:42:32 PM	4	305	20530	45.8	1	215	90	43.84
54	July 12, 2002	5:51:43-5:57:07 PM	30	324	20530	43.1	1	215	109	53.09
55	July 12, 2002	6:05:47-6:09:59 PM	0	252	20530	55.4	0	215	37	18.02
56	July 15, 2002	4:02:29-4:12:15 PM	258	586	20530	23.8	1	215	371	180.71
57	July 15, 2002	4:21:01-4:32:29 PM	340	688	20530	20.3	3	215	473	230.39
58	July 15, 2002	4:39:18-4:49:01 PM	157	583	20530	24.0	3	215	368	179.25
59	July 15, 2002	4:55:38-5:05:07 PM	198	569	20530	24.5	1	215	354	172.43
60	July 15, 2002	5:11:21-5:21:48 PM	209	627	20530	22.3	2	215	412	200.68
61	July 15, 2002	5:42:32-5:53:11 PM	362	639	20530	21.9	2	215	424	206.53
62	July 15, 2002	5:59:43-6:11:11 PM	200	688	20530	20.3	2	215	473	230.39
63	August 2, 2002	4:34:25-4:38:54 PM	0	269	20530	51.9	0	215	54	26.30
64	August 2, 2002	4:52:48-4:56:50 PM	0	242	20530	57.7	0	215	27	13.15
65	August 2, 2002	5:03:31-5:07:24 PM	0	233	20530	59.9	0	215	18	8.77
66	August 2, 2002	5:26:28-5:30:28 PM	0	240	20530	58.2	0	215	25	12.18
67	August 2, 2002	5:39:50-5:43:44 PM	0	234	20530	59.7	0	215	19	9.25
68	August 2, 2002	5:50:37-5:54:16 PM	0	219	20530	63.8	0	215	4	1.95
69	August 2, 2002	6:00:59-6:05:00 PM	0	241	20530	58.0	0	215	26	12.66
		Average	**25.48**	**279.62**	**20530.00**	**54.73**	**0.23**	**215.00**	**64.81**	**31.57**

TRAVEL TIME DATA FOR THE 'AFTER' PERIOD FOR THE 2002 CONSTRUCTION SEASON FOR THE PM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	October 2,2002	4:42:09-4:46:29	0	260	20620	54.0	0	215	45	21.8
2	October 2,2002	4:55:35 -4:59:31	0	236	20620	59.4	0	215	21	10.2
3	October 2,2002	5:17:27 -5:21:28	0	241	20620	58.2	0	215	26	12.6
4	October 2,2002	5:31:15 :5:35:33	0	258	20620	54.4	0	215	43	20.9
5	October 2,2002	5:45:10 -5:49:03	0	233	20620	60.2	0	215	18	8.7
6	October 2,2002	5:57:15 -6:00:59	0	224	20620	62.6	0	215	9	4.4
7	October 10,2002	3:26:42 -3:30:40	0	238	20620	58.9	0	215	23	11.2
8	October 10,2002	3:40:45 3:45:00	0	255	20620	55.0	0	215	40	19.4
9	October 10,2002	3:55:40 -3:59:29	0	229	20620	61.3	0	215	14	6.8
10	October 10,2002	4:09:03-4:13:19	0	256	20620	54.8	0	215	41	19.9
11	October 10,2002	4:33:01 -4:38:37	0	336	20620	41.7	0	215	121	58.7
12	October 11,2002	4:27:46 -4:31:54	0	248	20620	56.6	0	215	33	16.0
13	October 11,2002	4:56:26-5:00:47	0	261	20620	53.7	0	215	46	22.3
14	October 11,2002	5:10:37-5:16:45	0	368	20620	38.1	0	215	153	74.2
15	October 11,2002	5:26:58-5:33:00	0	362	20620	38.7	0	215	147	71.3
16	October 11,2002	5:42:14 -5:48:26	0	372	20620	37.7	0	215	157	76.1
17	October 21,2002	3:08:52-3:12:41	0	229	20620	61.3	0	215	14	6.8
18	October 21,2002	3:26:21 -3:30:04	0	223	20620	62.9	0	215	8	3.9
19	October 21,2002	3:36:17-3:39:49	0	212	20620	66.2	0	215	0	0.0
20	October 21,2002	3:46:32-3:50:58	0	266	20620	52.7	0	215	51	24.7
21	October 21,2002	3:56:39 -4:00:17	0	218	20620	64.3	0	215	3	1.5
22	October 21,2002	4:15:41 -4:19:40	0	239	20620	58.7	0	215	24	11.6
23	October 21,2002	4:26:16-4:32:23	0	367	20620	38.2	0	215	152	73.7
24	October 23,2002	4:27:28- 4:31:17	0	229	20620	61.3	0	215	0	0.0
25	October 23,2002	4:43:40 -4:47:24	0	224	20620	62.6	0	215	0	0.0
26	October 23,2002	4:53:51-4:57:23	0	212	20620	66.2	0	215	0	0.0
27	October 23,2002	5:03:41 -5:07:25	0	224	20620	62.6	0	215	9	4.4
28	October 23,2002	5:14:14 -5:18:08	0	234	20620	59.9	0	215	19	9.2
29	October 23,2002	5:25:33-5:29:27	0	234	20620	59.9	0	215	19	9.2
		Average	**0.00**	**258.21**	**20620.00**	**55.94**	**0.00**	**215.00**	**42.62**	**20.67**

