Evaluating the Benefits of Dynamic Message Signs on Missouri's Rural Corridors

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Evaluating the Benefits of Dynamic Message Signs on Missouri's Rural Corridors

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Missouri Department of Transportation
Organizational Results

by

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16. Abstract

Dynamic message signs (DMSs) are traffic control devices that provide real-time traveler information and are used for traffic warning, regulation, routing and management. DMSs on freeways in rural areas in southeast Missouri were evaluated. First, motorist surveys were conducted to obtain the perception of both commercial vehicle drivers and personal vehicle drivers towards DMSs. Second, field studies were conducted to assess the impact of DMSs in alerting drivers of an upcoming work zone. Third, the effectiveness of DMSs in diverting traffic to a detour route during a full freeway closure was investigated.

In the surveys, motorists said they were highly favorable towards DMSs. Motorists seemed to be very satisfied with how MoDOT was utilizing their DMSs in rural areas. Overall, 94% of the surveyed motorists said they took the action provided by the DMSs. Within the subgroups, 96% of work-related trip makers said they took action versus 89% of recreational trip makers. Nearly all truck drivers (98%) said they took the action advised by DMSs.

The work zone traveler information case studies were conducted at two construction work zones on I-55. DMSs displayed messages alerting drivers of the upcoming work zone. Average speed decreases of 3.64 mph and 1.25 mph were observed at the first and second sites and were found to be statistically significant, indicating a positive safety effect of DMSs.

The benefits of DMSs in detouring traffic during a full freeway closure were investigated for a case study of bridge closure on I-57 over the Mississippi River. Traffic traveling on I-57 between the states of Missouri and Illinois had to detour. Motorist surveys indicated that motorists were satisfied with traveler information provided by MoDOT through DMSs, trusted the accuracy and sufficiency of detour information provided on DMSs, and utilized the recommendations provided by the DMSs during the closure. The survey revealed that 41% of drivers relied solely on DMSs to get the traveler information.

A significant increase in traffic flow was observed on the detour route during the bridge closure. To isolate the benefits of DMSs from other traveler information modes such as newspaper, TV, and radio, traffic simulation was used. Several plausible percentages of traffic that relied solely on DMSs were evaluated. Depending on the proportion of drivers who chose to divert solely based on DMSs monetary benefits ranging from $5,163 to $55,929 are realized for the 3-day bridge closure.

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EXECUTIVE SUMMARY

Dynamic message signs (DMSs) are traffic control devices that provide real-time traveler information and are used for traffic warning, regulation, routing and management. DMSs are a major component of advanced traveler information systems implemented by state departments of transportation (DOTs). Several studies on the effectiveness of DMSs have been conducted for urban areas. Same is not the case for rural DMS deployments. In this project, DMSs on freeways in rural areas in southeast Missouri were evaluated. The evaluation procedure involved three steps. First, motorist surveys were conducted to obtain the perception of both commercial vehicle (truck) drivers and personal vehicle (e.g., passenger car) drivers towards DMSs. Second, field studies were conducted to assess the impact of DMSs in alerting drivers of an upcoming work zone. Third, the effectiveness of DMSs in diverting traffic to a detour route during a full freeway closure was investigated.

The motorist surveys were conducted at two truck stops in the study region. In the surveys, motorists said they were highly favorable towards DMSs, responding with very high scores on survey questions. Motorists seemed to be very satisfied with how MoDOT was utilizing their DMSs in rural areas. On a scale of 1 to 5 with 1 being strongly disagree and 5 being strongly agree, the average respondent scores were greater than 4 for majority of the questions. When motorists were separated into subgroups for analysis, there were some differences in mean scores in the “Vehicle Type” (between trucks and private vehicles) and “Trip Purpose” (between work and recreation) subgroups. These differences were significant for the “Signs Readable, “Easy to Understand,” and “Accurate” questions. The work trips and truck drivers tended to be more critical on questions related to the readability, ease of comprehension, and accuracy of the DMSs. This could be due to the increased attention toward DMSs when motorists were driving on official business and were in time critical situations such as in meeting arrival times. Since most commercial truck drivers work when they are in their trucks, there is likely a large correlation between these work trips and commercial drivers. Overall, 94% of the surveyed motorists said they took the action provided by the DMSs. Within the subgroups, 96% of work-related trip makers said they took action versus 89% of recreational trip makers. Nearly all truck drivers (98%) said they took the action advised by DMSs.

