Effectiveness of Dynamic Messaging on Driver Behavior for Late Merge Lane Road Closures

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ABSTRACT

Efforts to improve safety and traffic flow through merge areas on high-volume/high-speed roadways have included early merge and late merge concepts and several studies of the effectiveness of these concepts have been conducted, many using Intelligent Transportation Systems for implementation. The Iowa Department of Transportation (Iowa DOT) planned to employ a system of dynamic message signs (DMS) to enhance standard temporary traffic control for lane closures and traffic merges at two bridge construction projects in western Iowa (Adair and Cass Counties) on I-80 during the 2008 construction season. This presentation will summarize efforts to evaluate the effectiveness of the DMS system implemented on I-80 by the Iowa DOT. The primary objective of the efforts was to examine driver merging actions.

Data were collected over four weekends but only two yielded sufficient data for evaluation: one with two short periods of moderately impacted (transition) traffic flow and the other with an extended period of congestion flow. For both of these periods, a review of the data did not indicate a statistically significant impact on driver merging actions when the DMS messaging was activated as compared to free flow conditions with no messaging.

Unforeseen difficulties with data collection efforts also adversely affected the ability to draw statistically significant conclusions on the project. Examples of such difficulties include personnel safety issues associated with the placement and retrieval of counting devices on a high-speed roadway, unsatisfactory equipment performance, and insufficient congestion to activate the DMS messaging hampered efforts.

Key words: dynamic message signs—mobility—safety—work zones
INTRODUCTION

Safety and mobility for traffic traveling through work areas on high-speed, high-volume, multi-lane roadways has been a concern for transportation agencies for many years. Over the years, many improvements in temporary traffic control have dramatically improved work zone safety for motorists and workers alike, but efforts for enhancing both safety and traffic flow have continued especially where lane closure can result in significant speed reduction, congestion, and delay.

One area where improvement efforts have focused in recent years has been in the merging practices of drivers in advance of lane closures on multi-lane roadways. Two techniques has been implemented and studied: early merge and late merge concepts. The names are quite self-descriptive. For early merge, traffic is encouraged to merge from a closed lane well in advance of the actual closure to avoid confusion and congestion at the point of closure. This concept may be most effective for relatively low traffic volume applications. The late merge concept encourages drivers to stay in their lanes until the actual merge point and then alternate in proceeding to merge into the remaining open lane(s) with the goal of maintaining maximum volume accommodation as long as possible. A late merge concept may be more effective at higher traffic volumes.

The Iowa Department of Transportation (Iowa DOT) has employed a standardized single lane closure temporary traffic control system with stationary mounted static work zone signs. Occasionally with higher traffic volumes, significant delays and queue build-up has resulted and the Iowa DOT desired to evaluate a late merge concept using dynamic message signs (DMS) to improve traffic flow through lane closures and reduce possible rear-end collisions. In addition, these signs can also be utilized to provide information to drivers about potential traffic slowdowns and delays occurring several miles in advance, thus reducing confusion and some frustration.

The purpose of this study is to evaluate any possible changes in driver behavior from the use of DMS sign messaging during periods of congestion and to make recommendations about this system’s potential value to Iowa’s current temporary traffic control (TTC) practices for long-term lane closures on high-speed/high-volume roadways.

LITERATURE REVIEW

Relying on the Manual of Uniform Traffic Control Devices (MUTCD), the Iowa DOT has used consistent design standards for selection, sequence, and spacing of traffic control devices for lane closures on its rural Interstate system, and the traveling public has grown accustomed to this standard.

However, early studies by Geza Pesti and Patrick McCoy in Nebraska (Pesti et al.1999) have shown that in areas of lower “commuter” traffic, these types of static signing failed to adequately handle congestion periods. Moreover, the addition of non-dynamic messages was also found to cause confusion and frustration when no congestion was present and drivers’ expectations were thus violated. This study by Pesti et al. (1999) led to the concept of variable and dynamic message signs.

The authors’ continued research (McCoy and Pesti 2001) on that topic led to the conclusion that the dynamic late merge concept can be a great safety benefit during times of heavy congestion. Having the ability to change the messages for drivers to correspond to changes in traffic flow and/or speed should promote a smoother transition as congestion develops and traffic speeds are slowed. This concept should minimize crashes as well as the frustrations of drivers during those slowdown periods. The authors also
noted that selecting the most effective sign messages, types, and spacing seems to be a crucial element for each situation.

A 2004 study in Minnesota conducted by URS Corporation (URS 2004) concluded that the maximum volume throughput through single-lane construction areas on rural Interstates was approximately 1,600 vehicles/hour.