APPENDIX II – TRAVEL TIME DATA COLLECTED FOR THE ‘BEFORE’ AND ‘AFTER’ PERIODS DURING THE 2003 CONSTRUCTION SEASON FOR THE AM AND PM PEAK PERIODS

TRAVEL TIME DATA FOR THE 'BEFORE' PERIOD FOR THE 2003 CONSTRUCTION SEASON FOR THE AM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	May 30, 2003	7:05:03 AM - 7:14:47 AM	57	584	19391	22.6	4	215	369	190.33
2	May 30, 2003	7:24:22 AM - 7:36:03 AM	169	701	19391	18.8	10	215	486	250.66
3	May 30, 2003	7:45:01 AM - 7:59:13 AM	322	852	19391	15.5	20	215	637	328.54
4	May 30, 2003	8:06:45 AM - 8:19:07 AM	173	742	19391	17.8	3	215	527	271.81
5	May 30, 2003	8:27:22 AM - 8:34:05 AM	35	403	19391	32.7	2	215	188	96.99
6	May 30, 2003	8:42:26 AM - 8:48:05 AM	10	339	19391	38.9	1	215	124	63.98
7	May 30, 2003	8:55:54 AM - 8:59:16 AM	0	202	19391	65.3	0	215	0	0.00
8	June 2, 2003	6:59:14 AM - 7:15:06 AM	121	952	19391	13.9	3	215	737	380.11
9	June 2, 2003	7:26:12 AM - 7:42:24 AM	307	972	19391	13.6	5	215	757	390.42
10	June 2, 2003	8:01:25 AM - 8:13:40 AM	59	735	19391	17.9	4	215	520	268.20
11	June 2, 2003	8:22:46 AM - 8:30:48 AM	45	482	19391	27.4	3	215	267	137.73
12	June 2, 2003	8:38:38 AM - 8:46:28 AM	49	470	19391	28.1	3	215	255	131.54
13	June 2, 2003	8:54:02 AM - 9:00:11 AM	29	269	19391	49.0	3	215	54	27.88
14	June 3, 2003	6:56:54 AM - 7:09:10 AM	116	736	19391	17.9	9	215	521	268.71
15	June 3, 2003	7:36:23 AM - 7:44:52 AM	28	509	19391	25.9	3	215	294	151.65
16	June 3, 2003	7:54:29 AM - 8:00:03 AM	5	334	19391	39.5	1	215	119	61.40
17	June 3, 2003	8:09:06 AM - 8:12:45 AM	0	219	19391	60.2	0	215	4	2.10
18	June 3, 2003	8:21:41 AM - 8:25:14 AM	0	213	19391	61.9	0	215	0	0.00
19	June 3, 2003	8:33:06 AM - 8:36:39 AM	0	213	19391	61.9	0	215	0	0.00
20	June 3, 2003	8:44:47 AM - 8:48:22 AM	0	215	19391	61.4	0	215	0	0.03
21	June 3, 2003	8:56:47 AM - 9:00:19 AM	0	212	19391	62.2	0	215	0	0.00
22	June 4, 2003	6:57:26 AM - 7:07:45 AM	73	618	25760	28.4	8	311	307	119.18
23	June 4, 2003	7:14:32 AM - 7:26:02 AM	34	680	25760	25.8	5	311	369	143.25
24	June 4, 2003	7:33:16 AM - 7:44:44 AM	33	688	25760	25.5	2	311	377	146.35
25	June 4, 2003	7:51:40 AM - 8:04:07 AM	110	747	25760	23.5	7	311	436	169.25
26	June 4, 2003	8:10:55 AM - 8:23:51 AM	68	776	25760	22.6	4	311	465	180.51
27	June 4, 2003	8:31:08 AM - 8:40:36 AM	28	568	25760	30.9	3	311	257	99.77
28	June 4, 2003	8:47:33 AM - 8:55:47 AM	21	494	25760	35.5	2	311	183	71.04
29	June 5, 2003	7:01:35 AM - 7:09:10 AM	40	623	25760	28.1	1	311	312	121.12
