Evaluation of 2004 Dynamic Late Merge System

for the Minnesota Department of Transportation

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1.0 Introduction

The Minnesota Department of Transportation (Mn/DOT) is in the second year of assessing a new traffic control strategy for lane closures in work zones. The first year of this evaluation looked at a single deployment location of a dynamic traffic control strategy called the Dynamic Late Merge System (DLMS). This system, which is in addition to the standard orange and black warning signs placed in advance of the lane closure, consists of three Changeable Message Signs (CMS) and a Remote Traffic Microwave Sensor (RTMS) detector. When congestion begins to form, the signs are activated to provide lane use instructions to drivers.

An evaluation report was created on this single location deployment of the DLMS on US 10 in Anoka, MN in the summer of 2003. The objective of this overall project was to develop, test, and evaluate a traffic control system that dynamically incorporates the best aspects of Early and Late Merge systems. A detailed section highlighting this original background information is given in the "Previous Approaches for Single Lane Closure" section of the 2003 DLMS Evaluation Report.

This report continues this past year's (2004) effort by evaluating the deployment of the DLMS at three locations around the Minneapolis – St. Paul metropolitan area. One of these locations was evaluated in both directions (I-494 in Plymouth, MN) and the remaining two (US 52 in St. Paul, MN and I-35 near Lakeville, MN) were investigated in a single direction. Only one of these deployments consisted of a time period where the system deployment had a brief baseline condition. The purpose of this second season of evaluation was to cross check the previous year's findings, assess the overall effectiveness of the system, and identify potential system improvements.

This report focuses its effort on analyzing the four deployments of the DLMS conducted during the summer and fall of 2004. The first section, titled *Background*, updates the previous report's literature search on other work zone traffic control strategies and gives a more in depth introduction to this season's four deployments. The next section *Mn/DOT's DLMS Deployment Locations* illustrates the three sites where the system was installed. Following is a section on *DLMS Individual Site Results* that contains subsections with the evaluation results from each location. These results are summarized in the section titled *Summary of Evaluation Findings* followed by some suggestions for the next round of deployments in *Considerations for Future DLMS Deployments*.

2.0 Background

The DLMS is designed to utilize the best aspects of the Early and Late Merge strategies. Through the use of technology, this DLMS traffic control strategy can dynamically change its lane use instructions based on the current traffic demands. This alters the traffic control theory from an early merge strategy under light traffic demand to a late merge strategy during periods of congestion. The motivation for this approach stems from a desire to make the roadways safer and eliminate conditions where motorists typically exhibit conflicting driver behaviors. During the summer of 2003 an evaluation of the DLMS was conducted on US 10 in Anoka, MN. More in depth discussion about the motivation for the DLMS is presented in the US 10 DLMS evaluation report.

Prior to the first deployment of the DLMS on US 10, five distinct potential benefits were outlined as possible advantages this traffic control strategy could produce. These five potential DLMS benefits are taken from the first evaluation report and are listed as follows:

Shorten Queue Lengths before Work Zone: By encouraging the use of both lanes in congested conditions, the length of a forming queue should be greatly reduced under the Dynamic Late Merge System. If *all* drivers follow the posted instructions, the queue length could be reduced by half, ensuring that no vehicles would encounter the back of a queue before first seeing the construction advanced warning sign.

Increase Traffic Capacity through Work Zone: Based on experiences from previous studies, it is hoped that having a single merging point at a defined location will increase the number of cars through the work zone.

Reduce Aggressive Driving: If no other benefits are achieved, reducing the stress level for drivers at the work zone could be beneficial enough to warrant the use of the Dynamic Late Merge System. Recent years have seen an escalation in the number of road rage incidents and aggressive driving behaviors around work zones. Impatient and antagonistic drivers have blocked other vehicles from passing or have driven around queues on the roadway shoulders or medians. Eliminating the causes of these outbursts could stabilize the behaviors of already frustrated drivers.

Decrease Number of Work Zone Related Incidents: The length of a typical system deployment will not provide enough data to definitively conclude whether or not the Dynamic Late Merge System decreased the incident rate. However, this system has the potential to eliminate many of the dangerous situations that result in collisions and incidents while reducing driver frustration. The elimination of multiple merge points, shorter queue lengths ensuring the viewing of the advanced warning signs, and eliminating conditions where higher speed traffic is adjacent to a lane of stopped/slow traffic are all benefits that should reduce the number of work zone related collisions.

Reduce Travel Times: Mn/DOT hopes that the travel times through the work zone will decrease through the use of the Dynamic Late Merge System. Previous work zone traffic control strategies have had mixed or inconclusive results pertaining to travel times.

Mn/DOT conducted a second round of deployments of the DLMS during the summer and fall of 2004. This report focuses on these deployments. The evaluation findings for each of the deployments (I-494 Northbound in Plymouth, MN, I-494 Southbound in Plymouth, MN, US 52 in St. Paul, MN, and I-35 around Lakeville, MN) are partitioned by these five key measures of effectiveness listed above. The evaluation report from the first deployment of the DLMS on US 10 in Anoka, MN, contains further information on the system background, other states' previous traffic control strategies, and evaluation results from the first year deployment.

2.1 Other Dynamic Control Strategy Updates

As noted in the literature search included in the first evaluation report of the Dynamic Late Merge System located on US 10 in the summer of 2003, other states have deployed a variety of traffic control strategies at work zones for single lane construction closures. In the time that has lapsed since the previous report was published, the state of Maryland deployed and evaluated a late merge strategy at a bridge construction site on I-83 near Cold Bottom Road. The theory behind this system was to encourage drivers, through the use of dynamic signs and automated flashers, to use both lanes when there was congestion. An evaluation report on Michigan's Dynamic Early Lane Merge Traffic Control System was also published in the past year. This system used dynamic features to create a do-not-pass zone, instructing drivers to move out of the discontinuous lane without passing other vehicles. Kansas also deployed a dynamic traffic control strategy, which displayed land use instructions under <u>all</u> traffic conditions. These three reports will be highlighted briefly in the following sections.

2.1.1 Maryland's Dynamic Late Merge System

Maryland's Dynamic Late Merge (DLM) System was comprised of a set of 4 Portable CMSs and 3 RTMS detectors that are added to the standard static traffic control devices utilized at construction lane closures. The CMS furthest upstream (~1.5 miles) from the taper alternated between the messages "USE BOTH LANES" and "TRAFFIC BACKUP." The next two CMS located at approximately ½ mile and ¼ mile from the taper displayed the message "USE BOTH LANES." Near the taper itself, the final CMS alternated between messages "TAKE YOUR TURN" and "MERGE HERE." The location of the CMS in the DLM System deployment is shown in Figure 2.1.

At intervals of 1500ft, 3500ft, and 7500ft from the taper RTMS detectors along with flashers were placed on static signs stating "USE BOTH LANES WHEN FLASHING" (see Figure 2.2). The master RTMS detector was furthest from the taper and could be programmed

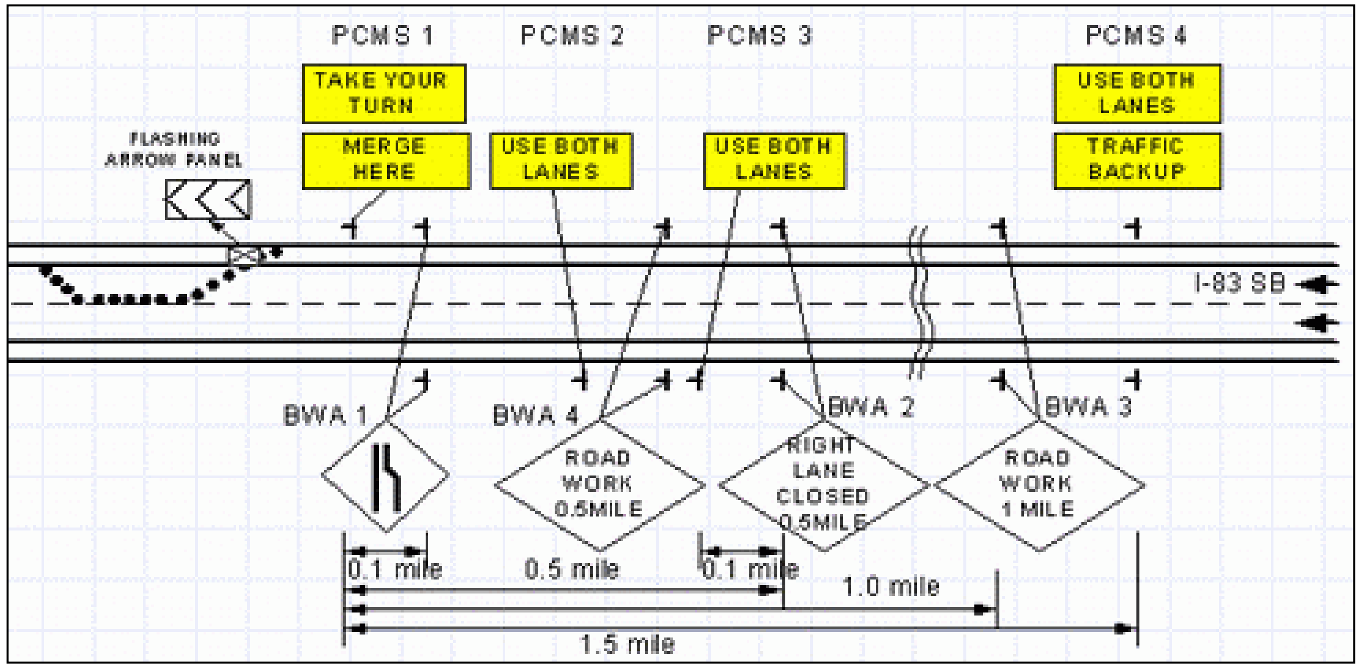


Figure 2.1: Maryland's Dynamic Late Merge (DLM) System
Source: http://attap.umd.edu/Projects.asp?ID=5&curPage=1

in a variety of methods of activating the CMS and flashers. For this deployment, the system was programmed to be either completely on or completely off.

The DLM System activated its signs and flashers when the occupancy of the roadway at the sensor exceeded 15% across all three RTMS detectors. The system remained active until the occupancy dropped below 5%.

The University of Maryland, College Park conducted the evaluation of this system by utilizing one day of baseline (or control) data where the road closure utilized only the standard static traffic control signs. This was followed by 4 days with the DLM System activated. Their evaluation looked at 4 main measures of effectiveness; work zone throughput, lane volume distribution, maximum queue length, and simulation data analysis.

According to the evaluation findings, the DLM System increased work zone throughputs when compared to the baseline conditions. Traffic volumes collected during 10-minute intervals during the 4 days of DLM System deployment were higher than under the baseline conditions. Another method of investigating traffic throughput utilized a calibrated computer simulation. The 10-minute traffic volumes collected upstream were entered as traffic demand and driver behavior characteristics were adjusted until the computer simulation output produced results equal to what was observed in the field. Then the simulation was altered to function under the DLM System behavior. The simulation had drivers use both lanes and then take turns merging at the designated merge point. This simulation showed an increase of 15% of vehicle throughput – similar to what was noticed in the field.

Lane volume distribution was also compared under the baseline and DLM System conditions. The results showed that more vehicles were in the discontinuous lane under the DLM System than with the baseline conditions. As the vehicles moved towards the taper, there were fewer vehicles in the discontinuous lane. Many drivers were observed merging before the designated merge location during the evaluation period. These early mergers resulted in multiple merging points and appeared to result in some confusion on the proper place to merge.

The queue lengths were observed to be reduced between 8% to 33% during the 4 days of evaluation with the activation of the DLM System. Unfortunately, numerous traffic conflicts were observed between the two lanes of traffic. Many vehicles were observed making forced merges at the taper point because they were not being allowed to merge. Some vehicles were seen straddling the centerline in an attempt to stop vehicles from passing and other vehicles were observed pacing the car in the continuous lane to block vehicles from filling the discontinuous lane. These conflicts resulted in conditions of stop and go traffic.

The authors of the University of Maryland evaluation stated that the advantages of the DLM System are increased throughput, shorter queue lengths, and more uniform distribution of lane use before the taper. The disadvantages were listed as increased stop and go conditions and multiple merging locations. The authors recommended that future deployments could add variable speed limit signs, change the distance between DLM System equipment based on perception/reaction time based on site-speed characteristics, and remove or separate static merging signs from the DLM System to avoid confusion on the correct merging location.

2.1.2 Michigan's Dynamic Early Lane Merge Traffic Control System

The Michigan Department of Transportation has deployed an early merge strategy over the past few years in an attempt to increase vehicle throughput and overall safety near construction lane closures. The Michigan system is known as the Dynamic Early Lane Merge Traffic Control System (DELMTCS). This traffic control strategy employed the early merge strategy by setting up a dynamic no passing zone. Michigan has used this strategy at both 2 to 1 and 3 to 2 lane closures on highways. The schematic for the 3 to 2 system is shown in Figure 2.3.

A sequence of "DO NOT PASS – WHEN FLASHING" sign trailers placed at 1500 ft intervals have instruments that read the traffic

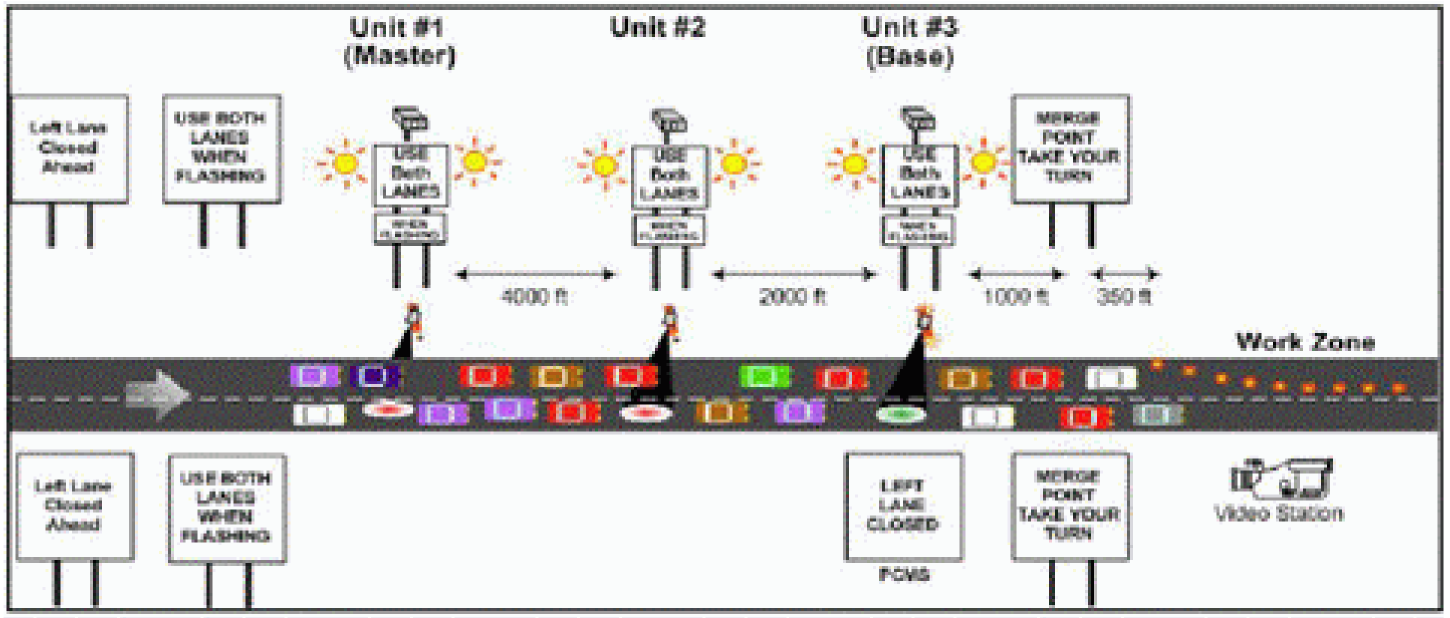


Figure 2.2: Maryland's Dynamic Late Merge (DLM) System
Source: http://attap.umd.edu/Projects.asp?ID=5&curPage=1