The work zone traveler information case studies were conducted at two construction work zones on I-55. One site consisted of a permanent DMS upstream of the work zone and the other site consisted of a portable DMS (or PCMS) upstream of the work zone. Both DMSs displayed messages alerting drivers of the upcoming work zone. Average speed decreases of 3.64 mph and 1.25 mph were observed at the first and second sites and were found to be statistically significant, indicating a positive safety effect of DMSs.

The benefits of DMSs in detouring traffic during a full freeway closure were investigated for a case study of bridge closure on I-57 over the Mississippi River. Due to the bridge closure, traffic traveling on I-57 between the states of Missouri and Illinois had to detour. Motorist surveys were conducted in the affected area to discover if motorists were aware of the bridge closure and detour, and to what extent they relied on DMSs to obtain traveler

information. Overall, motorists said they were satisfied with traveler information provided by MoDOT through DMSs, they trusted the accuracy and sufficiency of detour information provided on DMSs, and they utilized the recommendations provided by the DMSs during the bridge closure project. The average score on every question exceeded 3.5 (on a scale of 1 to 5) which was between the 'neutral' and 'somewhat agree' with responses on most questions being closer to 'somewhat agree'. Commercial vehicle (truck) drivers were more satisfied with the overall information dissemination process. Their average rating for every question was higher than the private vehicle drivers. Noteworthy among the responses was their high rating for the amount of trust in the suggested detours, utilization of the DMS recommendations, and sufficiency of the DMS information. Of the 109 motorists who responded to the question on how they knew about the bridge closure, 62 answered DMS, 38 TV, 15 radio, 12 newspaper, and 11 other means. Some respondents checked more than one option (e.g., DMS and newspaper). Further analysis revealed that 45 respondents checked ONLY DMS as the means used to learn about the bridge closure. Therefore, about 41% (45/109) of the driving population were aware of the bridge closure only through DMSs.

A significant increase in traffic flow was observed on the detour route (and corresponding decrease on US 60/I 57) during the bridge closure days. The percentage changes in the traffic flows for various movements are reported in Table ES1.

Table ES1. Percent change in the peak hour traffic flows during the bridge closure project

		Percent change in hourly flows (treatment-control)/control		
Location	**Movements**	**Passenger**	**Truck**	**Total**
I-55 @ US 60 (Exit 66)	**I-55 NB**	18% ↑	75% ↑	33% ↑
	I-55 SB	3% ↑	-10% ↓	-3% ↓
	I-55 NB to US 60 EB	-22% ↓	-73% ↓	-59% ↓
	I-55 SB to US 60 EB	-13% ↓	107% ↑	1% ↑
	US 60 EB	-4% ↓	-5% ↓	-4% ↓
	US 60 WB	-42% ↓	-83% ↓	-57% ↓
	US 60 EB to I-55 NB	14% ↑	85% ↑	19% ↑
I-55 @ Sprigg St (Exit 93)	**I-55 NB**	2% ↑	69% ↑	9% ↑
	I-55 SB	8% ↑	49% ↑	12% ↑
	I-55 NB to MO 74	-4% ↓	39% ↑	8% ↑
I-55 @ MO 74 (Exit 95)	**I-55 NB**	6% ↑	25% ↑	8% ↑
	I-55 SB	1% ↑	0%	1% ↑
	I-55 NB to MO 74	15% ↑	959% ↑	54% ↑
	I-55 SB to MO 74	-9% ↓	-21% ↓	-10% ↓
	MO 74 to I-55 SB	20% ↑	717% ↑	36% ↑

The impact of DMSs in alerting motorists of the bridge closure and detour route information was evaluated. To isolate the benefits of DMSs from other modes of traveler information such as newspaper, TV, and radio, traffic simulation was used. Several plausible percentages of traffic that relied solely on DMSs for traveler information were evaluated. Depending on the proportion of drivers who chose to divert solely based on DMSs, total travel time savings ranged from 35.4 hours (10% of drivers) to 394.4 hours (100% of drivers). These savings translated to monetary benefits ranging from $5,163 to $55,929 for the 3-day bridge closure project.