30	June 5, 2003	7:15:33 AM - 7:24:37 AM	18	544	25760	32.2	2	311	233	90.45
31	June 5, 2003	7:31:14 AM - 7:39:12 AM	23	478	25760	36.7	2	311	167	64.83
32	June 5, 2003	7:46:12 AM - 7:52:38 AM	0	386	25760	45.4	0	311	75	29.11
33	June 5, 2003	7:59:45 AM - 8:04:44 AM	0	299	25760	58.6	0	311	0	0.00
34	June 5, 2003	8:11:26 AM - 8:16:50 AM	0	324	25760	54.1	0	311	13	5.05
35	June 5, 2003	8:23:38 AM - 8:28:31 AM	0	293	25760	59.8	0	311	0	0.00
36	June 5, 2003	8:35:12 AM - 8:40:03 AM	0	291	25760	60.2	0	311	0	0.00
37	June 5, 2003	8:46:38 AM - 8:51:10 AM	0	272	25760	64.4	0	311	0	0.00
38	June 9, 2003	6:57:44 AM - 7:08:51 AM	40	667	25760	26.3	4	311	356	138.20
39	June 9, 2003	7:15:17 AM - 7:27:59 AM	10	762	25760	23.0	1	311	451	175.08
40	June 9, 2003	7:34:28 AM - 7:45:47 AM	31	679	25760	25.8	2	311	368	142.86
41	June 9, 2003	7:53:09 AM - 8:03:18 AM	42	609	25760	28.8	4	311	298	115.68
42	June 9, 2003	8:10:04 AM - 8:17:35 AM	0	451	25760	38.9	0	311	140	54.35
43	June 9, 2003	8:24:38 AM - 8:29:23 AM	0	285	25760	61.5	0	311	0	0.00
44	June 9, 2003	8:35:47 AM - 8:40:54 AM	0	307	25760	57.1	0	311	0	0.00
45	June 9, 2003	8:47:35 AM - 8:52:49 AM	0	314	25760	55.8	0	311	3	1.16
46	June 9, 2003	8:59:10 AM - 9:03:47 AM	0	277	25760	63.3	0	311	0	0.00
47	June 10, 2003	6:59:26 AM - 7:09:01 AM	14	575	25760	30.5	3	311	264	102.48
48	June 10, 2003	7:15:49 AM - 7:23:53 AM	23	484	25760	36.2	2	311	173	67.16
49	June 10, 2003	7:30:19 AM - 7:38:32 AM	0	493	25760	35.5	0	311	182	70.65
50	June 10, 2003	7:45:19 AM - 7:54:35 AM	31	556	25760	31.5	2	311	245	95.11
51	June 10, 2003	8:01:06 AM - 8:08:58 AM	10	472	25760	37.1	1	311	161	62.50
52	June 10, 2003	8:15:31 AM - 8:22:06 AM	4	395	25760	44.4	1	311	84	32.61
53	June 10, 2003	8:28:26 AM - 8:33:06 AM	0	280	25760	62.6	0	311	0	0.00
54	June 10, 2003	8:39:39 AM - 8:44:35 AM	0	296	25760	59.2	0	311	0	0.00
55	June 11, 2003	6:59:33 AM - 7:07:44 AM	13	491	25760	35.7	2	311	180	69.88
56	June 11, 2003	7:14:27 AM - 7:22:50 AM	5	503	25760	34.8	1	311	192	74.53
57	June 11, 2003	7:29:50 AM - 7:42:43 AM	81	773	25760	22.7	9	311	462	179.35
58	June 11, 2003	7:49:19 AM - 8:00:16 AM	57	557	25760	31.5	5	311	246	95.50
59	June 11, 2003	8:06:52 AM - 8:14:20 AM	0	448	25760	39.1	0	311	137	53.18
60	June 11, 2003	8:29:52 AM - 8:35:20 AM	0	328	25760	53.4	0	311	17	6.60
61	June 11, 2003	8:42:07 AM - 8:47:24 AM	0	317	25760	55.3	0	311	6	2.33
		Average	**25.70**	**425.10**	**25760.00**	**40.04**	**1.75**		**197.92**	**95.10**