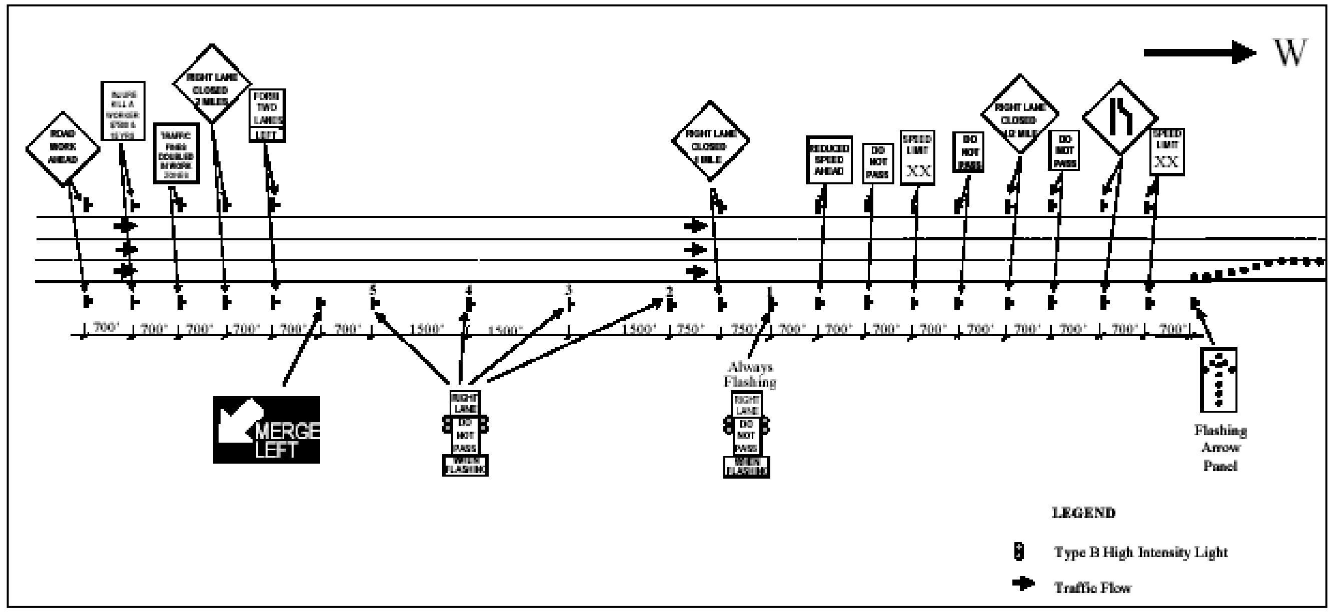


Figure 2.3: Michigan's Dynamic Early Lane Merge Traffic Control System
Source: Datta, T. Development and Evaluation of an Advanced Dynamic Lane Merge Traffic Control System for 3 to 2 l Transition Areas in Work Zones http://www. michigan.gov/documents/mdot_ RC-1451_97846_7.pdf

conditions and then activate the flashers at the onset of the congestion queue. An additional CMS is placed upstream from the "DO NOT PASS" signs which, when activated, displays a large arrow and the instructions to Merge Left or Merge Right. This system requires drivers to get out of the closed lane early, before passing any vehicle that is already a part of the forming queue.

The evaluation of Michigan's early merge study was conducted by Wayne State University. According to published evaluation results, the DELMTCS achieved its goals of reducing aggressive driving behavior, improved overall safety, and reduced lane closure related delay when deployed on 2 to 1 lane construction closures. The results of the DELMTCS system were similar when deployed over 2002 and 2003 on 3 to 2 lane construction closures.

Using a "before and after" study comparison, the operational characteristics along the study test section of the freeway showed a reduction in travel time delays, number of stops, and aggressive driving maneuvers for similar flow rated during the morning and afternoon peak periods. This study extended these findings into a benefit cost analysis showing the overall reduction in fuel usage, vehicle emissions, and overall travel time. Report also highlighted recommendations for the deployment of the DELMTCS by giving specific suggestions for the number of signs and placement of specific pieces of equipment.

One part of the study recorded the presence or absence of police enforcement on each of the travel time runs. The requirements of this system suggest that enforcement is necessary to ensure that drivers follow the early merge requirements and do not "cheat" by using the discontinuous lane. Enforcement requirements would obviously add financial costs to the overall DELMTCS deployment.

It should be noted that at the time of the publication of the Michigan DELMTC paper (January 2004), the authors did not find any documentation on any DLM Systems such as the Mn/DOT Dynamic Late Merge System (DLMS), so no comparisons of the results were made in this report.

2.1.3 Kansas' Construction Area Late Merge System Deployment

The University of Kansas, in cooperation with the Kansas Department of Transportation and Scientex Corporation, deployed and evaluated a dynamic late merge traffic control strategy during a construction project in the spring of 2003. Like others, this system also utilized wireless communication between RTMS detectors and portable CMS to display lane use instructions to drivers based on traffic conditions. The evaluation report titled "Construction Area Late Merge (CALM) System Evaluation" was published in February 2004.

The CALM system utilized a set of 3 portable CMS and two RTMS detectors to display messages to drivers under all traffic conditions. Figure 2.4 shows relative sign and RTMS placement along with distances (in miles) from the lane closure taper.

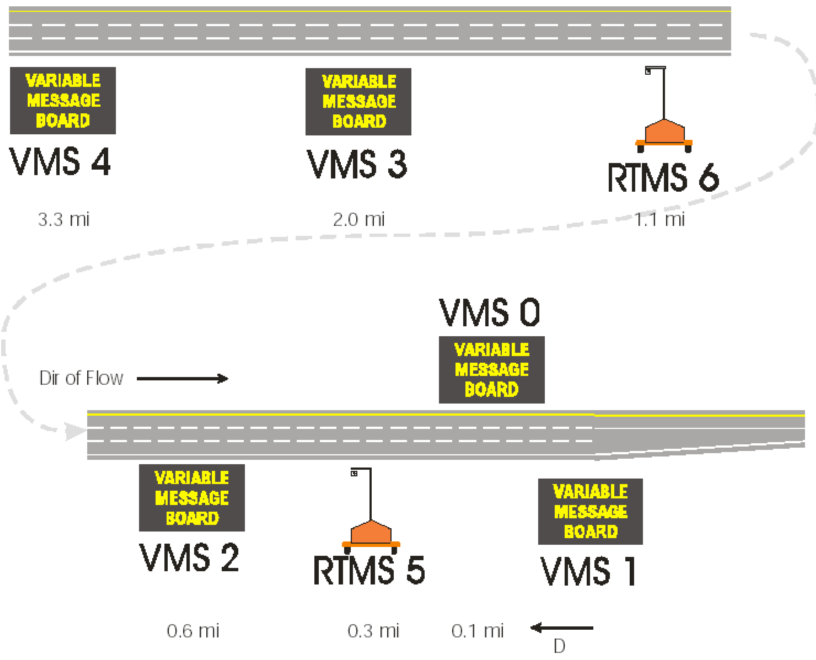


Figure 2.4: Kansas' Construction Area Late Merge (CALM) System
Source: http://www.matc.unl.edu/research/MwSWZDI/CALM%20Final%20Report%20r7.pdf

This system was designed to operate in three distinct modes – Early Merge, Late Merge, and Incident. The Incident category was a special case of a late merge strategy when traffic speeds were "exceptionally low." Transitions between the modes occurred seamlessly based on the current traffic average operating speed. Figure 2.5 highlights the mode operating speeds and transition thresholds between the three modes.

A more complex set of logic governed which messages were displayed on the set of five signs. These signs displayed messages pertaining to average speed further downstream when in the early merge scenario, and instructions to "USE BOTH LANES," "TAKE TURNS – MERGE HERE," "USE ALL LANE TO MERGE POINT – DO NOT PASS," and "STOPPED TRAFFIC AHEAD" at the onset of congestion. The exact condition and corresponding message for each sign is shown in the final evaluation report of the CALM system.

Level	**Speed Range (Lane 2)**	**Speed Range (3-lane average)**
1	>35 mph	> 46 mph
2	15 to 40 mph	15 to 51 mph
3	0 to 20 mph	0 to 20 mph

From	**To**	**At**
Level 1	**Level 2**	46
Level 2	**Level 1**	51
Level 2	**Level 3**	15
Level 3	**Level 2**	20

Figure 2.5: Mode Operating Speeds & Transition Threshold Between Three Modes
Source: http://www.matc.unl.edu/research/MwSWZDI/CALM%20Final%20Report%2Or7.pdf

The deployment of the CALM system took place during the spring of 2003 on a section of I-70 in Kansas City, KS. The construction closure was taking three lanes and shifting traffic down to two in the eastbound direction. The construction period was scheduled to be six months during which a four-week evaluation would take place. Because congestion periods were of main interest, only the weekdays were considered in the analysis.

According to evaluation results, dynamic late merge systems have the potential to improve the freeway operations around construction lane closures. The evaluation also highlighted the importance considering the location of entrance and exit ramps when placing the signs and sensors.

The total volume in the discontinuous lane was examined to determine if drivers were following the directions posted on the signs. The percent in the discontinuous lane decreased slightly during the beginning of the deployment but then increased above "before condition" percentages for the remainder of the evaluation period. The report suggested that drivers did change their behavior but it required a "training period to be fully realized."

The total flow through the construction zone did not appear to be negatively affected by the deployment of the CALM system. The total throughput varied around the original baseline values of the construction zone without the CALM system. The author concluded that the sparseness of data suggested that the study was inconclusive on this issue.

Final recommendations from the report suggested that density be used in lieu of speed for the threshold parameter for activating the different modes of the signs. Another proposition was to assign a person to oversee system operations by performing a visual check of the system operation daily and coordinating weekly system maintenance. The report also mentioned the importance of placing the portable CMS on the shoulder closest to the lane being closed. This ensures that drivers in the discontinuous lane have an easier time viewing the messages.

3.0 Mn/DOT's DLMS Deployment Locations

Mn/DOT's Dynamic Late Merge System (DLMS) was deployed at three different locations around the Minneapolis/St. Paul metropolitan area during the summer of 2004. The locations were I-494 (northbound and southbound) in Plymouth, US 52 in St. Paul, and I-35 around Lakeville. These site deployments are shown in Figure 3.1 below.

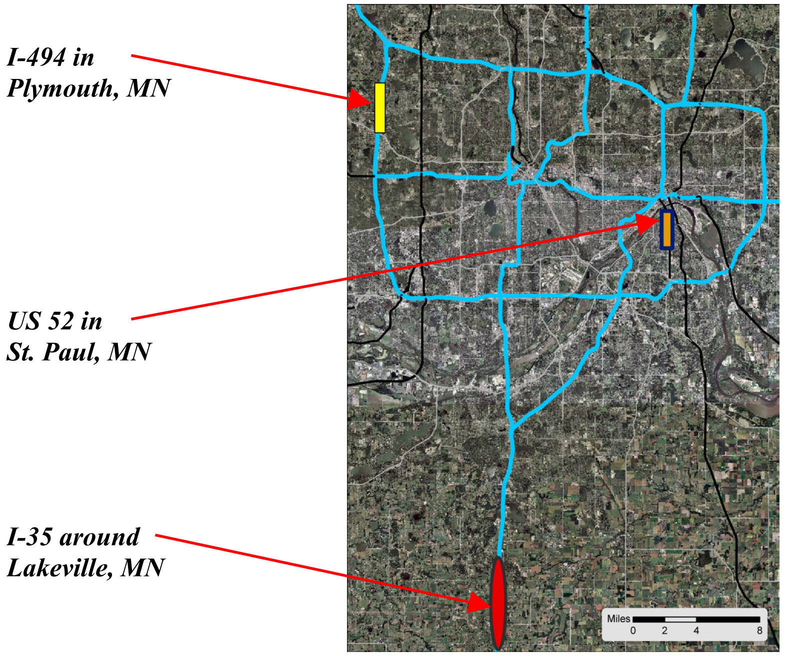


Figure 3.1: Mn/DOT's DLMS Deployment Locations

Because each deployment site had unique traffic characteristics, roadway geometry, and lane closure requirements, this evaluation report will examine each deployment site individually. As mentioned in Section 2.0, this evaluation will focus on the areas of potential benefit by reporting the results of evaluation findings on each of the five topics (queue length, work zone capacity, incidents, aggressive driving conditions, and travel times). An overall summary of all evaluation results will be presented following the individual site results.

4.0 DLMS Individual Site Results

4.1 I-494 Northbound

Mn/DOT's DLMS was deployed on the northbound lanes of I-494 in Plymouth, MN while two bridge deck surfaces were rehabilitated. The two northbound lanes were reduced to a single lane by closing the left lane just after County Road 9. The system was implemented on June 2, 2004 and removed with the opening of both lanes during the weekend of June 12, 2004 (see Figure 4.1).

June 2004

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

Figure 4.1: I-494 NB DLMS Deployment

The first US 10 DLMS deployment included three CMS in addition to the static traffic control signs usually present at construction lane closures. For deployment of the I-94 Northbound DLMS the same equipment set up was used. The first deployment of the DLMS in 2003 suggested that each CMS should be positioned on the shoulder nearest the lane being closed. Unfortunately, the CMS closest to the taper point on I-494 Northbound had to be located on the right shoulder due to the lack of a firm footing and steep grade of the median. Adding fill to this location was not cost effective due to the short duration of the project.

The messages posted at the three CMS locations were the same as those of the US10 deployment during the summer of 2003: furthest from the taper "STOPPED TRAFFIC AHEAD" – "USE BOTH LANES," next "USE BOTH LANES" – "MERGE AHEAD," and "MERGE HERE" – "TAKE TURNS." Figure 4.2 is an image taken just before the taper point showing the position of and messages displayed on the last CMS.

Due to the short duration of this project, Mn/DOT decided to deploy the DLMS immediately when the construction zone was set up. Consequently, there was no baseline condition data of a lane closure with a standard traffic control system. Therefore, no comparisons could be made between the standard traffic control and the DLMS. The following sections will highlight the evaluation findings collected during the DLMS deployment on I-494 Northbound alone.

4.1.1 Discontinuous Lane Use

Figure 4.2: Position and Messages Displayed on Last CMS on I-494 NB

The typically observed behavior when drivers encounter the advanced warning signs of a construction zone lane closure is for drivers to move out of the closed (discontinuous) lane to the lane continuing through the construction zone. Some drivers have even been observed to brake radically in order to join the end of a queue forming in the continuous lane after seeing the first static advanced-warning sign. These early merging behaviors result in a long single lane queue; a scenario with many dangerous driving conditions. A more in depth description of early merging behaviors is included in DLMS US 10 Evaluation Report Section Titled Motivation for Dynamic Late Merge.