A more recent study in Virginia by Beacher et al. (2004) found a marked improvement of traffic flow when a dynamic late merge system (DLMS) was used, but only for a 3-to-1 lane reduction. No statistically significant change in the capacity was noted in a 2-to-1 lane reduction; however, little data were available for analysis. The study also noted that the percentage of heavy vehicles had a strong relationship to vehicle capacity or throughput, and a late merge concept became more efficient than the standard recommended MUTCD treatment as the percentage of heavy vehicles increased.

The Maryland State Highway Administration evaluated the effectiveness of dynamic late merge systems in highway work zone locations to measure the systems’ impact on vehicle throughput, volume distribution, and queue lengths. This testing utilized portable changeable message signs (PCMS) to display messages to motorists when the dynamic late merge system is active. Remote traffic microwave sensors (RTMS) were used to detect traffic conditions. Standard TTC signs were in place to inform motorists of the work zone and merging traffic when the dynamic late merge system was inactive. The PCMS boards were activated when the RTMS detected lane occupancies of greater than 15% and were deactivated if occupancy was below 5%. The results showed that the use of a dynamic late merge system can improve traffic throughput, balance lane volume distribution, and reduce maximum queue lengths. However, placement of the PCMS and static TTC must be correct or there will be an increase in stop-and-go maneuvers by motorists confused by the messages being presented (Kang et al. 2006).

In October 2008, the FHWA’s Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones (Luttrell et al. 2008) summarized the benefits of using TTS in work zones on five separate study sites in Washington, D.C.; Hillsboro, Texas; Kalamazoo, Michigan; Little Rock, Arkansas; and Winston Salem, North Carolina. Projects were accomplished between 1999 and 2006 and utilized different systems. However, with variable deployment schedules, data collection difficulties, and differing construction schedules, quantifiable benefits were difficult to assess at some sites, but a few showed some quantifiable benefits.

METHODOLOGY

With this study, the Iowa DOT desired to examine the potential benefits of using a system of speed sensors and DMS to enhance traffic flow through work zones. This system will be referred to as the DLMS. The observation sites were pre-chosen at two bridge replacement sites on Interstate 80 in western Iowa (Adair and Cass Counties). Interstate 80 in this area is a four-lane divided highway. DMS had previously been installed at these two sites for both directions of travel before this study commenced, except in the westbound lanes in Cass County. Therefore, it was determined this Cass County site would serve as a “control” location, with no DMS present. TTC for these projects consisted of complete closure of I-80 in the area of the bridge work with diversion of vehicles via median crossovers to sharing the opposing roadway in head-to-head travel with opposite direction traffic. This is a commonly used temporary traffic control scheme for this type of work in Iowa.
**Operation of DMS Equipment**

To properly collect data to analyze DLMS effectiveness, the process for activating these signs needed to be understood, and three possible modes of operation needed to be distinguished.

The DLMS consisted of several sign messaging units that were activated when the average of measured traffic speeds (see the sensors in Figure 1) dropped below pre-selected levels, indicating that free flow of traffic was hampered and congestion was beginning.

For most of the study period, the higher reduced average speed level or “trigger” was set at 50 mph for the first messaging, defined as *transition* flow for this study. Speeds below that trigger point activated the DLMS and turned on signs # 1–5 with their respective messages.

Speeds below the lower average measured speed of 30 mph were designated the *congested* flow category and activated the second messaging pattern, changing the messages on # 3–5 and turning on # 6 and 7 (shown in Figure 2), which were located 3.6 and 5.8 miles, respectively, in advance of the merge point.

![Figure 1. Relative positions of DMS 1–5, closest to merge point](image)

![Figure 2. Relative position of DMS 6 and 7, furthest from merge point](image)
Refer to Table 1 below for DMS messaging at the average speed thresholds.

<table>
<thead>
<tr>
<th>DMS Sign Identification</th>
<th>Traffic Flow Situations Message Presented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free Flow</td>
</tr>
<tr>
<td>EB-7</td>
<td>Off</td>
</tr>
<tr>
<td>EB-6</td>
<td>Off</td>
</tr>
<tr>
<td>EB-5</td>
<td>Off</td>
</tr>
<tr>
<td>EB-4</td>
<td>Off</td>
</tr>
<tr>
<td>EB-3</td>
<td>Off</td>
</tr>
<tr>
<td>EB-2</td>
<td>Off</td>
</tr>
<tr>
<td>EB-1</td>
<td>Off</td>
</tr>
</tbody>
</table>

Figure 3. Typical components of the DLMS—speed sensor, left; and DMS and video camera, right

The prime contractor for the entire lane merge “package” was Quality Traffic Control (QTC) of Des Moines, IA. ASTI of New Castle, DE provided the cameras, Wavetronics speed sensors, and cellular communications. The portable DMS signs were manufactured by Precision Solar Controls (PSC) of Garland, TX.