TRAVEL TIME DATA FOR THE 'AFTER' PERIOD FOR THE 2003 CONSTRUCTION SEASON FOR THE AM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	August 7, 2003	7:09:09 AM-7:13:54 AM	0	285	25760	61.5	0	215	70	27.2
2	August 7, 2003	7:21:09 AM-7:25:43 AM	0	274	25760	64.0	0	215	59	22.9
3	August 7, 2003	7:32:43 AM-7:38:05 AM	0	322	25760	54.4	0	215	107	41.6
4	August 7, 2003	7:45:03 AM-7:49:40 AM	0	277	25760	63.3	0	215	62	24.1
5	August 7, 2003	7:56:34 AM-8:01:17 AM	0	283	25760	61.9	0	215	68	26.4
6	August 7, 2003	8:08:07 AM-8:13:43 AM	0	336	25760	52.2	0	215	121	47.0
7	August 7, 2003	8:20:57 AM-8:25:42 AM	0	285	25760	61.5	0	215	70	27.2
8	August 7, 2003	8:32:40 AM-8:37:29 AM	0	289	25760	60.6	0	215	74	28.8
9	August 7, 2003	8:44:32 AM-8:49:15 AM	0	283	25760	61.9	0	215	68	26.4
10	August 7, 2003	8:56:02 AM-9:00:57 AM	0	295	25760	59.4	0	215	80	31.1
11	August 11, 2003	7:07:22 AM-7:12:22 AM	0	300	25760	58.4	0	215	85	33.0
12	August 11, 2003	7:19:14 AM-7:24:13 AM	0	299	25760	58.6	0	215	84	32.6
13	August 11, 2003	7:31:19 AM-7:36:13 AM	0	294	25760	59.6	0	215	79	30.7
14	August 11, 2003	7:43:10 AM-7:48:17 AM	0	307	25760	57.1	0	215	92	35.7
15	August 11, 2003	7:55:30 AM-8:00:34 AM	0	304	25760	57.6	0	215	89	34.6
16	August 11, 2003	8:08:11 AM-8:13:13 AM	0	302	25760	58.0	0	215	87	33.8
17	August 11, 2003	8:20:35 AM-8:25:13 AM	0	278	25760	63.0	0	215	63	24.5
18	August 11, 2003	8:32:38 AM-8:37:23 AM	0	285	25760	61.5	0	215	70	27.2
19	August 11, 2003	8:44:28 AM-8:49:28 AM	0	300	25760	58.4	0	215	85	33.0
20	August 11, 2003	8:56:40 AM-9:01:26 AM	0	286	25760	61.3	0	215	71	27.6
21	August 12, 2003	7:16:09 AM-7:31:17 AM	257	908	25760	19.3	3	215	693	269.0
22	August 12, 2003	7:38:26 AM-7:52:03 AM	164	817	25760	21.4	5	215	602	233.7
23	August 12, 2003	7:58:59 AM-8:11:45 AM	230	766	25760	22.9	4	215	551	213.9
24	August 12, 2003	8:27:08 AM-8:38:20 AM	60	672	25760	26.1	4	215	457	177.4
25	August 12, 2003	8:45:47 AM-8:57:49 AM	192	722	25760	24.3	5	311	411	159.5
26	August 13, 2003	7:11:40 AM-7:22:21 AM	24	521	25760	33.6	2	311	210	81.5
27	August 13, 2003	7:29:23 AM-7:43:07 AM	181	824	25760	21.3	8	311	513	199.1
28	August 13, 2003	7:50:28 AM-8:00:25 AM	56	597	25760	29.4	2	311	286	111.0
29	August 13, 2003	8:07:25 AM-8:15:51 AM	0	506	25760	34.6	0	311	195	75.7
30	August 13, 2003	8:23:04 AM-8:28:27 AM	0	323	25760	54.3	0	311	12	4.7
31	August 13, 2003	8:35:24 AM-8:40:10 AM	0	286	25760	61.3	0	311	0	0.0
32	August 13, 2003	8:46:45 AM-8:51:41 AM	0	296	25760	59.2	0	311	0	0.0
33	August 13, 2003	8:58:32 AM-9:03:07 AM	0	275	25760	63.7	0	311	0	0.0
34	August 14, 2003	7:17:06 AM-7:26:46 AM	92	580	25760	30.2	6	311	269	104.4
35	August 14, 2003	7:33:53 AM-7:42:35 AM	64	522	25760	33.6	2	311	211	81.9
36	August 14, 2003	7:52:08 AM-8:00:02 AM	44	474	25760	37.0	2	311	163	63.3
37	August 14, 2003	8:10:26 AM-8:17:28 AM	7	422	25760	41.5	1	311	111	43.1
38	August 14, 2003	8:27:52 AM-8:34:12 AM	0	380	25760	46.1	0	311	69	26.8
39	August 14, 2003	8:43:35 AM-8:49:27 AM	0	352	25760	49.8	0	311	41	15.9
40	August 19, 2003	7:13:17 AM-7:22:54 AM	55	577	25760	30.4	2	311	266	103.3
41	August 19, 2003	7:29:38 AM-7:38:26 AM	25	528	25760	33.2	2	311	217	84.2
42	August 19, 2003	7:45:24 AM-7:55:07 AM	108	583	25760	30.1	2	311	272	105.6
43	August 19, 2003	8:01:58 AM-8:10:13 AM	38	495	25760	35.4	2	311	184	71.4
44	August 19, 2003	8:16:41 AM-8:23:36 AM	44	415	25760	42.2	2	311	104	40.4
45	August 19, 2003	8:30:28 AM-8:35:57 AM	0	329	25760	53.3	0	311	18	7.0
46	August 19, 2003	8:42:47 AM-8:47:30 AM	0	283	25760	61.9	0	311	0	0.0
47	August 20, 2003	7:15:52 AM-7:25:37 AM	0	585	25760	30.0	0	311	274	106.4
48	August 20, 2003	7:33:58 AM-7:46:21 AM	112	743	25760	23.6	4	311	432	167.7
49	August 20, 2003	7:54:42 AM-8:08:14 AM	168	812	25760	21.6	5	311	501	194.5
50	August 20, 2003	8:15:49 AM-8:26:01 AM	109	612	25760	28.6	5	311	301	116.8
51	August 20, 2003	8:32:49 AM-8:40:32 AM	38	463	25760	37.8	1	311	152	59.0
52	August 20, 2003	8:48:30 AM-8:56:48 AM	0	498	25760	35.2	0	311	187	72.6
		Average	**26.18**	**291.77**	**25760.00**	**45.52**	**0.96**	**311.00**	**178.61**	**69.33**