Value of time savings and operating cost savings for different percentages are plotted in Figure ES 1. As expected, the total savings increase as the percentage of drivers alerted by DMSs increases. The motorist survey revealed that 41% of drivers relied solely on DMSs to get the traveler information. At this market penetration level, potential benefits of $21,365 are realized for the 3-day project.

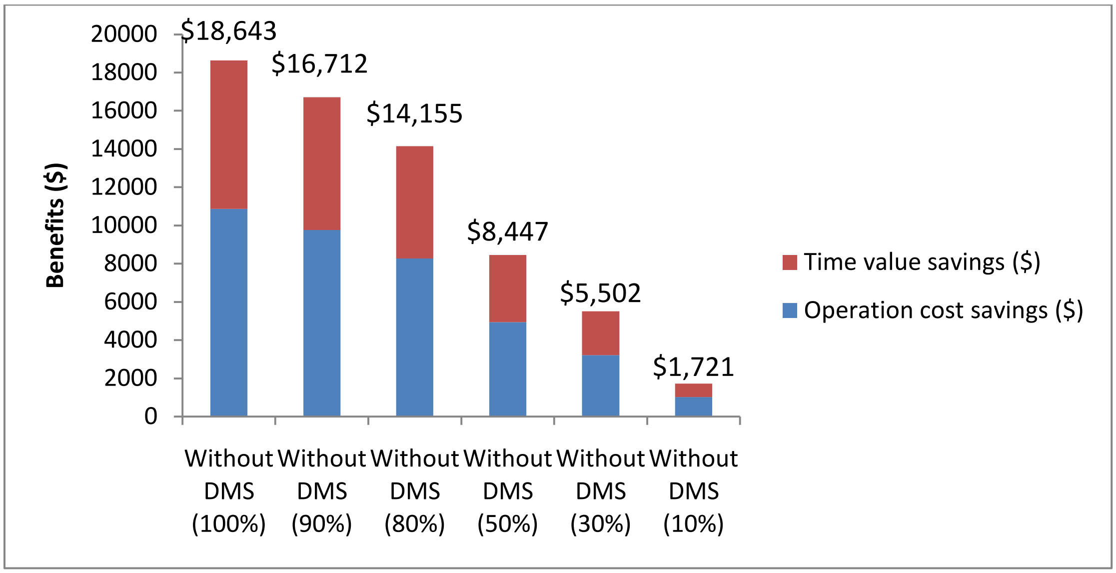

Figure ES 1. Monetary value of travel time and operation cost savings per closure

The benefits accrued over the life of deployed DMSs can be significant. For example, five full closure projects in one year could result in benefits ranging from $25,815 to $279,645. Additional monetary benefits of DMSs in alerting drivers of work zones, incidents, and inclement weather conditions were not estimated in this project.

DMSs are primarily intended for traveler information and not as an active safety treatment. Nevertheless, crash analysis was conducted using 5 years of data before DMSs and 1 year of data after DMSs deployment. The mean values for work zone and weather related crashes showed an increase in the number of crashes in the after period. This finding could be due to the existence of several confounding factors that were not accounted for in this research due to lack of data. For example, factors such as the increase in number of work zones, greater number of inclement weather events, increase in traffic levels in the study corridors, during the after period may have contributed to this increase. Given the limited amount of after period data available for the study the findings of crash analysis in this report must be considered as preliminary. In the future, crash analysis must be revisited when multiple years of after period data becomes available.

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1. BACKGROUND OF DYNAMIC MESSAGE SIGNS

Dynamic message signs (DMSs), also known as changeable message signs (CMSs) and variable message signs, are traffic control devices used for traffic warning, regulation, routing and management, and are intended to affect the behavior of drivers by providing real-time traffic-related information (Dudek 2004). DMS have become a very prominent aspect of advanced traveler information systems and have continued to see growth. The total investment by state departments of transportation (DOTs) in deploying DMSs was estimated at $330 million by 2002 (Paniati 2004). Dudek (2008) reported that 29 state DOTs in the US had a written policy or guidelines on the design and operation of CMSs. Example of a DMS displaying detour information to motorists is shown in Figure 1.