The two advanced warning CMS farthest from the taper alert drivers to the stopped traffic ahead and instruct them to continue using both lanes. Permanent loop detectors located before the work zone taper record vehicle counts and can give an accurate picture of how each lane is being utilized as traffic approaches the construction zone.

Three different sets of loop detectors, at approximately 0.25 miles, 0.75 miles, and 1.75 miles from the taper, were analyzed to determine how the discontinuous lane was being utilized at these locations. These locations are downstream from the first CMS displaying the lane use message "USE BOTH LANES." For each set of detectors, total counts were calculated and used as the baseline to calculate a percent of vehicles utilizing the discontinuous (left) lane during that 5-minute interval.

Figure 4.3 shows the location of the detectors with a graph displaying the typical lane use percentage at each location on weekdays, broken out by 5-minute intervals. The first notable observation made when examining the three graphs is the marked change in the typical

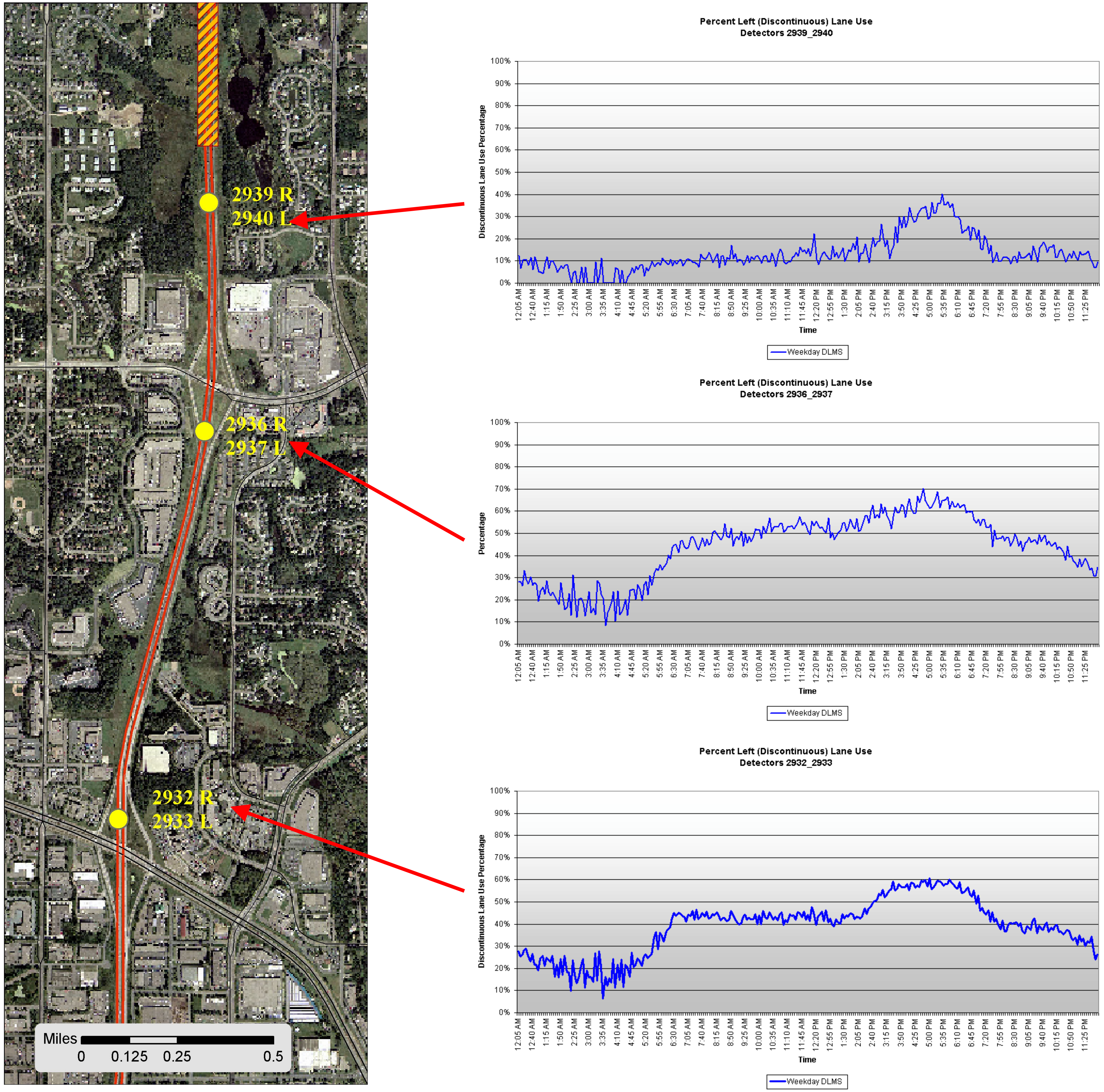


Figure 4.3: I-494 NB Detector Location and Typical Lane Use Percentage

discontinuous lane use percentage at the detector nearest the taper point. At intervals of 0.75 miles and 1.75 miles from the taper, the lane use percent ranged around the 50% mark, sometimes exceeding this percentage during peak periods. At the location nearest the taper, that percentage drops to around 10% to 20%. Drivers were obviously choosing to merge from the discontinuous lane before reaching the last CMS instructing them to "MERGE HERE."

Another notable pattern is the drastic increase in discontinuous lane use on weekdays during the afternoon rush period. For the two detector locations farthest from the taper, the typical lane use percent changes from around 45% during the morning and early afternoon to upwards of 60% during the afternoon rush. The fact that this increase took place during the afternoon is not a surprise since the route is a commonly used road for commuters to return home to the northwest suburbs from the downtown areas. The surprising part of this inquiry was the fact that the discontinuous lane use percentage increased to the levels it reached. The previous deployment of the DLMS on US 10 had discontinuous lane usage reach near 50% at detectors upstream from the taper but not over 50%. These detectors show that a larger volume of vehicles were using the discontinuous lane than the open lane. This pattern drastically changes by the time the traffic flow reaches the detectors closest the taper – where only 10% of vehicles use the discontinuous lane during the day, except during the afternoon rush when the level increases to almost 40%.

One possible explanation for this phenomenon is based on observations made in the field. The peak of the afternoon rush sees the highest levels of congestion. It was observed that during this time, unlike periods of less congestion, vehicles were most willing to remain in their lane all the way up to the merge location. (This observation is supported by the data in the top graph in Figure 4.3 for detectors 2939, 2940.) While vehicles proceeded in the discontinuous lane, a few vehicles from that lane would merge early (see Figure

Figure 4.4: Early Merging Locations

4.4). This early merge caused the continuous lane to slow because of the addition of this vehicle and left a gap in the discontinuous lane. Other vehicles in the discontinuous lane continuing towards the construction zone filled this gap and passed the early merging vehicle. This type of scenario occurred repeatedly at various locations throughout the queue. It was observed that the most common place for this behavior was just after the County Rd 9 location (after passing over the detectors 2936, 2937 shown on the second graph of Figure 4.3, but before reaching 2939, 2940 shown on the first graph of Figure 4.3). This position corresponded to the position of the static sign with the word MERGE and a right arrow. It appeared that drivers believed this was the suggested location to make their merging maneuver, possibly because the last CMS was hard to view at its position on the right shoulder. As mentioned previously, the preferred place for the last CMS was on the left shoulder. This alternative installation position would have helped provide better site distance to the sign and its message, which may have reduced the number of early merges at the static sign.

Figure 4.5: Furthest CMS from Taper on I-494 NB

One possible explanation for the large number of people willing to use the discontinuous lane farther back from the taper may have resulted from the one advanced CMS placed on the left shoulder (see Figure 4.5). This location provided good site distance from all lanes and was clearly visible for a large distance. Another potential explanation could be long distance commuters who are comfortable traveling in the left lane. These drivers may traditionally use this lane to avoid all the merging/diverging behavior occurring in the right lane throughout this stretch of road in order to reach their destinations quicker. This attitude would have carried over during the construction period as well.

It appeared that the DLMS was successful at encouraging drivers to use both lanes when drivers were far from the taper point of the construction zone. As vehicles approached the lane closure, a significant number of drivers decided to merge early and join the continuous lane sooner than suggested by the last CMS. Unfortunately, this created multiple merging locations and may have led to confusion amongst drivers as to the correct place to make their merging maneuver. It appeared that drivers never caught on to the idea of staying in their respective lanes until the designated merge location.

4.1.2 Work Zone Traffic Capacity

One set of Mn/DOT permanent loop detectors was located within the single lane work zone. During the two-week construction period, one of the two detector locations was always open to the traffic moving along this stretch of road. Together, these detectors counted the number of vehicles through the construction zone. During the daylight hours, there is usually a queue of varying lengths waiting to enter the work zone. This continuous demand at the entrance of the work zone suggests that this loop data within the construction area gives a snapshot of the capacity of the work zone during this project.

As previously mentioned, a lack of a baseline period prohibited comparing the DLMS against any type of a control group. However, the DLMS deployment on US 10 in 2003 also collected work zone capacity data. Even though the data is from two different locations, the type of road (limited access 4-lane divided) is similar. Figure 4.6 shows the average 5-minute vehicle counts during DLMS deployment in 2003 on US 10 and the DLMS deployment in 2004 on northbound I-494.

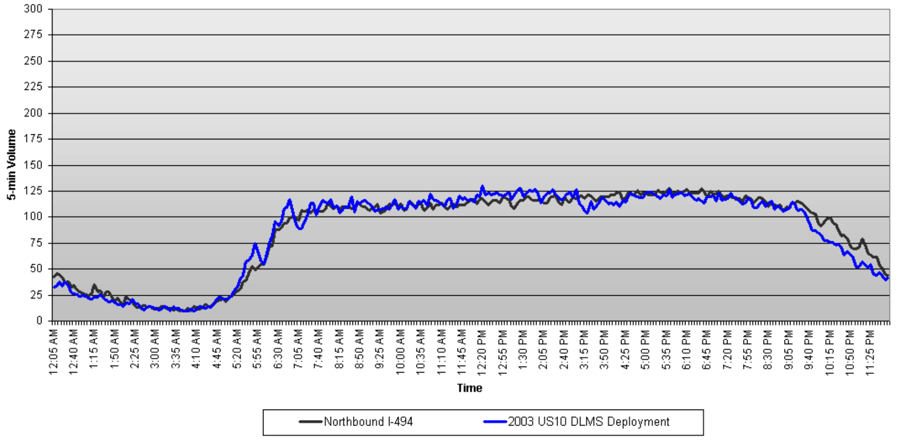


Figure 4.6: Comparison of 2003 US 10 DLMS Deployment and 2004 NB I-494 DLMS Deployment

Figure 4.6 shows that the throughput in each construction zone is remarkably similar. The plateau shape of both volume counts shows a clear upper bound at approximately 125 vehicles per 5 minutes (1500 veh/hr). This is consistent with previous research on the capacity of a single lane construction closure. However, it is unknown whether this capacity threshold at this location would have been any higher or lower without the deployment of the DLMS.

As a side note, because both locations were within the influence of the Twin Cities metropolitan area, the time of day during which the traffic levels increased and then fell off were similar because of the similar commuting patterns of the region. Even during the traditionally non-peak periods during the day, each construction zone had a short queue continually feeding the work zone, which kept the single lane filled with vehicles.

4.1.3 Queue Length

One of the benefits of the US 10 DLMS during its deployment in the summer of 2003 was its success in reducing the length of the overall queue of vehicles waiting to enter the construction zone. The queue length varied under two distinct conditions: the afternoon rush period and the non-rush periods.

Figure 4.7 displays a chart showing the typical queue lengths on I-494 Northbound under these two conditions. During the afternoon rush period, the queue would typically extend to just north of the overpass of County Road 6. This represents a queue length of 2 miles. During the non-rush periods, the queue commonly extended to between County Road 9 and State Highway 55. This queue length was approximately 0.75 miles. As noted earlier, the lack of a control condition prohibits any assertions on how the DLMS influenced the queue length during this lane closure but it is important to note that the length of the queue was typically the same in

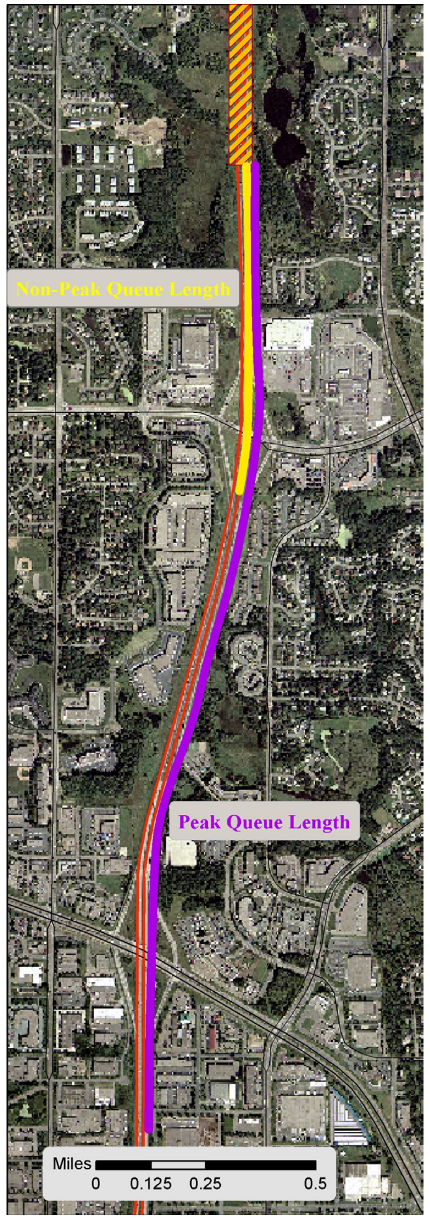


Figure 4.7: I-494 NB Typical Queue Length

both lanes, suggesting that the overall queue length was essentially minimized.

4.1.4 Travel Times

Vehicle travel times were not collected during this deployment of the DLMS because there was no baseline condition to use as a standard for comparison. The very short duration of deployment would have resulted in a very small data set from which to sample. Any atypical traffic pattern during a day of this deployment could have skewed the overall results. Additionally, travel time data has little meaning without the ability to contrast travel times under the two different traffic control strategies.

4.1.5 Incident Information

The Minnesota Department of Public Safety records incident information for reported traffic crashes. This information takes many months to enter into the database system. As suggested by Mn/DOT personnel, due to this extended backlog, the incident information will be omitted in this report. Any future investigation of the DLMS will examine the incident data from these deployments.

4.1.6 System Reliability

During this short deployment, the Dynamic Late Merge System appeared to perform its lane use instructions task successfully. Unfortunately, the system was not completely free of problems. By recording the Mn/DOT's Regional Traffic Management Center's camera images on the web, it was clear that the system became active during the overnight of June 9 – 10, 2004 (see Figure 4.8). The signs were active all night, despite the lack of traffic demand.

Figure 4.8: I-494 NB DLMS Active Overnight of June 9-10, 2004

Traffic Technologies, the contractor in charge of technology deployment for this project, stated that this problem dealt with a sign controller of a specific type of CMS. While relatively uncommon, this issue caused the sign to freeze and continue to display the lane use instructions, even when traffic demands decreased. This controller problem was discussed with the manufacturer and a resolution for the particular controller for the specific CMS was under review at the time of publication. Other than this issue, no other reliability concerns surfaced during this deployment. One method of ensuring system reliability would be to require the contractor to record the current system state and traffic data at regular intervals and provide this information to the client.