TRAVEL TIME DATA FOR THE 'BEFORE' PERIOD FOR THE 2003 CONSTRUCTION SEASON FOR THE PM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	May 29, 2003	4:21:18 PM - 4:25:11 PM	0	233	19391	56.6	0	215	18.1	9.32
2	May 29, 2003	4:35:16 PM - 4:39:43 PM	0	267	19391	49.4	0	215	52.1	26.85
3	May 29, 2003	4:48:22 PM - 4:54:00 PM	20	338	19391	39.0	2	215	123.1	63.46
4	May 29, 2003	5:03:06 PM - 5:07:28 PM	0	262	19391	50.3	0	215	47.1	24.27
5	June 3, 2003	4:08:21 PM - 4:13:12 PM	0	291	25760	60.2	0	311	0.0	0.00
6	June 3, 2003	4:20:26 PM - 4:25:18 PM	0	292	25760	60.0	0	311	0.0	0.00
7	June 3, 2003	4:31:52 PM - 4:36:31 PM	0	279	25760	62.8	0	311	0.0	0.00
8	June 3, 2003	4:43:36 PM - 4:48:54 PM	0	318	25760	55.1	0	311	7.0	2.72
9	June 3, 2003	4:55:33 PM - 5:00:22 PM	0	289	25760	60.6	0	311	0.0	0.00
10	June 3, 2003	5:07:00 PM - 5:12:10 PM	0	310	25760	56.5	0	311	0.0	0.00
11	June 3, 2003	5:19:46 PM - 5:24:36 PM	0	290	25760	60.4	0	311	0.0	0.00
12	June 3, 2003	5:31:34 PM - 5:36:17 PM	0	283	25760	61.9	0	311	0.0	0.00
13	June 3, 2003	5:43:08 PM - 5:47:52 PM	0	284	25760	61.7	0	311	0.0	0.00
14	June 3, 2003	5:54:21 PM- 5:59:01 PM	0	280	25760	62.6	0	311	0.0	0.00
15	June 6, 2003	4:10:06 PM - 4:15:14 PM	0	308	25760	56.9	0	311	0.0	0.00
16	June 6, 2003	4:21:31 PM - 4:26:38 PM	0	307	25760	57.1	0	311	0.0	0.00
17	June 6, 2003	4:33:43 PM - 4:38:24 PM	0	281	25760	62.4	0	311	0.0	0.00
18	June 6, 2003	4:45:10 PM - 4:50:09 PM	0	299	25760	58.6	0	311	0.0	0.00
19	June 6, 2003	4:56:47 PM - 5:01:30 PM	0	283	25760	61.9	0	311	0.0	0.00
20	June 6, 2003	5:08:48 PM - 5:13:22 PM	0	274	25760	64.0	0	311	0.0	0.00
		Average	**1.00**	**288.40**	**24486.20**	**57.91**	**0.10**	**291.79**	**12.36**	**6.33**