Figure 1. Picture of a dynamic message sign

The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA 2009) states that for traffic control devices (such as DMSs) to be effective five requirements must be met:

1. Fulfill a need.
2. Command attention.
3. Convey a clear, simple meaning.
4. Command respect from travelers.
5. Give adequate time for proper response.

Using the guidelines above messages can be intelligently formulated to warn motorists of emergencies, unexpected road or weather conditions, congestion, and child abduction alerts in the area. The DMS can also be used to provide other information including travel times, future work zone dates, or approved public service messages that may improve highway safety or traffic flow. Specifically, chapter 2L of the MUTCD provides standards and guidance for CMSs. The following are listed as possible applications of CMSs (FHWA 2009):

1. Incident management and route diversion
2. Warning of adverse weather conditions
3. Special event applications associated with traffic control or conditions
4. Control at crossing situations
5. Lane, ramp, and roadway control
6. Priced or other types of managed lanes
7. Travel times
8. Warning situations
9. Traffic regulations
10. Speed control
11. Destination guidance

Guidance on the operation of CMSs and design of messages has been developed by FHWA (Dudek 2004). The guidance document consists of detailed information on the principles of message design, length, formatting, dynamicity; and operations procedures and guidelines. The document is intended to assist practitioners in local and regional transportation agencies and state DOTs. In Missouri, like in other states, the DMSs are primarily used to provide real-time traveler information on traffic conditions to the traveling public. The MoDOT's Engineering Policy Guide (EPG) states, "DMSs are used to warn, regulate, route and manage traffic." The EPG provides guidelines on the basic requirements, message formats, acceptable use of words, and others.

A review of the research literature on DMS evaluations showed that majority of the DMS deployments by DOTs across the country are in urban areas with very limited rural deployments. This is not a surprise given the dynamic nature of traffic conditions in urban areas and the need to inform motorists of those conditions. The traffic volumes in urban areas are also a lot higher than in rural areas. However, DMSs offer several potential benefits in rural areas as well. They provide useful traveler information to motorists during incidents, work zones, road closures, inclement weather, evacuation situations, among others. The information not only makes the motorists more aware of the downstream traffic conditions but also encourages them to consider switching to alternate routes to save delays.

The USDOT's rural safety innovation program (RSIP) provides funds to improve safety on rural roadways. Missouri DOT was awarded a grant in 2008 to deploy DMSs and closed-circuit television (CCTV) cameras on rural segments of I-55, I-57, and US 60 in the southeast region of Missouri. Interstate 55 carries traffic from St. Louis to Arkansas and I-57 and US 60 carry traffic to and from Illinois. A map showing the DMS and CCTV camera locations is shown in Figure 2.

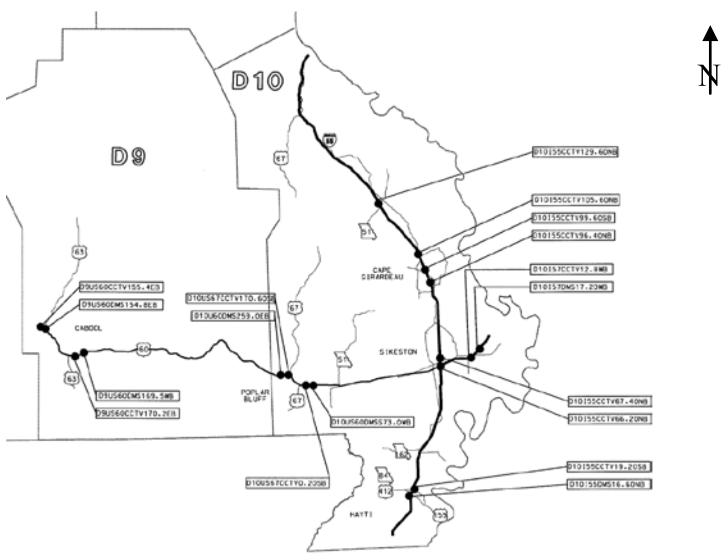


Figure 2 DMS and CCTV deployments on I-55, I-57, and Rt. 60 corridors
(Source: Preliminary construction plans provided by MoDOT)

The University of Missouri was selected to perform an evaluation of these DMS deployments in southeast Missouri. This report documents the results of the evaluation. Several tasks were carried out in order to perform the evaluation including motorist surveys, field studies at work zones and full roadway closures, simulation studies, and crash analysis.