4.1.7 General Observations

Permanent loop detector data and observations made at the site confirm that drivers were willing to use the discontinuous lane up to a quarter mile from the taper under this deployment of the DLMS. After this point, many drivers exhibited a behavior that suggested they were not comfortable using the discontinuous lane close to the taper itself. Many early merges were observed around the location of County Road 9 (approximately ¼ mile from taper). These merges disrupted the flow of traffic in the continuous lane and left a gap in the discontinuous lane, which was typically filled by the subsequent vehicles moving forward in the queue.

Another behavior observed in the last half mile of the discontinuous lane was lane blocking. A small percentage of vehicles in the discontinuous lane were observed pacing the vehicle next to them in the continuous lane instead of continuing up to the designated merge location. Vehicles trailing this blocking vehicle were commonly seen merging early from the discontinuous lane. This action could possibly be attributed to the blocking vehicle.

Other vehicles modified this blocking behavior slightly by straddling both lanes. Though not as common as lane blockers, when observed, this behavior commonly set up a dangerous conflict scenario. Frequently, trailing vehicles still attempted to pass the straddling vehicle by using part of the shoulder while the straddling vehicle sometimes was observed swerving towards the path of the trailing vehicle.

Figure 4.9 indicates examples of blocking vehicles observed during this system deployment.

It was observed at the deployment site that vehicles frequently merged at the static orange sign with the word "MERGE" and a right arrow. The message of the sign coupled with the fact that the last CMS (on the right shoulder) was not easily viewed appeared to suggest to drivers that this was the designated location to merge. Mn/DOT was aware of this dilemma before the deployment of the system but believed the extra expense and effort to truck in base material for the left shoulder was not justified given the short duration of the project.

Figure 4.9: I-494 NB Blocking Vehicles

4.2 I-494 Southbound

Bridge rehabilitation work shifted from the northbound lanes of I-494 to the southbound lanes with a southbound closure that began on June 14, 2004 (see Figure 4.10). Once again, Mn/DOT's DLMS was deployed with the initiation of the lane closure, eliminating any period for collecting data under a baseline condition of the standard traffic control alone.


July 2004

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Figure 4.10: I-494 SB DLMS Deployment

This deployment of the DLMS included a slightly altered configuration of the CMS. While the two CMS locations farthest from the taper remained at similar locations, the CMS nearest the construction zone was moved from its position at the beginning of the taper to a position further upstream. Noting that many vehicles had chosen to perform an early merge at the location of the static "MERGE" sign with the arrow, the last CMS was placed near to this sign on the left side of the road (see Figure 4.11).

This placement improved overall visibility of the sign, especially by those in the discontinuous lane on the left side of the interstate, and solved the apparent contradiction in correct merging location between the static sign and the last CMS.

The deployment of this system was also very brief. The system, along with the lane closure itself, was removed on Thursday June 24, 2004 (see Figure 4.10). As done with the I-494 Northbound deployment findings in Section 4.1, the following sections will highlight the evaluation findings collected during this I-494 Southbound DLMS deployment alone.

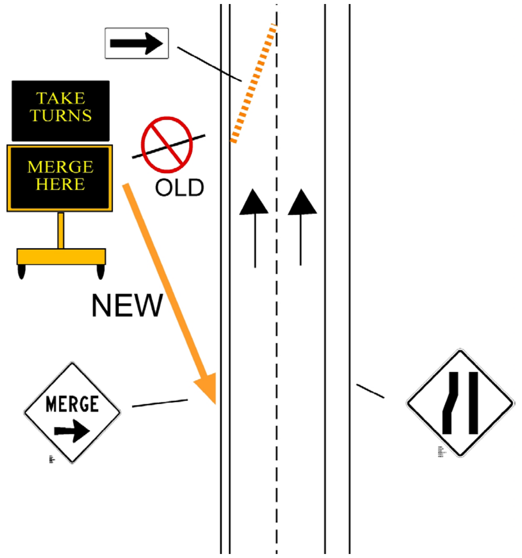


Figure 4.11: CMS Placement

4.2.1 Discontinuous Lane Use

Permanent loop detectors at three locations upstream from the construction taper continually collected traffic data on this stretch of roadway. These detectors were approximately 0.20, 0.70, and 1.0 mile from the work zone taper. This data was used to calculate the percentage of vehicles utilizing the discontinuous left lane as traffic approached the merge location.

Figure 4.12 (on the next page) shows the location of the detectors with a graph displaying the typical lane use percentage at each location on weekdays, broken out by 5-minute intervals. The short duration of deployment included only a single weekend, so this small sample of data was not used in the analysis.

Similar to the DLMS deployment a week earlier, the pattern of discontinuous lane use changed as drivers neared the taper point. At the permanent loop detector location farthest from the lane closure had approximately 40% discontinuous lane use. Approximately at three tenths of a mile closer to the closure, this value peaked at 60%. Discontinuous lane use at the permanent loop detector closest the construction closure averaged around 20% during the daylight hours. Only during the morning peak period did this percentage increased to approximately 30%.

This strange pattern of discontinuous lane use may have been influenced of the geometry of the road at this location. When vehicles are at detector location 2866-2867, the lane closure taper is not viewable because of the curvature and elevation of the road. Three tenths of a mile downstream (near detectors 2868-2869), the lane closure was then within the line of sight. This is also the location where the discontinuous lane use percentage increased noticeably. During site visits, many vehicles were observed leaving the continuous lane and entering the discontinuous lane to avoid the end of the forming queue.

The change of location of the last CMS to the location of the static sign with words "MERGE" and the arrow made a large difference at the merging location. The usual behavior during this deployment was to see vehicles approach the CMS and make their merging maneuver at this location. This setup appeared to make much more sense to drivers because they followed directions to use the discontinuous lane to the merge point. The number of early merges observed was reduced and it appeared drivers were more willing to merge at this location. Another potential reason this setup worked better was the fact that there was a buffer between the designated merge location and the actual lane closure. The remaining approximately 750ft of open lane may have allowed drivers to feel less pressure to make their merging maneuver.

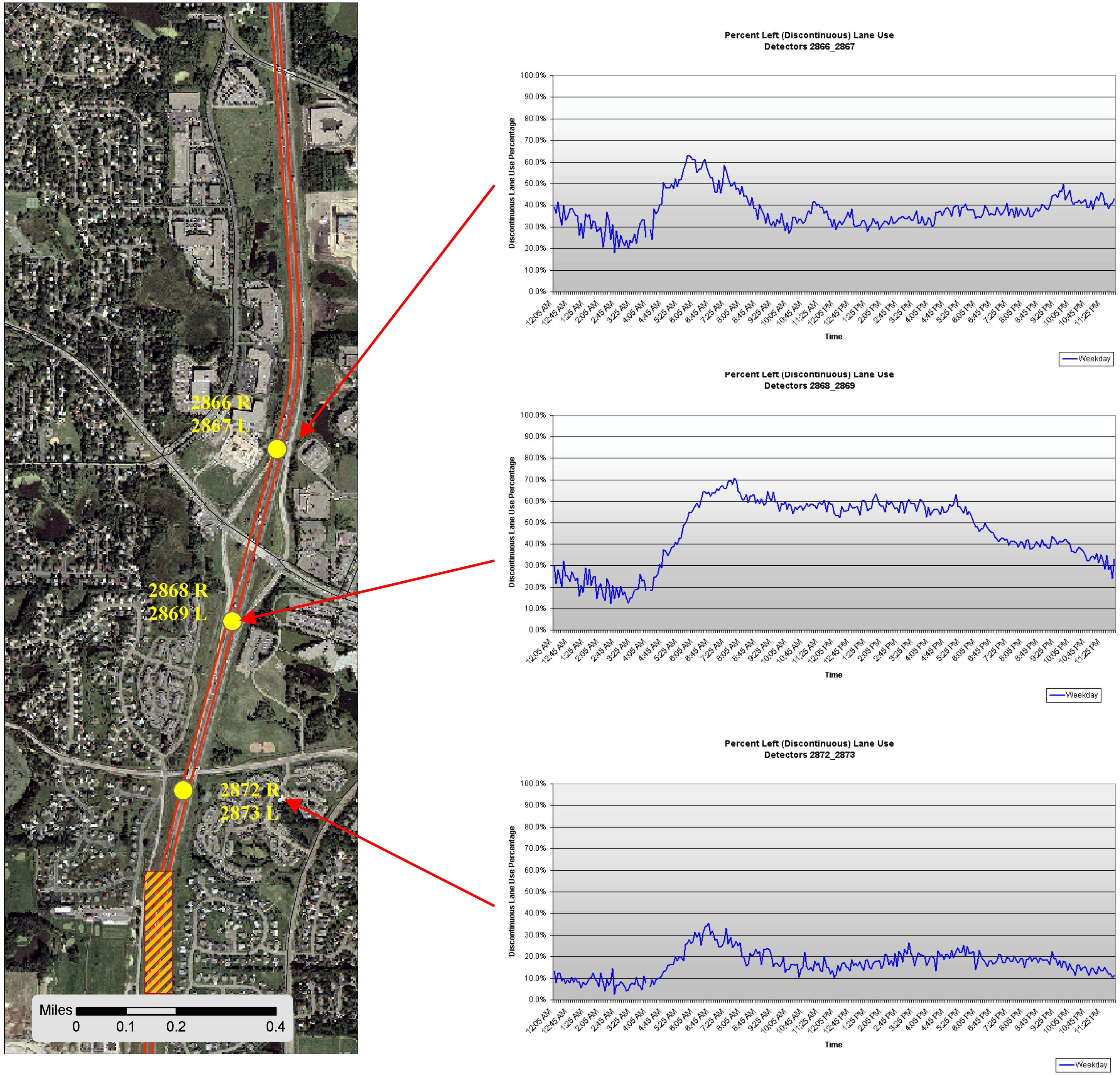


Figure 4.12: I-494 SB DLMS Location and Typical Lane Use Percentage

4.2.2 Work Zone Traffic Capacity

The total throughput of traffic through the construction zone is shown in Figure 4.13. Because of this location's heavy traffic volume throughout the entire day, at least some type of queue was usually present. This was evident during the daylight hours, where demand exceeded capacity and there were always cars waiting to enter the construction zone. This continuous flow of traffic could be considered the work zone's overall traffic capacity.

Figure 4.13 shows the southbound I-494 DLMS traffic capacity along with the values for the northbound deployment and the previous year's deployment on US 10. It can easily be seen on the graph that there is a clear upper limit to the traffic volume at approximately 130 vehicles per 5 minutes (1560 veh/hr) for all three deployments. This ceiling appears to be consistent across the various deployments, suggesting that this would be the approximate maximum throughput the Dynamic Late Merge System can achieve during a single lane construction closure where two lanes are reduced to one.

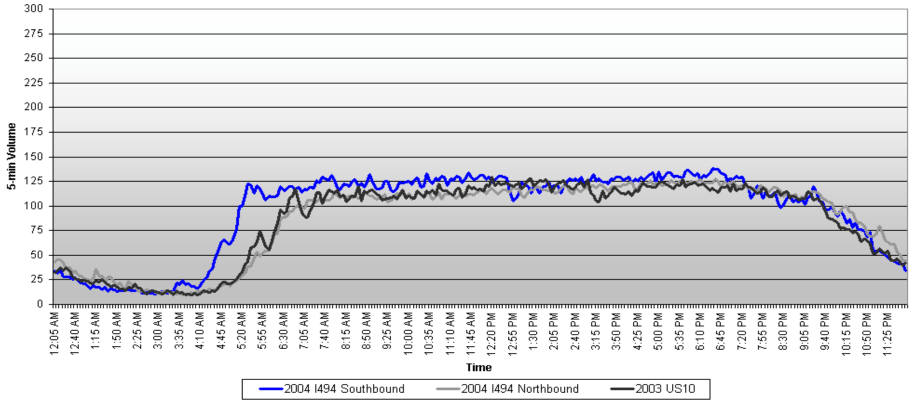


Figure 4.13 Comparison of 2003 US 10, 2004 NB I-494, and 2004 SB I-494 DLMS Deployments

4.2.3 Queue Length

The typical queue length during the morning peak period stretched northward from the taper location to a half mile south of the I-694/494/94 Fish Lake Interchange. This was a distance of approximately 0.75 miles. The queue did not grow any longer because of a natural bottleneck in the freeway north of the Fish Lake Interchange. This restricted the flow of traffic out of this section of road, limiting the effective demand. During non-peak periods, the queue only grew to a length of 2.5 miles, near the intersection of I-494 and Bass Lake Rd. During all observation periods, the queue formed approximately equally in both lanes. There did, however, appear to be a tendency for some drivers to stay in the right (continuous) lane regardless if there was a shorter queue length in the left lane (see Figure 4.14).

Figure 4.14: I-494 SB Formation of Queue

4.2.4 Travel Times

Vehicle travel times were not collected during this deployment of the DLMS because there was no baseline condition to use as a standard for comparison. Travel time data has little meaning without the ability to contrast travel times under two different conditions.

4.2.5 Incident Information

As highlighted earlier in this report, the incident data takes many months to enter into the database system. As suggested by Mn/DOT personnel, due to this extended backlog the incident information will be omitted in this report. Any future investigation of the DLMS will examine the incident data from these deployments.

4.2.6 System Reliability

No system problems were noticed or reported during this deployment. However, the data from the system was not recorded by the hardware. Because of this lack of data there is no recording of the system to evaluate this claim.

4.2.7 Other Observations

While the evaluation team was taking video and pictures of the deployment site, one citizen stopped to inquire what was taking place at the construction zone closure. This person stated that they noticed the signs and instructions but didn't understand the concept. This driver had used this section of road repeatedly but was unwilling to use the discontinuous lane because of an opinion that this was still "cheating." After being given a brief clarification of the concept and purpose, the driver stated that this concept makes sense but would not have previously understood the overall idea. This lack of driver understanding can recreate a large problem with trying to improve the percentage of people who follow lane use instructions accurately. Even a small percentage of vehicles blocking would still have a negative effect on the operations of the merging procedure.

Figure 4.15: Example of Semi Truck Straddling Centerline

It was quite apparent that semi-trailer trucks are still unwilling to move further up in traffic and are much more content to pace the vehicle next to them or straddle the centerline to block passing vehicles (see Figure 4.15). Because semi trucks appear to be a disproportionally higher percentage of blocking vehicles, if they could be educated about the purpose of the system, this may improve overall operations. One Intelligent Transportation System (ITS) technology that could be considered would be the use of a CB broadcast system. This system could place instructions out over a CB frequency in the area of the construction taper. This automated system could be used as a tool to instruct the semis not to block and provide additional information on the purpose of the system.

4.3 US 52 Deployment

The Dynamic Late Merge System was deployed along northbound US52 in St. Paul, MN during a bridge rehabilitation project in the late summer. This roadway had surprisingly low volumes, possibly due to alternative routes in the area, and it was determined that this deployment would not make a good case study. The lack of permanent loop detectors and typically very low traffic volumes did not warrant the collection of additional data, so the decision was made not to examine this site any further. A few notes on the overall deployment will be subsequently given.