TRAVEL TIME DATA FOR THE 'AFTER' PERIOD FOR THE 2003 CONSTRUCTION SEASON FOR THE PM PEAK PERIOD

Run No.	Date	Time Interval	Total Stop Time (Sec/Vehicle)	Total Travel Time (Sec/Vehicle)	Overall Distance Traveled (Feet)	Average Travel Speed (mph)	Number of Stops per Vehicle	Expected Travel Time (Sec/Vehicle)	Actual Delay (Sec/Vehicle)	Delay (Sec/Veh/10,000 Feet)
1	September 19, 2003	4:25:09 PM-4:29:59 PM	0	290	25760	60.4	0	311	0	0.0
2	September 19, 2003	4:38:06 PM-4:42:50 PM	0	284	25760	61.7	0	311	0	0.0
3	September 19, 2003	4:51:09 PM-4:56:03 PM	0	294	25760	59.6	0	311	0	0.0
4	September 19, 2003	5:03:49 PM-5:08:45 PM	0	306	25760	57.3	0	311	0	0.0
5	September 19, 2003	5:16:47 PM-5:21:33 PM	0	286	25760	61.3	0	311	0	0.0
6	September 29, 2003	4:26:12 PM-4:32:04 PM	0	352	25760	49.8	0	311	41	15.9
7	September 29, 2003	4:42:07 PM-4:47:26 PM	0	319	25760	54.9	0	311	8	3.1
8	September 29, 2003	4:56:12 PM-5:01:03 PM	0	291	25760	60.2	0	311	0	0.0
9	September 29, 2003	5:11:37 PM-5:16:48 PM	0	311	25760	56.3	0	311	0	0.0
10	September 29, 2003	5:25:27 PM-5:30:38 PM	0	311	25760	56.3	0	311	0	0.0
11	September 29, 2003	5:39:39 PM-5:44:26 PM	0	287	25760	61.1	0	311	0	0.0
12	September 29, 2003	5:53:22 PM-5:58:20 PM	0	298	25760	58.8	0	311	0	0.0
		Average	**0.00**	**302.42**	**25760.00**	**58.15**	**0.00**	**311.00**	**4.08**	**1.59**

APPENDIX III – TRAFFIC CRASH DATA ON WB I-94 FOR THE YEAR 2002

TRAFFIC CRASH DATA ON WESTBOUND I-94 FOR THE YEAR 2002

Westbound I-94 FROM Henry B Joy Blvd TO Hall/ W I 94 RAMP
MILE 12.919 MILE 14.152