This report is organized as follows. The objectives of the study are presented in the next section. A review of literature on evaluating the effectiveness and benefits of DMSs is presented in section 3. In section 4, the results of each task are presented in detail. Conclusions and recommendations are made in sections 5 and 6, respectively.

2. STUDY OBJECTIVES

1) ***To obtain the perception of motorists towards DMSs in rural areas***. This objective was accomplished by surveying motorists in the study area. Two rounds of surveys were conducted at gas stations and truck stops during the course of the project. The perceptions of both commercial vehicle (truck) drivers and personal vehicle (e.g., passenger car) drivers were obtained.
2) ***To evaluate the impact of DMSs in alerting drivers of an upcoming work zone.*** Field studies were conducted near two construction work zones on I-55 segments in the study area. One site consisted of a permanent DMS upstream of a work zone and the other site consisted of a portable DMS (or PCMS) upstream of a work zone. Both DMS displayed messages alerting drivers of the upcoming work zone. Speeds of vehicles were measured before and after the DMS to ascertain if drivers adjusted their speeds in response to the displayed message.
3) ***To evaluate the impact of DMSs in diverting traffic to a detour route during full freeway closure.*** A case study of a I-57 bridge closure for three days was studied to accomplish this objective. Traffic data was collected from CCTV cameras, pneumatic tubes, and additional video cameras before, during , and after the bridge closure. This data was then used to analyze traffic diversion and to build simulation models to estimate savings resulting from DMS deployment.

3. REVIEW OF STUDIES ON EVALUATION OF DYNAMIC MESSAGE SIGNS

This section reviews previous research studies that evaluated the impact of DMSs. These studies often involved collecting and analyzing traffic data (speeds, diversion rates) and driver surveys. The methodologies and lessons learned from previous studies were helpful in designing the current study.

Existing research on DMS evaluation can be separated into two categories – studies that collected and analyzed traffic data and studies that conducted stated preference surveys to obtain public perceptions towards DMS.

3.1 Evaluations based on traffic data

In terms of studies that used traffic data, Lee and Kim (2006) performed a work zone study on Interstate 15 in Devore, California to determine the impact of an automated work zone information system (AWIS). During an 18 day period, nine total kilometers of deteriorated truck lanes were rebuilt with 24 hour construction operations. The goal was to implement an automated work zone information system (AWIS) in order to increase work zone safety by reducing end of queue crash potential and provide speed advisories using DMSs. Four portable DMSs were located at different locations along Interstate 15, informing motorists to take local detours and warning them of the work zone. Traffic diversion was observed on two dates, with a conclusion that AWIS also successfully diverted traffic away from the construction work zone. The study showed an average northbound traffic reduction during nonpeak hours to be less than 7%, but up to 21% during peak hours. The ADT volumes decreased by 19% on Interstate 15 southbound and 16% on Interstate 15 northbound during the construction period, while only increasing ADT volumes on I-10 eastbound by 10% and 15% on I-215 southbound. It concluded the AWIS operation reduced traffic flow through the construction work zone and provided a safer work zone environment.

Hardy et al. (2006) performed a rural study on the use of DMSs to warn drivers of animals in efforts to reduce animal-vehicle crashes (AVCs). This study focused on the fact that most AVC studies relate to speed being positively correlated to AVC rates. The study was located between mile markers 311 and 330 on Interstate 90 in Montana. Two permanent DMSs and one portable DMS were used to administer one control message and three treatment messages, two of which alerted motorists of potential animals. The treatment messages included a generic traveler information message, a wildlife advisory message, and a more specific wildlife message stating the number of animals hit on the segment for the year. Results showed that the portable DMS during dark conditions had the largest effect on speed. Both DMSs possessing an animal warning message did have an effect on the speed of drivers, with the portable DMS showing a consistently higher reduction.