The system placed the CMS farthest upstream on the left side, which provided a more visible location for all drivers to view the message (see Figure 4.16). The remaining signs were placed on the right shoulder due to lack of available space on the left side of the roadway. The following messages were displayed on the signs (bold indicates changed message):

STOPPED TRAFFIC AHEAD – USE BOTH LANES
USE BOTH LANES – **PREPARE TO STOP**
TAKE TURNS – MERGE HERE

Figure 4.16: US 52 Left Side CMS

As congestion formed, the system would warn drivers upstream by displaying a single message on the closest sign upstream: PREPARE TO STOP.

Figure 4.17 shows the line of site towards the construction zone. The road takes a large left turn, obscuring the last CMS and the actual merge location until within a quarter mile. If there were heavier traffic, this type of geometry may have reduced the number of early merges.

Figure 4:17: US 52 Line of Site Toward the Construction Zone

Figure 4.18 shows the typical traffic pattern during the construction period. Vehicles were not commonly observed using the discontinuous lane to the merge point very frequently. This may have been due to the fact the queue was typically quite short and merging back into the continuous lane would not result in any addition time savings. Typically, people appeared content to wait their turn in the short queue.

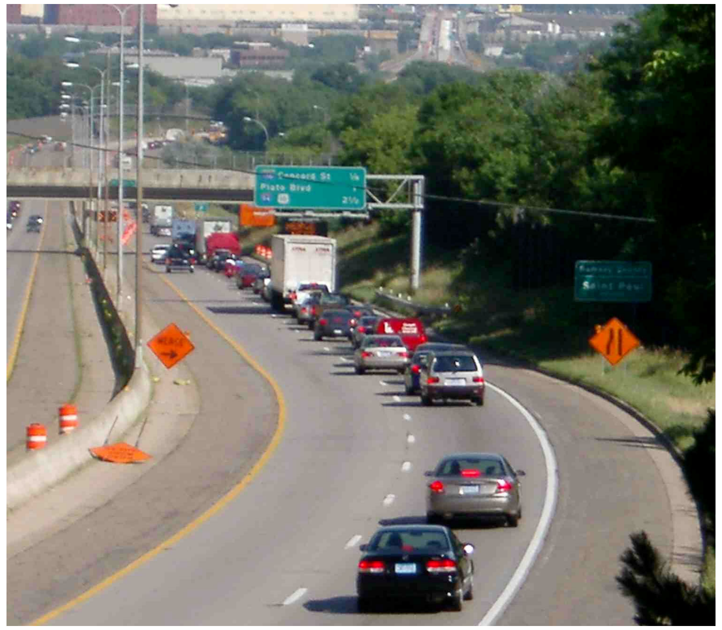


Figure 4.18: US 52 Typical Traffic Patter During Construction

4.4 I-35 Deployment

The Dynamic Late Merge System was deployed along a section of Interstate 35 south of the Twin Cities metropolitan area. A stretch of southbound I-35 approximately 8 miles long was undergoing a complete reconstruction. During this project, traffic was reduced to a single lane in the southbound direction and then transitioned across the median into one of the lanes of the northbound direction. During the first period of the closure, the baseline conditions were collected when the left lane was closed. A few weeks later, the taper location was moved further upstream and the layout of the construction zone changed. Unlike many other lane closures occurring at construction zones in Minnesota, the final and main duration of **this construction zone closed the right lane instead of the left**. A left lane closure occurred in the northbound direction to accommodate the traffic from the southbound lanes.

This deployment of the DLMS was much longer in duration than any of the previous deployments of the system in Minnesota. This system was activated in May 2004 and ran through the middle of October 2004 (See Figure 4.20). This system deployment consisted of three CMS located at approximately 500ft, 1.5 miles, and 3.25 miles from the taper along with a single RTMS detector located approximately 1500ft from the beginning of the lane closure.

The messages on the three CMSs were changed from previous deployments to read:

STOPPED TRAFFIC AHEAD – USE BOTH LANES
USE BOTH LANES – **MERGE 1.5 MILES AHEAD**
MERGE HERE – TAKE TURNS

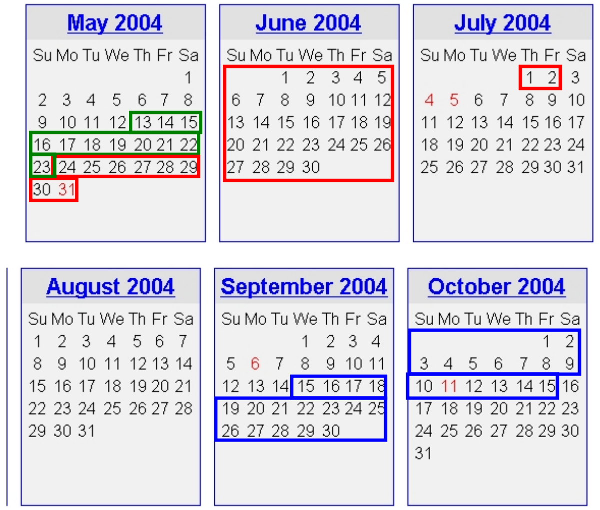
Figure 4.19: I-35 2nd DMS From Taper

Other messages called "flash messages" were displayed by the system when a specific traffic condition at the location of one of the CMS signs took place. If the radar detector mounted on the sign detected an abnormally high speed, it would flash a message such as "REDUCE SPEED – WORK ZONE AHEAD" or "REDUCE SPEED – STOPPED TRAFFIC AHEAD" depending on the traffic conditions further downstream. When the speed fell below a designated "very low speed" threshold, the signs would state "SORRY FOR DELAY" in addition to the standard message of "STOPPED TRAFFIC AHEAD" or "USE BOTH LANES."

During the first month of system deployment it became apparent that traffic volumes in the southbound direction were resulting in more significant queuing. This information suggested that the southbound direction be examined in more detail so the northbound lanes were dropped from further evaluation.

Southbound

Three distinct time periods of data were collected during the extended deployment of the Dynamic Late Merge System at this location. Baseline conditions were collected for a short duration when the lane closure was in place, but the Dynamic Late Merge System was not activated. Data during these baseline conditions were collected from May 13, 2004 to May 23, 2004 (see Figure 4.20). The RTMS detector that was being readied for deployment with the DLMS was the only traffic sensing-instrument recording data along this stretch of road. The system activated on May 24, 2004 and data from the RTMS detector was saved through July 2, 2004 during the beginning of the deployment. The data consisted of 15-minute aggregations of total volume and average speed over these intervals.



May 2004

Su	Mo	Tu	We	Th	Fr	Sa
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2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

June 2004

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

July 2004

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

August 2004

Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

September 2004

Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

October 2004

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Figure 4.20: I-35 DLMS Deployment

A third period of data was recorded later into the system deployment. For one month, from September 15 to October 15, 2004, average speed and total volumes were recorded under 5-minute aggregations from the main RTMS detector (see Figure 4.20). Because no other permanent loop detectors were present over this stretch of highway, two additional RTMS detectors (see Figure 4.21) were placed further upstream to collect more information on the dynamic traffic conditions for this month. Similarly, the information from the radar detectors that read speed at each of the three changeable message signs was also recorded by DLMS system hardware.

Figure 4.21: Additional RTMS Data Collection

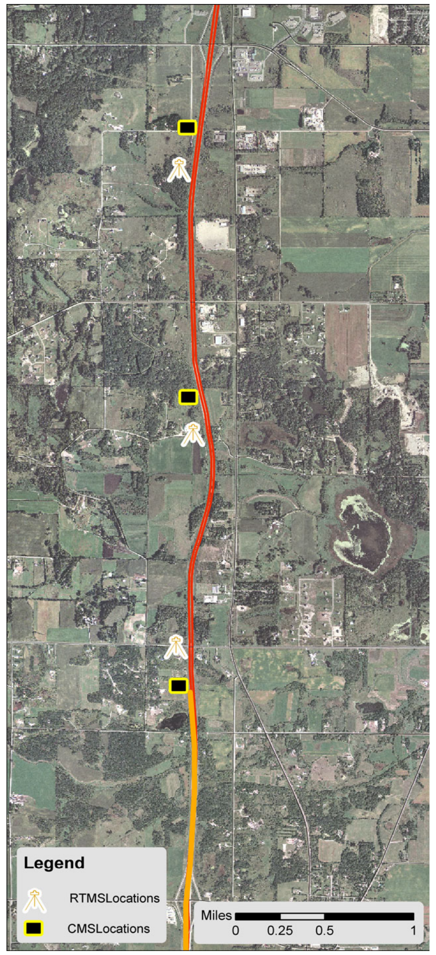


Figure 4.22: I-35 Radar and RTMS Detector Locations in Sept/Oct

These detectors provided information on traffic conditions at a variety of points upstream from the work zone taper. The detectors were added near the end of the deployment to ensure that repetitive traffic conditions, such as commuter traffic patterns, reached equilibrium under the construction environment. Clearly, this would not account for drivers unfamiliar with the area that may not have ever encountered a similar type of work zone traffic control. Figure 4.22 on the previous page displays the location of the three RTMS detectors and the three CMS.

4.4.1 Baseline Conditions

Due to the fact that the baseline conditions were collected with a single RTMS detector, traffic conditions during this period are known only at the single location where this detector was deployed. (For the baseline conditions, this detector was approximately ½ mile upstream from the construction closure.) This fact, coupled with the short duration of deployment, means that there is not a lot known about the "before" conditions of a typical construction lane closure at this location. However, this data does reveal certain traffic characteristics under these conditions.

The overall traffic demand during this baseline condition was not very high. Most schools were in session and summer vacation traffic has yet to start during the month of May. As shown in Figure 4.23, the typical 5-min volume was not at the 140 vehicles per 5-min capacity threshold that was seen at the previous DLMS deployment locations. This lack of heavy demand meant that queues rarely formed during the baseline conditions.

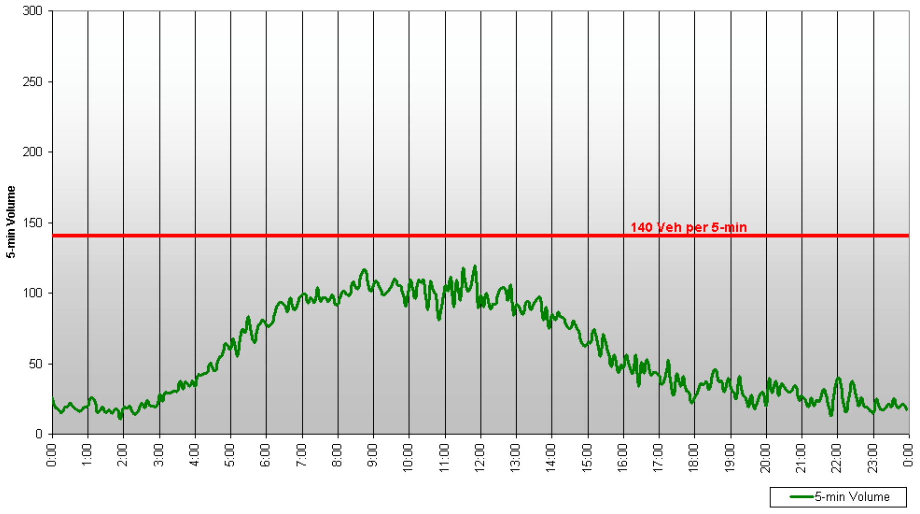


Figure 4.23: Baseline Conditions Typical Volume

Heaviest volumes at this location usually occur on weekends, especially Friday afternoons. The only two times a queue formed during this period were the two Friday afternoons. Figure 4.24 shows the volume and speed information from Friday and Saturday, May 21st and May 22nd. The speed information was filtered due to the RTMS detector's inability to accurately calculate speeds at low volumes. Data containing volumes below 15 vehicles per 5 minutes were removed due to this detector characteristic. During the highest volume periods, the speeds at this detector fell from around 60mph to around 35-40mph. This slowing indicated that the demand was heavy enough to force vehicles to slow before entering the construction zone but not heavy enough to extend the queue to the location of the detector. If the queue had grown to this location, the vehicle speed would have dropped much more considerably.

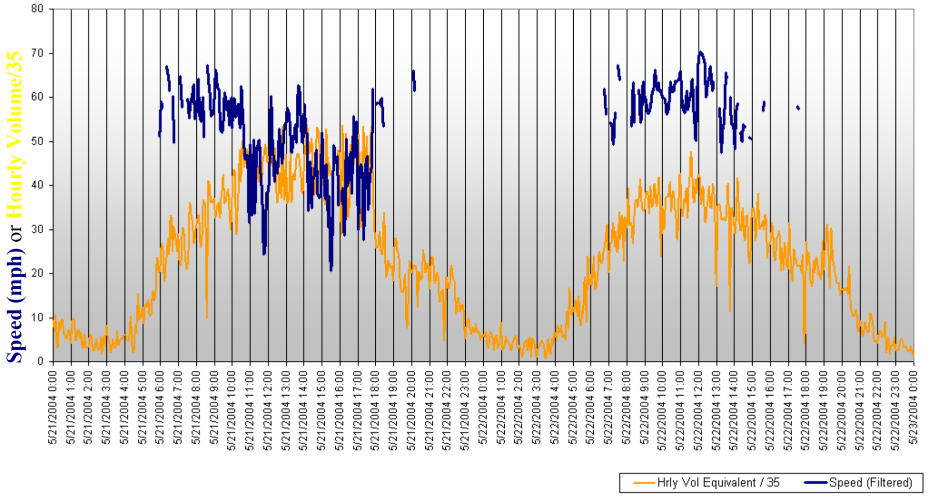


Figure 4.24: Filtered Speed and Volume
Friday, May 21 and Saturday, May 22

The RTMS detector records the traffic characteristics for each lane separately. The volumes during each 5-min period were examined to determine how the traffic was utilizing each of the two lanes upstream from the taper. Figure 4.25 shows the discontinuous lane use percentage for the same Friday and Saturday as in Figure 4.24. This graph shows that only approximately 25% of the traffic volume utilized the lane that was being closed at a location of ¼ mile upstream. This pattern of traffic is typical of what has been observed at other single lane construction closures. The lane use percentages were calculated during the rest of the baseline period and similar percentages were noted. (See Figure 4.26)

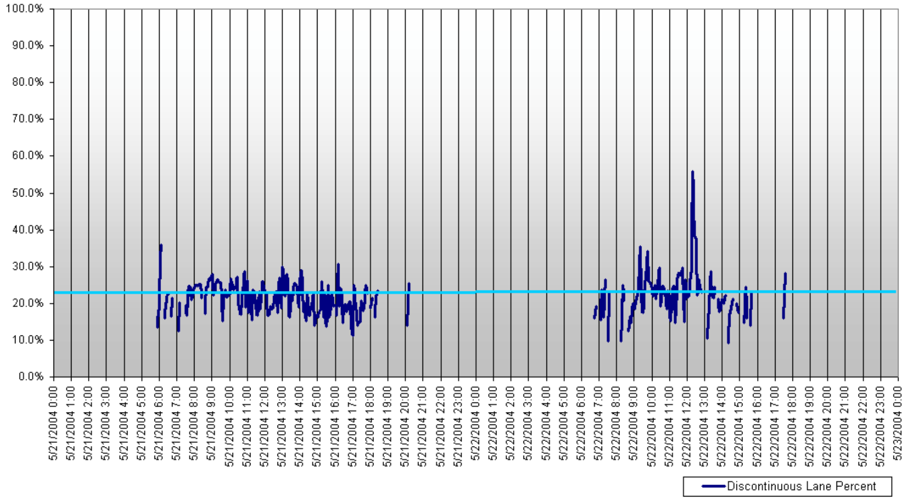


Figure 4.25: Discontinuous Lane Use Percentage
Friday, May 21 and Saturday, May 22

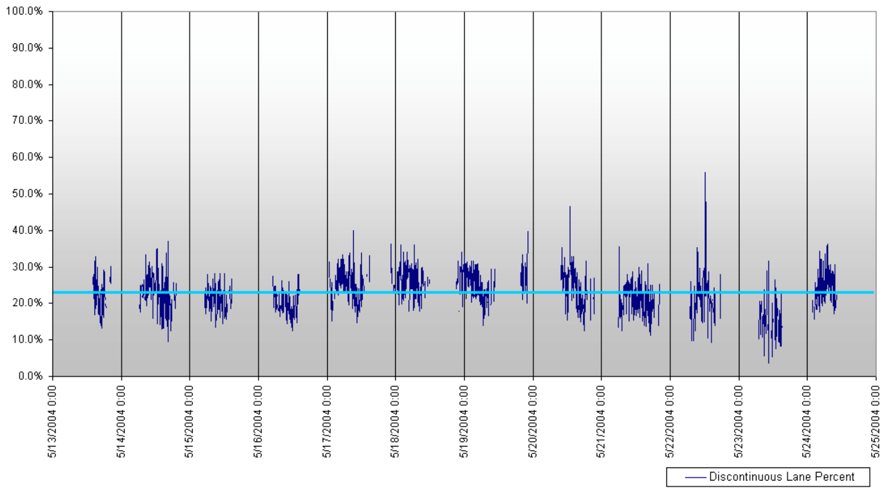


Figure 4.26: Discontinuous Lane Use Percent during Baseline Period

The subsequent subsections will mainly use the data gathered during September/October at three radar detectors mounted on the CMSs along with the RMTS detectors to investigate the overall performance of the DLMS system. Data pertaining to the baseline conditions will be mentioned during subsections where data from the single RTMS proves relevant.