Placement of Counters

To assess the merging actions by drivers both with and without the DLMS activated, the researchers collected traffic speeds, volumes, and classifications at three selected spot locations approaching and within the merging areas. These positions (P1, P2, and P3) are shown in Figure 4 for a typical approach installation.
By using four properly spaced data collection road tubes at the P1 counter location, traffic volume, speed, and vehicle classification were obtained in both lanes simultaneously. Two properly spaced road tubes at the positions P2 and P3 were required to record the traffic volumes, speeds, and vehicle classifications in the lane being closed. Open lane data were determined mathematically at both the P2 and P3 positions as the difference in the total P1 information (both lanes), minus the data for the respective closing lane information at P2 and P3. The typical Jamar counter used at all these positions is shown in Figure 5.

Once sufficient data were obtained, driver behavior was to be defined by the percentage of drivers (by vehicle classification) that remained in the closing lane at P2 and P3 during the three possible DMS messages. Once the parameters were selected by the DOT to determine when the DMS sign messages would activate, all traffic data for both lanes were determined at P1, and the vehicle percentages for each desired element and situation were calculated and tabulated. The process of sorting, calculating, and tabulating the data was repeated for any time periods when the measured traffic speed fell below the trigger speeds at P2 and/or P3, which activated the DLMS. Final conclusions for the DLMS effectiveness were to be based on the locations of lane merges, as defined by significant shifts in the noted percentages of vehicles, by classification remaining in the closing lanes at positions P2 and P3. The vehicle classifications for this study were 2 axle (passenger vehicles), 3–4 axle (single unit trucks), and 5+ axles (truck-trailer combinations).
DATA COLLECTION

Data collection was conducted over four separate weekends. The data collection periods were from Friday at approximately 12:00 p.m. until the following Monday at approximately 8:00 a.m. Traffic volumes during these time periods were anticipated to be highest at two separate approaches to the construction sites on I-80 in Adair and Cass Counties.

The Jamar road tubes were installed by laying the tubes in the vendor specified setup pattern and using 4 in. wide road tape to hold the tubes to the pavement. At position 1, two tubes were laid across both lanes and two tubes across one lane. At positions 2 and 3, the tubes were only installed in the lane that was to be closed. Typical road tube installations are shown in Figure 6.

![Figure 6. Typical P1 (left) and P2 or P3 (right) installation](image)

Although Iowa DOT maintenance staff provided traffic control by temporarily closing a lane for installation and removal or the road tubes, placement of the cross road tubes at P1 locations and near the centerline at P2 and P3 locations was still potentially hazardous. To reduce the time of exposure to moving traffic, NuMetric Hi Star NC-97 plates were also installed, first as back-up devices, and finally as the only data collection units on the final weekend. These plates were centered in the middle of a lane and a cover of 12 in. wide road tape was placed over the top of the unit and the corners and edges were taped down with strips of 4 in. wide road tape (Figure 7).
Although cutting the tape and removing the road tubes from the pavement was a relatively quick operation, removal of residual tape from the tubes after use was a very extensive and laborious effort, although it was necessary for repeated usages. The NuMetrics plates initially used were older (1997) models and did not function well. However, new models acquired later did appear to provide usable data. Side-fire radar units, commonly known as “Wavetronics” in Iowa, were considered as an alternative for data collection, but experiences of other researchers have shown that in addition to requiring “binning” of the data into time intervals, these units cannot differentiate between lanes and may not record data accurately when two vehicles are parallel or in close proximity in adjacent lanes.

**Weekend Summaries**

*August 1–4, 2008*

Westbound Approach to Lane Closure in Cass County

No DMS signs were on site in this control location. Heavy-duty road tubes with Jamar traffic counters and NuMetrics electronic plates were both at this location for the observation period from Friday afternoon through the following Monday morning.

Westbound Approach to Lane Closure in Adair County

DMS signs were in place, with the trigger speeds preset with a 50 mph upper limit and a 30 mph lower limit for activating the sign messaging as was explained earlier. Heavy-duty road tubes were used for data collection.