NO.	SERIAL_NUMBER	DATE	DAY	TIME	SEVERITY	CRASH_TYPE	WEATHER	LIGHTING	ROAD	MILE	UNIT	VEHICLE_TYPE	HAZARDOUS ACTION
1	2776285	18-Jan-02	Fri	3pm-4pm	PDO	Swipe-same	Cloudy	Daylight	Dry	13.978	1	Small truck	Improper lane use
	2776285	18-Jan-02	Fri	3pm-4pm	PDO	Swipe-same	Cloudy	Daylight	Dry	13.978	2	Car/wagon	None
2	2775176	2-Apr-02	Tue	10am-11am	PDO	Single veh.	Rain	Daylight	Wet	14.099	1	Car/wagon	Drove too fast
3	3036652	20-Jun-02	Thu	5pm-6pm	PDO	Single veh.	Clear	Daylight	Dry	13.745	1	Car/wagon	None
4	2775269	26-Jul-02	Fri	6pm-7pm	PDO	Swipe-same	Clear	Daylight	Dry	13.838	1	Pickup	None
	2775269	26-Jul-02	Fri	6pm-7pm	PDO	Swipe-same	Clear	Daylight	Dry	13.838	2	Car/wagon	Other
5	3739003	9-Aug-02	Fri	6pm-7pm	Fatal	Other	Clear	Daylight	Dry	12.937	1	Car/wagon	Careless driving
	3739003	9-Aug-02	Fri	6pm-7pm	Fatal	Other	Clear	Daylight	Dry	12.937	2	Uncoded/errors	None
	3739003	9-Aug-02	Fri	6pm-7pm	Fatal	Other	Clear	Daylight	Dry	12.937	3	Uncoded/errors	None
	3739003	9-Aug-02	Fri	6pm-7pm	Fatal	Other	Clear	Daylight	Dry	12.937	4	Pickup	None
6	3742926	11-Aug-02	Sun	4am-5am	A-level	Single veh.	Clear	Dusk	Dry	13.745	1	Pickup	Other
⑦	3742681	16-Sep-02	Mon	7am-8am	A-level	Rear-end	Clear	Daylight	Dry	14.117	1	Car/wagon	None
	3742681	16-Sep-02	Mon	7am-8am	A-level	Rear-end	Clear	Daylight	Dry	14.117	2	Car/wagon	None
	3742681	16-Sep-02	Mon	7am-8am	A-level	Rear-end	Clear	Daylight	Dry	14.117	3	Car/wagon	Unable to stop
⑧	2774689	25-Sep-02	Wed	7am-8am	B-level	Rear-end	Clear	Daylight	Dry	13.745	1	Car/wagon	Unable to stop
	2774689	25-Sep-02	Wed	7am-8am	B-level	Rear-end	Clear	Daylight	Dry	13.745	2	Car/wagon	None
	2774689	25-Sep-02	Wed	7am-8am	B-level	Rear-end	Clear	Daylight	Dry	13.745	3	Car/wagon	None
⑨	2778718	28-Oct-02	Mon	7am-8am	PDO	Rear-end	Cloudy	Daylight	Dry	13.745	1	Car/wagon	Unable to stop
	2778718	28-Oct-02	Mon	7am-8am	PDO	Rear-end	Cloudy	Daylight	Dry	13.745	2	Car/wagon	None
10	4521221	17-Nov-02	Sun	8am-9am	PDO	Single veh.	Uncoded	Daylight	Icy	12.919	1	Car/wagon	Drove too fast
11	4650079	7-Dec-02	Sat	5pm-6pm	PDO	Swipe-same	Clear	Dark	Dry	14.099	1	Car/wagon	Failed to yield
	4650079	7-Dec-02	Sat	5pm-6pm	PDO	Swipe-same	Clear	Dark	Dry	14.099	2	Van/RV	None
12	4577557	8-Dec-02	Sun	3pm-4pm	PDO	Single veh.	Clear	Daylight	Dry	14.117	1	Car/wagon	None
13	4520819	12-Dec-02	Thu	4pm-5pm	PDO	Single veh.	Clear	Daylight	Dry	12.928	1	Van/RV	None

Westbound I-94 FROM W I 94/ River RAMP TO Henry B Joy Blvd
MILE 11.871 MILE 12.919