4.4.2 Queue

The speed/volume information gathered by the three RTMS detectors upstream from the work zone closure was used to determine when a congestion queue formed and how long this queue became. The majority of the time, traffic demand along I-35 did NOT exceed capacity. This meant that there was no queue forming during most of the evaluation time periods.

It should be noted that there was an additional construction region to the north of this main construction closure with the deployed DLMS. This single lane closure, which was present only between the morning and evening peak periods, altered the flow of traffic into the southbound DLMS. The effect of this occasional closure are unknown and unaccounted for in this evaluation.

This evaluation defined a queue to be forming at a detector if the average speed at the detector over the time sample was below 30 mph. For each time sample, the three RTMS detectors were examined to determine if the speed at the first RTMS detector dropped below 30 mph. If a queue formed during this time interval at the first RTMS, the speed information for the second RTMS detector at this time was also examined. If the speed at this second detector was also below 30 mph, the queue was defined to have stretched past the first two detectors. This logic was repeated with the data from the third RTMS detector. Figure 4.27 displays the times and lengths when a queue formed during the detailed investigation that took place in September and October 2004.

Investigating the lane use percentages during this time period shows that the discontinuous lane was used much more when the DLMS system was deployed. (Compare Figures 4.26 and 4.28) At the RTMS detector nearest the taper, the lane use varied by time period and congestion level, but it varied around the 50% level. This is a dramatic increase over the approximately 25% discontinuous lane use seen during the baseline conditions.

The logic that determined the queue length only examined the overall average speed of both lanes to determine the formation of a queue. This did not mean that the queue lengths in each lane were necessarily of equal length. During the time periods where queues started to form, detailed analysis was performed to investigate the speeds in the individual lanes. If the queues formed in each lane were of equal length with equal traffic demands, it would be assumed that the speeds in these lanes would also be of similar values.

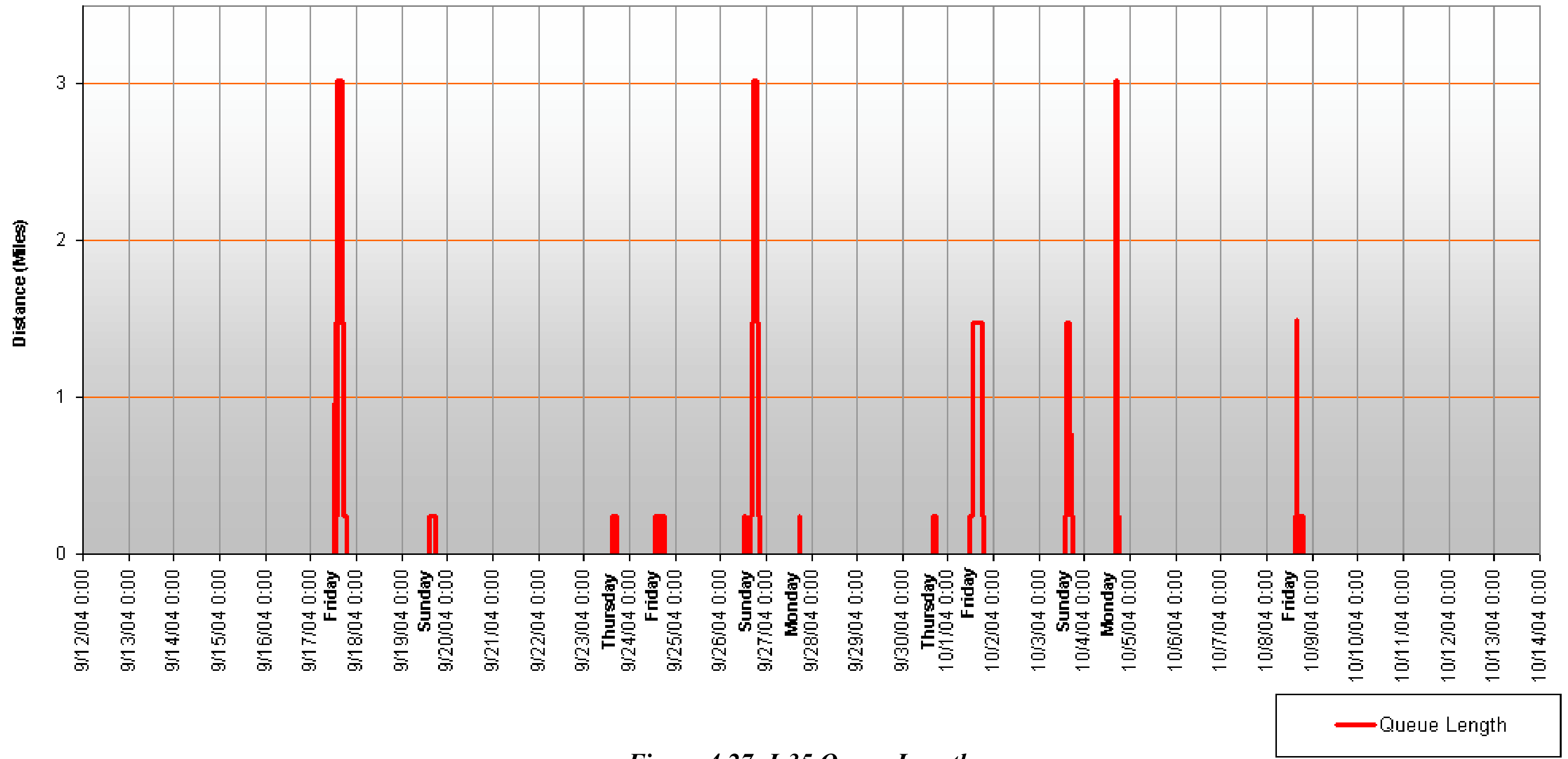


Figure 4.27: I-35 Queue Lengths

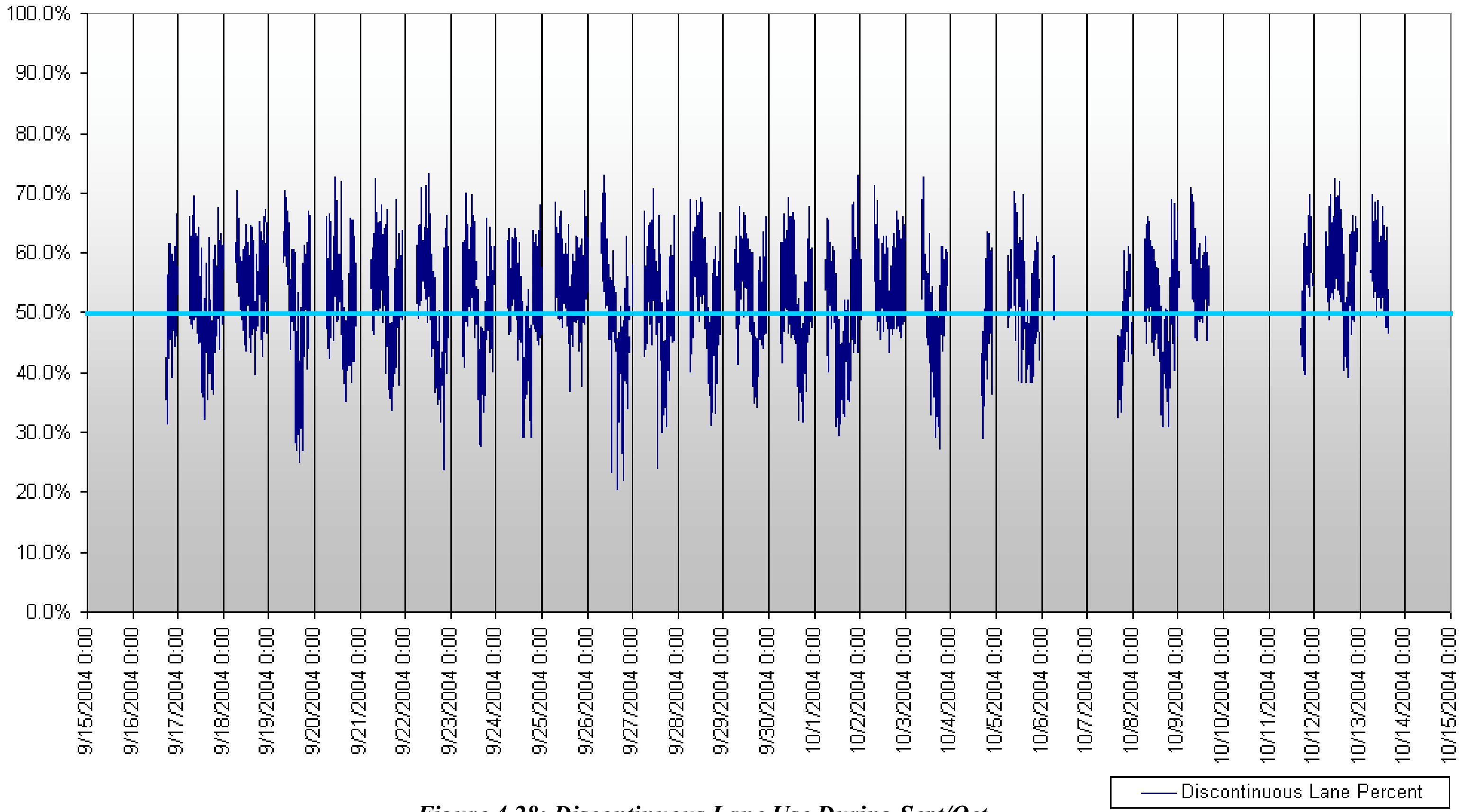


Figure 4.28: Discontinuous Lane Use During Sept/Oct

Figure 4.29 displays the right and left lane average speeds over the 5-minute intervals at the three RTMS detectors for a single day with a long queue. All other time periods with queues were also investigated and all showed the same tendencies described in the following paragraphs.

In this set of three graphs, the green line represents the left lane, the blue line the right lane, and the red line is a scaled version of the queue length. This scaled queue length represents a queue length of approximately ¼ mile, 1.5 miles, or 3 miles. These queue lengths are shown as scaled values of approximately 1, 10, or 15.

One of the first notable observations about these graphs is the very similar speed data for the left and right lane at the RTMS detector nearest the taper (RTMS 1). This could suggest that the queue lengths are equal at this detector. Upstream from this location, the speed data tells a different story.

The second and third RTMS detectors have discontinuous lane speeds that are significantly higher than the continuous lane values. The volumes at these locations were also investigated. Although not shown in graph form, the left (continuous) lane volumes were slightly higher than the discontinuous lane values. This combined volume and speed data gives evidence that drivers were not following the instructions on the CMS by utilizing both lanes equally farther back from the taper.

Onsite observations confirmed this tendency. While both lanes were definitely more fully utilized nearest the taper, many drivers appeared content to stay in a longer queue in the discontinuous lane as the overall queue grew in length. Because this construction closure was an uncustomary right lane closure, it would not have been the natural tendency for drivers to move to the left lane unless they were purposely moving into the open lane before reaching the congestion. As stated earlier, this tendency was shown every time a queue formed during the month long evaluation period.

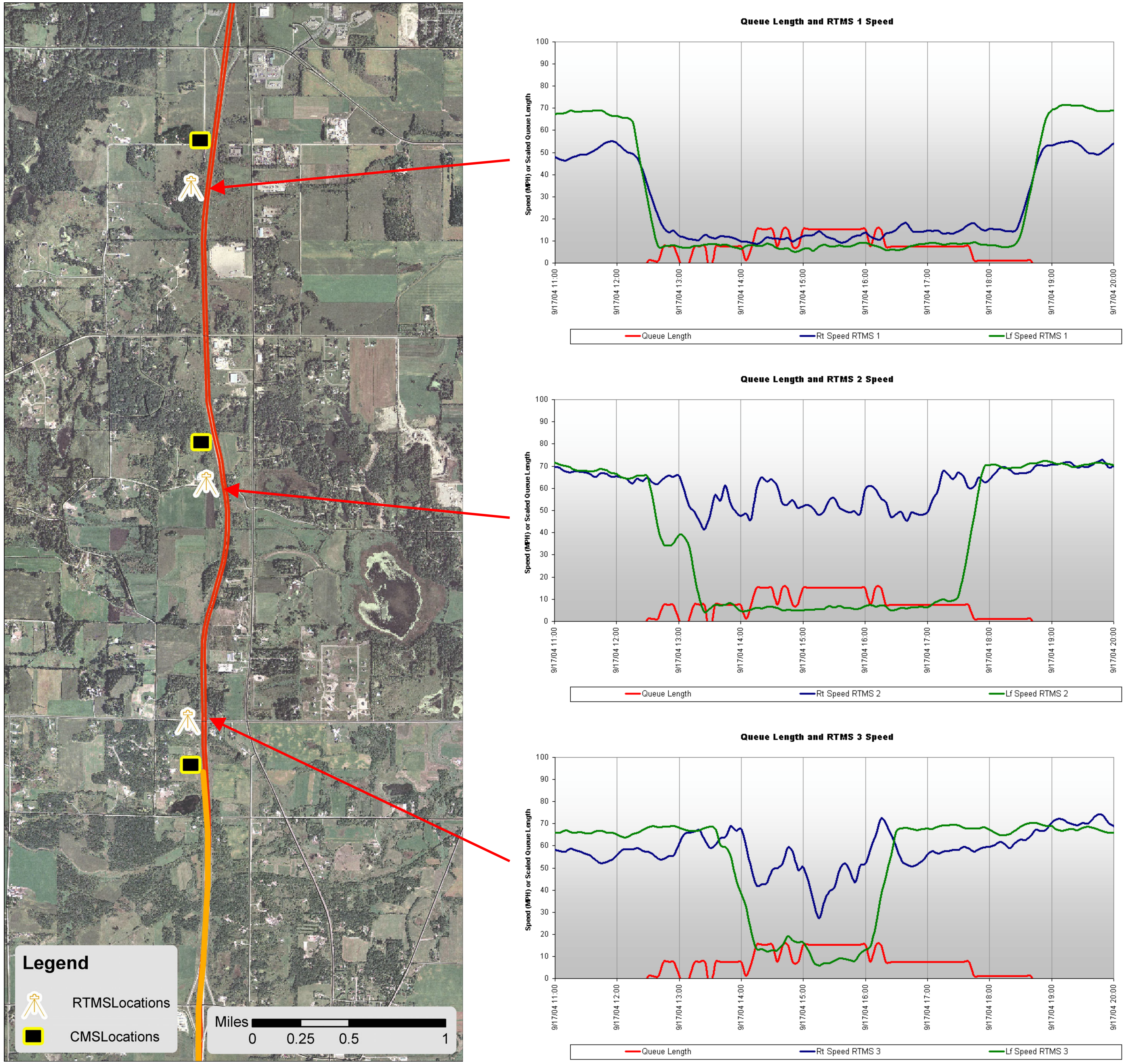


Figure 4.29: I-35 Right and Left Lane Average Speeds

4.4.3 Traffic Capacity

The traffic volume through the construction zone once again was investigated during this deployment to determine the effectiveness of the DLMS at getting vehicles through the construction zone. Figure 4.30 of 5-minute traffic volumes at the entrance to the construction zone for each of the DLMS deployments shows that there is a distinct capacity limit during the single lane closure.