*August 8–11, 2008*

Eastbound Approach to Lane Closure in Adair County

DMS signs were in place, with the trigger speeds preset for a 50 mph upper limit and a 30 mph lower limit for activation of messaging. In addition to the heavy-duty road tubes and Jamar counters, NuMetrics plates were again placed to gather data. The Jamar counter at location P2 did not function correctly, but the back-up NuMetrics plate did collect data for a substantial portion of this period. Therefore, the information gathered by both methods was compared and statistically tested for correlation and, when possible, the plate data was used to complete the information needed for analysis. Iowa DOT maintenance personnel reported that an extensive traffic backup occurred in the EB direction at Adair County on
Friday, August 8, from the early afternoon until approximately 9:00 p.m. and also again on Sunday, August 10, from about 5:00 p.m. to 9:00 p.m.

Eastbound Approach to Lane Closure in Cass County

DMS signs were in place with the trigger speeds preset for a 50 mph upper limit and a 30 mph lower limit for activation of messaging. Heavy-duty road tubes with Jamar traffic counters were used for this observation period from Friday afternoon through the following Monday morning. A severed road tube found at the P2 position on August 11 may have resulted when the metal end plate became embedded in a vehicle’s tires.

August 14–18, 2008

Eastbound Approach to Lane Closure in Adair County

To reduce activation times for the DMS signs, the Iowa DOT reduced the trigger speeds to a 40 mph upper limit and a 20 mph lower limit for activation of the messaging. A combination of heavy-duty road tubes and NuMetrics plates was utilized for data collection, but due to malfunctioning equipment and lack of traffic congestion periods, no usable data were obtained.

Westbound Approach to Lane Closure in Adair County

Trigger speeds for DMS sign activation were also used here, and again, a combination of road tubes and NuMetric plates were used for data collection. No usable data were collected from this observation period.

October 17–20, 2008

One final weekend was selected for data collection in anticipation of high traffic volumes generated by a popular sporting event. Only one site was used for data collection.

Eastbound Approach to Lane Closure in Cass County

Trigger speeds for the DMS signs were set with a 40 mph upper limit and a 20 mph lower limit for activation of the messaging. Only NuMetrics plates were used for data collection but the anticipated traffic congestion did not occur and no usable data were collected.

DATA SUMMARY

Overview of Data

Two short periods of transition speed messaging, one a period of 6 min involving some 211 vehicles, and a second period of 39 min involving about 1,038 vehicles occurred during the afternoon of August 1 at the westbound Adair County site. These events were the only evidence found of the initial DMS sign activation during a transition period (average speed falling below the upper trigger).

A congestion speed event during the weekend of August 8–11 was of sufficient duration (about 8½ hours) that approximately 5,000 vehicles were affected. Many of those vehicles indicated speeds of less than 10
mph at the P1 position, which is the location of the initial static TTC signing (Road Work Ahead) from the point of lane closure. This speed reduction and traffic back-up period extended from 12:30 p.m. to 9:00 p.m. on August 8.

There was also a reduced speed and queue build-up period with speeds less than 10 mph on the evening of Sunday, August 10, between about 5:45 p.m. and 8:15 p.m. This period could not be analyzed because one of the Jamar counters had stopped operating earlier and a full set of data for the period was therefore unavailable. However, the active DMS signs that were most distant (9.5 miles) from the closure point provided additional warning to over 8 miles of potentially queued traffic, which included vehicles that had not yet reached the static TTC signing. Therefore, the DLMS did provide additional information and degree of safety for drivers, despite the apparent minimal impact on driver behavior regarding merging actions.

A summary of collected late merge data is illustrated below in graphical form. These graphs show the percentages of vehicles in the closing lane at locations P1, P2, and P3, by classification under all the available DMS options. The information is first shown for the control situation in the top left graph, where no DMS signs were in place. In the top right graph all usable data was combined from all weekends where the DMS signs were in place but not activated (i.e., the speeds remained above the upper trigger speed). The graph on the bottom left shows the merging data for transition flows of traffic (DMS signs 1–5 activated). And finally, the graph on the bottom right illustrates the data for the flow of traffic during congestion periods with all DMS messaging activated.

Figure 8. Percentage of total traffic, by classification, traveling in the closing (merging) lane
Note that the percentage of early merging taking place by cars and heavy trucks is less with no DMS signs present than with them in place but not activated. This might indicate that the presence of DMS signs on the site promotes early merging; however, in comparing merging practices for all three vehicle classifications in all four DMS messaging options, little discernable impact from the DMS signs can be concluded.

**Comparison of Data Collection Systems**

During data review and analysis, some significant variations in the data were noted between collection systems. To assess these differences, a comparison of road tube and NuMetrics plate data was made with data from the Iowa DOT permanent automatic traffic recorders (ATRs) at a Cass County (Atlantic) site. No definitive conclusions could be drawn from this comparison and more evaluation on this concern is warranted.