NO.	SERIAL_NUMBER	DATE	DAY	TIME	SEVERITY	CRASH_TYPE	WEATHER	LIGHTING	ROAD	MILE	UNIT	VEHICLE_TYPE	HAZARDOUS ACTION
⑭	3740276	23-Sep-02	Mon	8am-9am	PDO	Rear-end	Clear	Daylight	Dry	12.117	1	Car/wagon	Unable to stop
	3740276	23-Sep-02	Mon	8am-9am	PDO	Rear-end	Clear	Daylight	Dry	12.117	2	Car/wagon	None
⑮	3741973	7-Oct-02	Mon	1pm-2pm	C-level	Rear-end	Clear	Daylight	Dry	12.117	1	Car/wagon	Unable to stop
	3741973	7-Oct-02	Mon	1pm-2pm	C-level	Rear-end	Clear	Daylight	Dry	12.117	2	Van/RV	None
⑯	3741548	11-Oct-02	Fri	7am-8am	PDO	Rear-end	Clear	Daylight	Dry	12.898	1	Car/wagon	None
	3741548	11-Oct-02	Fri	7am-8am	PDO	Rear-end	Clear	Daylight	Dry	12.898	2	Car/wagon	Other
17	4492454	20-Nov-02	Wed	Other	PDO	Single veh.	Clear	Str. lights	Dry	12.117	1	Pickup	None

Westbound I-94 FROM Crocker Blvd TO River Rd
MILE 10.742 MILE 11.555

NO.	SERIAL_NUMBER	DATE	DAY	TIME	SEVERITY	CRASH_TYPE	WEATHER	LIGHTING	ROAD	MILE	UNIT	VEHICLE_TYPE	HAZARDOUS ACTION
18	2776365	9-May-02	Thu	7am-8am	PDO	Rear-end	Rain	Daylight	Wet	10.989	1	Car/wagon	Unable to stop
	2776365	9-May-02	Thu	7am-8am	PDO	Rear-end	Rain	Daylight	Wet	10.989	2	Van/RV	None
19	3741508	10-Jul-02	Wed	6am-7am	PDO	Rear-end	Clear	Daylight	Dry	10.742	1	Van/RV	None
	3741508	10-Jul-02	Wed	6am-7am	PDO	Rear-end	Clear	Daylight	Dry	10.742	2	Van/RV	None
	3741508	10-Jul-02	Wed	6am-7am	PDO	Rear-end	Clear	Daylight	Dry	10.742	3	Uncoded/errors	Unable to stop
20	3038527	3-Aug-02	Sat	2am-3am	PDO	Swipe-same	Clear	Dark	Dry	11.545	1	Car/wagon	Other
	3038527	3-Aug-02	Sat	2am-3am	PDO	Swipe-same	Clear	Dark	Dry	11.545	2	Truck/bus	Uncoded
21	4520390	26-Nov-02	Tue	5pm-6pm	PDO	Single veh.	Snow	Str. lights	Wet	10.781	1	Car/wagon	None
	4520390	26-Nov-02	Tue	5pm-6pm	PDO	Single veh.	Snow	Str. lights	Wet	10.781	2	Car/wagon	Other

Westbound I-94 FROM Metropolitan Parkway TO Crocker Blvd
MILE 10.534 MILE 10.742

NO.	SERIAL_NUMBER	DATE	DAY	TIME	SEVERITY	CRASH_TYPE	WEATHER	LIGHTING	ROAD	MILE	UNIT	VEHICLE_TYPE	HAZARDOUS ACTION
22	3152537	4-Sep-02	Wed	9am-10am	PDO	Rear-end	Clear	Daylight	Dry	10.731	1	Uncoded/errors	Uncoded
	3152537	4-Sep-02	Wed	9am-10am	PDO	Rear-end	Clear	Daylight	Dry	10.731	2	Car/wagon	None
	3152537	4-Sep-02	Wed	9am-10am	PDO	Rear-end	Clear	Daylight	Dry	10.731	3	Pickup	None
	3152537	4-Sep-02	Wed	9am-10am	PDO	Rear-end	Clear	Daylight	Dry	10.731	4	Pickup	None
23	3152538	5-Sep-02	Thu	6am-7am	PDO	Rear-end	Cloudy	Daylight	Dry	10.698	1	Car/wagon	Unable to stop
	3152538	5-Sep-02	Thu	6am-7am	PDO	Rear-end	Cloudy	Daylight	Dry	10.698	2	Pickup	None

LEGEND

▨ #	Before Period Crashes
(#)	After Period Crashes