The approximate maximum traffic capacity for all of these deployments is near 140 vehicles per 5-minute period (1600 veh/hr). The southbound I-35 line has a distinct peak in the late afternoon. During most of the other times of the day, there was not enough demand present to assume that vehicles were always waiting to enter the construction zone. This lack of demand prohibits assuming that the lower values would be capacity values. The highest demand occurred during the afternoon at this deployment location.

Zooming in on the graph in Figure 4.30 into the afternoon period shows how similar the maximum throughput values are for all of the four deployment locations (see Figure 4.31). (This time period is highlighted because of the typically higher demand during this time at these locations.) This similarity clearly suggests that this could be the expected capacity of the single lane closure with the DLMS. This value of approximately 1600 veh/hr corresponds to the capacity of the single lane closure collected under the baseline conditions during the 2003 US 10 DLMS deployment.

4.4.4 Incident Information

As highlighted earlier in this report, the incident data takes many months to enter into the database system. As suggested by Mn/DOT personnel, due to this extended backlog the incident information will be omitted in this report. Any future investigation of the DLMS will examine the incident data from these deployments. It should be noted that the DLMS helps reduce aggressive driving conditions because drivers have been told they have permission to use either lane. If a driver is unhappy with the speed in a given lane, they are given the opportunity to switch lanes without feeling that they are cutting their way to the front of the line. This system also reduces the speed differential of vehicles in adjacent lanes, creating safer driving conditions.

4.4.5 System Activation Threshold

Determining whether or not a construction lane closure can benefit from deploying the DLMS is a difficult decision. Traffic demand and vehicle usage characteristics change at different deployment locations of the DLMS. There are a large number of unknown variables that will affect the overall traffic demand and flow. One traffic flow theory holds true despite all these variables; if demand exceeds capacity – a queue will form.

The data gathered during September and October of 2004 was analyzed to determine the traffic conditions that were present when the speeds dropped well below the free flow speeds at locations upstream from the work zone taper. The status of the DLMS was also investigated to ensure that the system activated every time congestion occurred.

Figure 4.32 displays an example graph that will be used to show the traffic conditions over this secondary evaluation period. This graph contains a brief explanation of the four pieces of information shown on the graph. Becoming familiar with this page will aid in understanding the remainder of the graphs in this I-35 evaluation section.

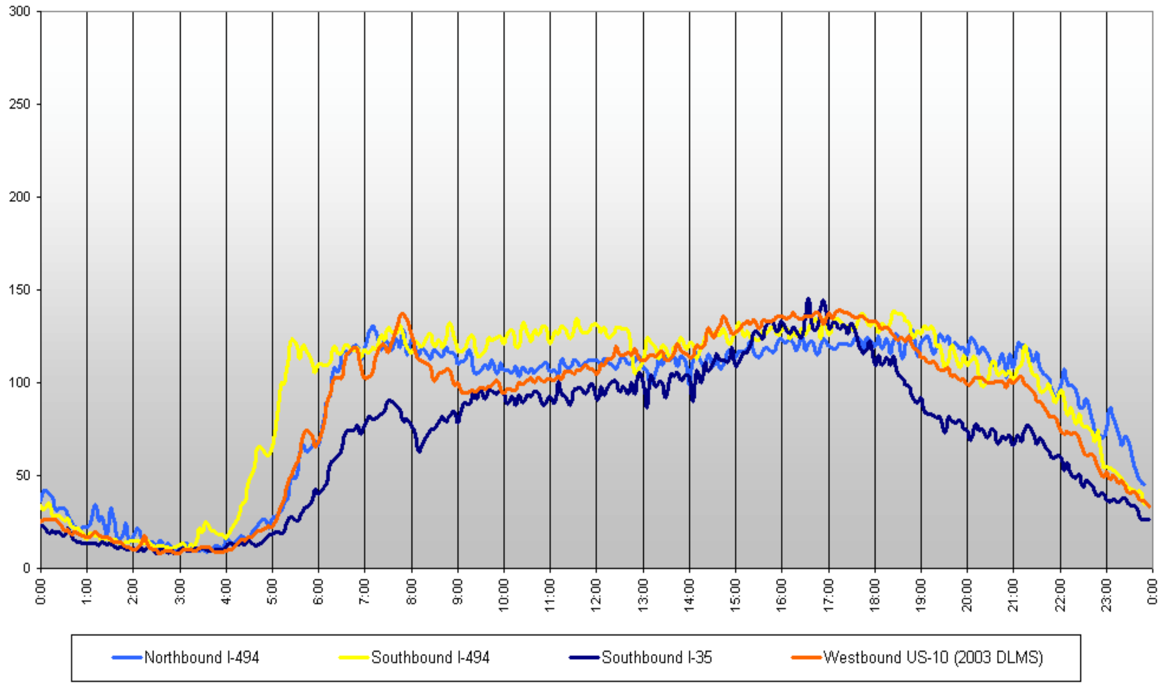


Figure 4.30: Traffic Volumes at the Entrance of the Construction Zone, Multiple Deployments

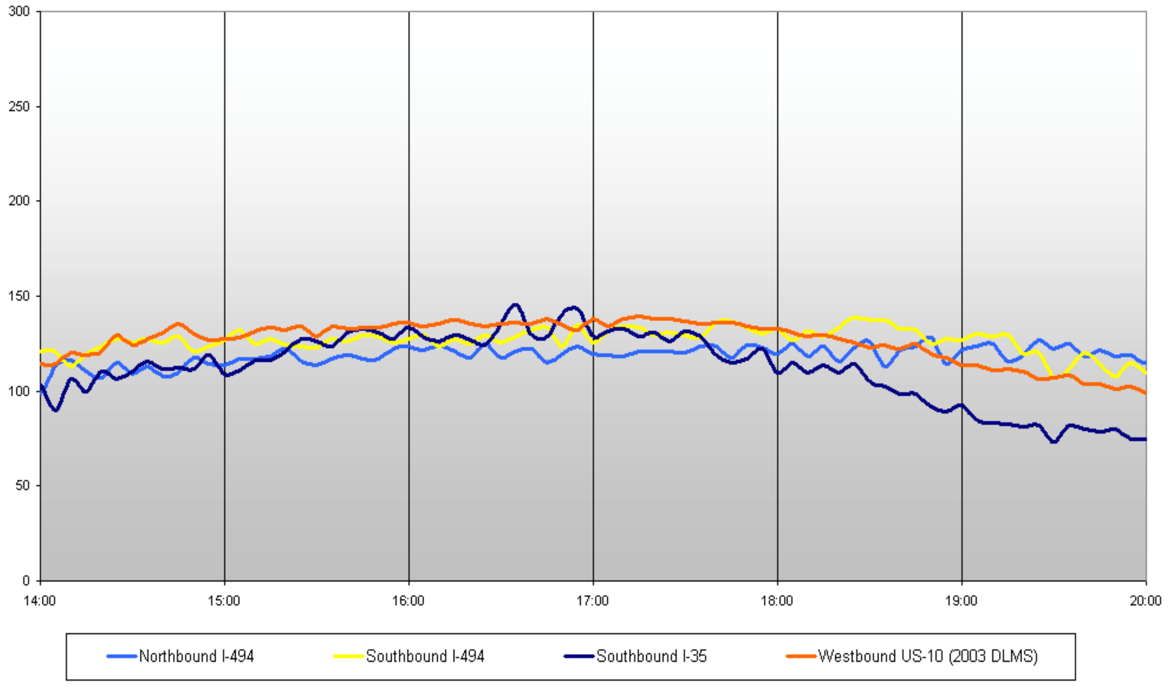


Figure 4.31: Afternoon Volumes at the Entrance to the Construction Zone, Multiple Deployments

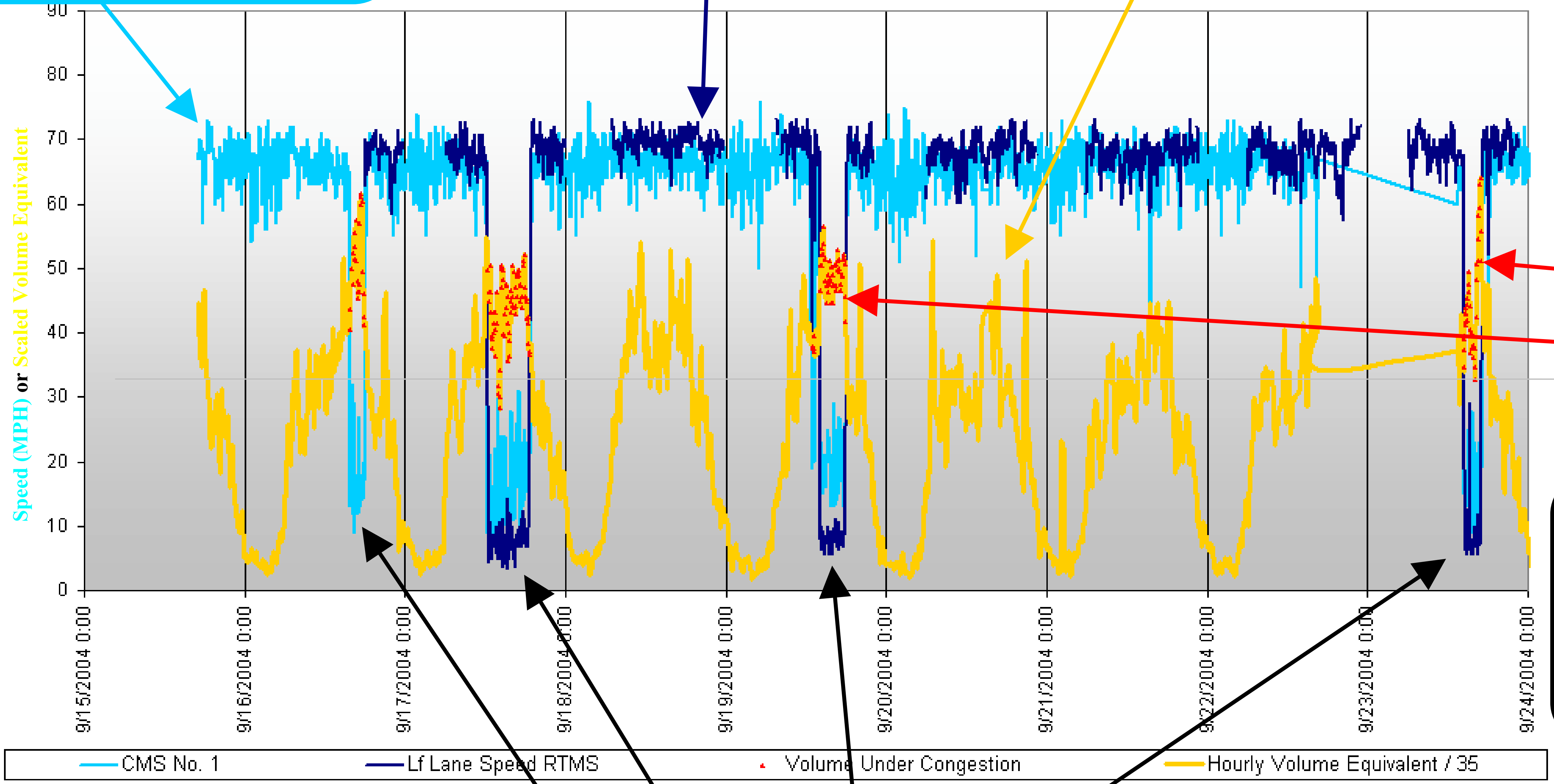
This color on the graph represents the average speed in MPH as calculated by the radar unit mounted on the Changeable Message Sign (CMS) over the sample interval.

Both CMS and RTMS detector speed information is graphed to determine if similar information was collected from two independent sources. Because these detectors were in relative close proximity to each other, both should read the same speed.

This color on the graph represents the average speed in MPH as calculated by the Remote Traffic Microwave Sensor (RTMS) unit over the sample interval.

Volumes below 15 vehicles per 5 minutes are filtered out due to the RTMS's inability to accurately calculate speeds under these very low volume conditions.

This color represents the scaled equivalent hourly volume. This was calculated by taking the 5-minute average, multiplying by 12 to get into an hourly equivalent and then dividing by 35 to make the graph fit on the scale with the speed. Reverse procedure to calculate the equivalent hourly volume at a particular time.



The vertical axis represents two different measurements. One is the speed (light and dark blue) in MPH. The other is the scaled hourly volume equivalent. See description for gold line.

The red points on the graph represent the hourly volume equivalents (see gold description) when the speed for the CMS radar dropped below 30 MPH at the CMS. This assumption was used to show the onset of congestion.

The horizontal axis displays time. Each major axis marking indicates midnight of one day. This graph currently shows nine days worth of speed and volume information.

These three regions would be representative of times where congestion conditions reached the deployment location of the RTMS detector. (The congestion condition was defined to be when the speed at the detector dropped below 30MPH). Notice that the volume (gold) is higher during this time and the speed (blue) has dropped significantly. These areas will be investigated in more detail in the report.

Figure 4.32: Example Graph to Show Traffic Conditions During the 2004 Evaluation Period

The amount of information displayed on the previous page's example speed/volume chart makes it difficult to decipher what is taking place during congestion periods. In order to clarify the information presented in the congestion periods, individual graphs shown in Figure 4.33 zooms in on four instances of abnormally low speed.