**CONCLUSIONS AND RECOMMENDATIONS**

Collection of relevant project data for analysis proved to be challenging. In addition to safety issues with the placement and retrieval of counting devices in close proximity to moving traffic on an Interstate highway, unsatisfactory equipment performance and insufficient traffic congestion to activate the DLMS hampered data collection efforts. The numerous problems with the collection equipment used as detailed in the project report compromised efforts to gather uniform, consistent, and relevant data.

Although the Jamar road tube data collection system seemed to be the most consistent and reliable devices used in this study, the severe damage to the heavy-duty, “D” road tubes from high-volume commercial traffic resulted in incomplete data collection because of tube failures early in the collection process. If this study were to be repeated, a more resilient and reliable hold-down system than tape should be considered for the tubes. Additionally, a more secure method for retaining the necessary tube end plugs in place needs to be developed. Using flat metal plate hold-downs at both ends of the tubes (off the traveled way where possible) would be a recommendation, but fastening those plates securely to the pavement structure would remain problematic both in potential damage to the pavement surface and in the time of exposure to moving traffic during the installation process.

For less exposure to moving traffic during equipment placement and pickup, the use of the newer model NuMetrics plate counters (NC-200) should be strongly considered, especially if this system can provide accurate and reliable data. The newer plates, which have the capability of identifying individual vehicles, seem to provide improved versatility and reliability than the older (Hi Star NC-97) models.

Since neither of the project data collection systems were found to be entirely reliable and comparable, further comparison testing of data collection devices, including the Iowa DOT’s ATR counters need to be undertaken to determine comparative accuracy and the circumstances when each system is most appropriate for use. It is recommended to undertake a comparative study of traffic data collected by road tubes, plate collectors, DOT ATR units, side fire radar units, and manual counts. However, it should be noted that variation in data from the Jamar road tubes and NuMetrics plates, while statistically significant, were in fact quite minor and acceptable for most studies.

Although data collection equipment did not function properly at times and traffic volumes at the collection sites were not sufficient to activate DMS messaging during much of the study period, some conclusions can be drawn and recommendations made following analysis of the usable data.
Results of statistical analyses of the data from two weekends when traffic speed reductions and congestion were observed did not indicate any significant impact on driver merging behavior, regardless of vehicle classification, from the DMS messaging deployed. Other DMS sign deployment arrays and variation in messaging may yield other results.

It should be noted that DMS messaging conflicted with existing static TTC signing during full activation with static signing indicating merging and the DMS signs showing “Use Both Lanes.” This apparently conflicting information may have resulted in confusion for drivers and less compliance with the late merge option. Future deployments of a DLMS could consider and address this possible conflict.

It was concluded that traffic volumes on I-80 in the western Iowa study sites may be insufficient to adequately test the capability and effectiveness of the DLMS. Therefore, it is not possible to predict a lane capacity (volume per hour), at which a system like this should be deployed. The traffic volumes observed with this study were, for the most part, below that level. The use of this type of DLMS to encourage late merging and potentially enhanced traffic capacity might be considered for other, more heavily traveled segments of Iowa’s Interstate system where hourly volumes are closer to a single-lane capacity of approximately 1,500 vehicles per hour (vph). In fact, current DOT practice is to consider extraordinary mitigation for potential delay and queue build-up when traffic volume is expected to surpass 1,350 vph per lane.

Although the DLMS had been in service for several weeks before this study began, it was obvious that with a complicated system such as this, numerous technical difficulties can, and do, occur. Also, the small number of activations, or trigger events experienced at these sites (as recorded by both the data collectors and the e-mail notification system that was developed later to advise interested parties of potential traffic slowdowns) would make the DLMS a very expensive tool unless deployed where frequent activation would be assured. This also points to the need to evaluate the speed thresholds to trigger the DMS (50 and 30 mph for most of this evaluation).

Activation of advance warning messaging on the DMS units located most distant from the actual merge point apparently provided sufficient information to drivers during the congestion period on the August 8–11 weekend since no crashes were recorded or complaints received from drivers during that time. Therefore, using traffic speed sensors, real-time activated changeable message signs located in advance of lane restrictions could possibly be used to advise traffic of potential congestion ahead less expensively than a complete DLMS. The type of system deployed for this study should probably be reserved for roadways with considerably higher traffic volumes than usually exist at the locations evaluated in this study. With more frequent periods of reduced speeds and congestion, the DLMS would prove to be much more effective.
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