These three graphs show that as volumes increased, there came a point at which the speeds at the detector deteriorated dramatically. During this transition period, the DLMS activated and began instructing vehicles to use both lanes. (This system activation is shown by the black line, which rises to the value 60, signifying the activation of the system.) These three sets of graphs all have a unique similarity. The horizontal red line on each graph corresponds to the scaled hourly volume equivalent defined earlier in this report. The hourly volume equivalent for all system activations highlighted ranged from approximately 43 (1500 veh/hr) to 51 (1785 veh/hr). A demand of approximately 1500 veh/hr to 1785 veh/hr appears to be a threshold value of when congestion can occur. It should be noted, however, that every time the hourly equivalent demand reached this level, congestion did not form.

Because the system aggregates data into 5-minute periods, variations in the data over smaller time intervals cannot be seen. The arrival of a large platoon of vehicles combined with the uncertainties of driver merging behavior could cause drivers to slow in order to complete lane-changing maneuvers. This type of event could take place even when the hourly demand was under 1500-1600 veh/hr for that 5-minute period. This situation would have the potential to cause a queue, in effect slowing the rest of the traffic nearing the work zone. If traffic demand is near capacity, the queue can rapidly grow when more vehicles arrive at the end of the queue that can pass through the construction zone during that time.

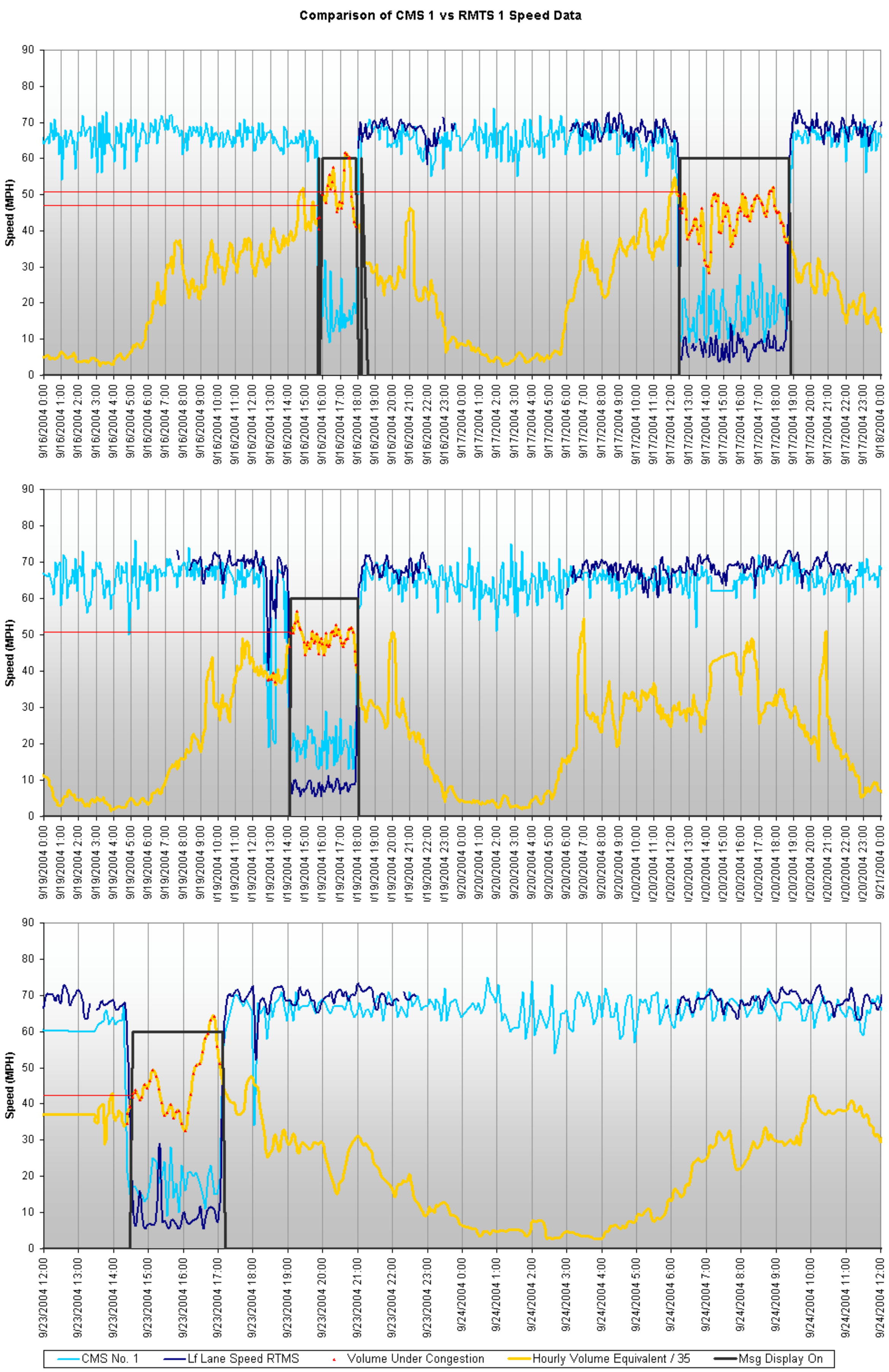


Figure 4.33: Comparison of CMS 1 vs RTMS 1 Speed Data

4.4.6 System Reliability

Overall, the operation of the DLMS was adequate. No extended outages or major problems were ever uncovered during the evaluation of this deployment. However, the data logger aspect of the system did not perform adequately enough to reinforce these assertions.

Figure 4.34 is an overview of data recorded during this one month period that highlights the sections of data that were either missing or had erroneous recordings from the ZoneManager system that controls the three CMS. The main RTMS controller did record its speed/volume information during most of these times but there is no information on the activation of the three CMSs. Note, missing segments in this data does NOT mean the system was not operating correctly. These are time periods where the data was not saved correctly or errors in the data logger occurred.

As indicated by the sections of "Missing Data" and "Erroneous Data" on the overall speed/volume chart, the system had a fair amount of difficulty recording its system state during this month long intensive investigation. Some of the missing data occurred because of the lack of storage capacity in the system and other unknown errors or bugs in the code contributed to other data recording problems. These errors affected the recording of the data, not necessarily any operations of the system. No system performance issues were uncovered, but it would be difficult to confirm or refute any claims of system performance without this log data. A data logging system that would record a week's worth of data easily and reliably would be a worthwhile benefit to be used to assess system performance and overall usefulness of a system on each deployment.

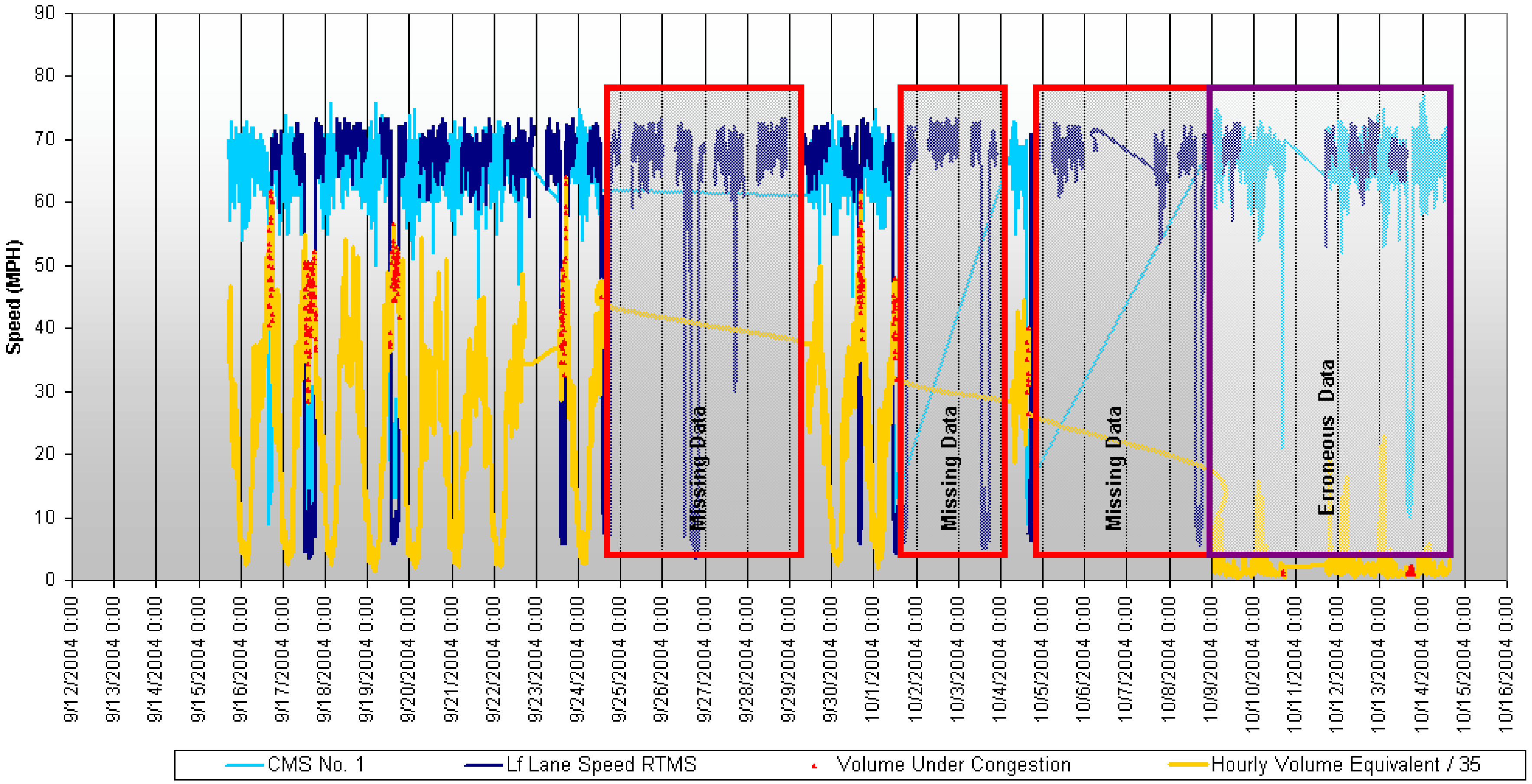


Figure 4.34: Comparison of CMS 1 vs RTMS 1 Speed Data

4.4.7 Travel Times

Vehicle travel times were not collected during this deployment of the DLMS because of insufficient baseline duration and lack of information on traffic conditions during this time. In addition, the location and length of the construction closure changed between baseline conditions and the main duration of the project. Travel time information under these conditions would not be a meaningful measure of effectiveness of the DLMS system.

5.0 Summary of Evaluation Findings for All Deployments

The four different deployments resulted in similar findings throughout all the work zone sites. The following subsections highlight the overall findings of the evaluations of the four deployment locations of the Dynamic Late Merge System.

5.1 Discontinuous Lane Use

As shown in the previous sections, the percentage of drivers utilizing the discontinuous lane during these four deployments increased dramatically when the CMS were activated. Most notable were the two deployments on north and southbound I-494. Especially during the heaviest demand, discontinuous lane use percentages increased to levels of upwards of almost 60% at sensor locations approximately a half-mile from the construction taper. This high percentage could come the fact that vehicles were observed making early merges at a variety of locations – leaving the space that was occupied by their vehicle open for the subsequent vehicle to fill. This pattern repeated, allowing more vehicles to use the discontinuous lane at these locations. Nearer the taper point, discontinuous lane use percentages dropped off to values between 30-40% during peak congestion times.

5.2 Queue Length

Even though these evaluations did not use a baseline condition of standard work zone traffic control to use as a comparison, vehicles were visually observed utilizing the majority of both lanes during congested periods. This pattern of lane use utilization resulted in a queue of nearly minimum length. However, it should be noted that there is a small but influential number of drivers who are unwilling to use both lanes. Some of these drivers have been observed to wait in a long single lane queue and other have been observed blocking vehicles from filling the discontinuous lane. With these exceptions, it appears that the DLMS does a good job of minimizing the length of the queue.

5.3 Driving Conditions

Despite the fact that, at the time of this publication, any information on incidents at any of the work zone locations is months from being available, the DLMS improves the overall driving conditions upstream of construction lane closures.

5.3.1 Incidents

Incident information will be added to any future evaluation of the DLMS.

5.3.2 Aggressive Driving

The DLMS allows drivers to fully utilize both lanes during periods of congestion. This system eliminates the confusion over lane use issues and the correct place to merge. These instructions should aid in eliminating aggressive driving conditions where vehicles with widely varying speeds are traveling in adjacent lanes or vehicles block the discontinuous lane to prevent vehicles from moving closer to the taper location.

5.3.3 Travel Times

Travel times were not investigated due to the lack of baseline conditions or because deployment characteristics changed. It should be noted that by minimizing the queue length, the overall distance traveled in congestion is reduced. Human factors studies have shown that drivers perceive the travel time to be shorter when the overall distance is reduced.

5.4 Total Volume

The maximum volume throughput within the single lane construction closure at deployment locations was nearly identical. Despite variations in road geometry, periods of congestion, and location within urban/rural areas, the maximum throughput within the single lane was approximately 1600 veh/hr. This threshold value was confirmed because congestion frequently formed when the demand exceeded approximately 1550-1700 veh/hr.

6.0 Considerations for Future DLMS Deployments

The following ideas are a summary of considerations to contemplate when launching new deployments of the Dynamic Late Merge System. Those suggestions that are agreeable to Mn/DOT could be summarized into a single guidance document or part of a work order contract.

6.1 CMS Positioning

One key finding from the various deployments over the summer of 2004 was the placement of the three CMS upstream from the taper. It is suggested that all CMS be placed on the shoulder or median nearest the discontinuous lane. This position makes the signs much more visible to the drivers who may have a tendency to leave the lane early instead of utilizing its full storage capabilities. The CMS closest to the taper point should be positioned adjacent to the last static merge sign. This position is advantageous because there is no contradiction in instructions from signs at two different locations. This placement also gives an additional buffer zone of distance to complete the merging procedure, which could encourage drivers to use this lane.

6.2 Data Archive Requirement

Determining the overall benefit of a traffic control strategy such as the DLMS requires a vast amount of data on the traffic conditions at various points along the road; the same type of data needed to control the operations of the system. While some of this data was saved at the request of Mn/DOT and the independent evaluator, data during all deployments was not recorded. It is suggested that part of the contract with equipment installations be a provision for requiring the system to archive data on volume and speed by lane along with an additional field that indicates whether the CMS messages were active. Reports could be sent via wireless connection to the contractor and then forwarded to the client as part of an operations report.

6.3 Potentially New Traffic Detection

During low volume conditions, the RTMS detectors have problems accurately reading traffic conditions. This is very similar to the problem experienced by loop detectors. Both loops and RTMS detectors use occupancy and a vehicle length constant to calculate an average speed. The different length vehicles are separated into separate bins and the RTMS has a difficult job performing this task when there are very few vehicles to use for readings. The end result is that the output speed is unreliable under certain conditions. Fortunately, the low volume conditions are not a concern for the DLMS with adequate logical programming. As new technologies come online, every effort should be made to ensure that the most accurate detectors are used as part of the DLMS to accurately read and record the rapidly changing traffic conditions.

Figure 4.35: Picture of RTMS Component of DLMS

6.4 Minimum Volume Demand

The data from these three deployment locations suggests that there is no need for a DLMS if there are no time periods during a construction project that would see demands in excess of 1500 veh/hr. For lane closures that anticipate traffic volumes above this threshold, a benefit/costs procedure should be examined to determine if these demands would be frequent enough to make deployment of the DLMS justified.

MINNESOTA DEPARTMENT OF TRANSPORTATION