Yu et al. (2010) conducted an evaluation of real-time advanced traveler information systems on two routes leading to Ocean City, Maryland. DMS was explicitly accounted for by being a control variable. ATIS yielded significantly positive effects on throughputs for the system and when DMS were used they accounted for an increase of roughly 200 vehicles per hour (vph) on the entire system throughputs. The study concluded that DMS displaying real-time information leads to better use of roadway capacity during congested periods.

Li et al. (2010) performed a study to determine the effectiveness of portable changeable message signs (PCMS) for one lane, two-way work zones on rural highways in Kansas. The researchers placed one PCMS each at two rural work zone locations. They analyzed driver speeds with the PCMS on, off, and absent. Using t-tests the project concluded that the PCMS significantly reduced driver speeds. The effect was greater if the PCMS was on than off and showed the least reduction with an absent PCMS.

Horowitz et al. (2003) conducted an experiment that evaluated DMS on rural Interstate 94 and multiple parallel highways in Racine County, Wisconsin. This study was important because the area was largely devoid of other real-time information, there were clearly alternative routes, and had enough traffic to cause congestion during peak hours. The study focused on southbound traffic on a 12 mile stretch of Interstate 94. The signage system utilized five microwave detectors and four portable DMS. Alternative routes were marked using fixed signs. The study acknowledged while many drivers are responsive to traffic delay warnings, there are many more drivers that will not divert even if it would be beneficial. The study concluded that during peak periods, diversion rates were between 7% and 10% of freeway traffic.

Foo et al. (2008) conducted a study over a system of 27 DMSs upstream of several collector transfer locations on Highway 401 in Toronto, Canada. Their effort focused on extracting the dynamic impacts of DMS on diversion rates using three years of loop detector data. The most significant findings from this research project were that drivers who notice a message change are more likely to divert. It also revealed that the DMS effectiveness was most effective within 10 minutes of the message change.

Schlaich (2010) conducted a study to determine the effects of DMS and broadcasted traffic news on route choice behavior in Germany by using mobile phone trajectory data. Maximum-likelihood estimations were used to determine the influence of DMS and the broadcasted traffic news. Regarding DMS, the study showed that roughly 30% of drivers change their standard route and drivers do not analyze or question the reason for the route recommendation.

3.2 Evaluations based on stated preference surveys

Al-Deek et al. (2009) performed a study involving the impact of DMS on satisfaction and diversion of toll road motorists. Stated preference surveys were distributed randomly to toll road users in the central Florida area to evaluate DMS performance relative to other available traffic information. The stated preference surveys included demographic information, trip characteristics, the user's source for acquiring traffic information on toll roads, and the perception of benefits and satisfaction from the DMS information. The surveys were handed out in two phases. In the first phase called pre-deployment, there was only one operational DMS on the four toll roads being examined. In the second phase or post-deployment, 29 DMS were operational on the four toll roads. They found the accuracy of travel time information was more important to users in pre-deployment than post-deployment. It was also discovered that special event information became more important towards overall satisfaction in post-deployment.

Lee et al. (2005) applied fuzzy set theory to evaluate drivers' perceptions of variable message signs. The researchers used data from two stated preference surveys, one performed by the Pennsylvania Transportation Institute and one by the researchers. A set of 322 quality measures were calculated, and aggregated to a solitary number using the arithmetic fuzzy mean.

Peeta et al. (2001) built logit models for a stated preference survey data to determine how content may alter a driver's choice to divert routes in northwestern Indiana. The survey consisted of 248 respondents asking drivers their willingness to divert for 8 independent message scenarios on a 5 point Likert scale. The key findings included revealing a difference between truck and non-truck drivers, and message content plays a significant role in improving system performance if accurate information is provided.

Peng et al. (2004) performed a study in Milwaukee regarding motorist response on arterial VMS. The survey consisted of 306 responses asking 14 different questions concerning the motorists' driving behavior, demographic information, and attitudes toward VMS. An ordered logit model was created to determine the correlation between a motorist's attitude toward the VMS and willingness to divert due to information provided by the VMS. The study found that there was a clear but not strong correlation for this phenomenon, and drivers were particularly inclined to divert routes if they would save time or avoid congestion.

Chatterjee et al. (2002) completed a study analyzing the driver response to VMS information in London notifying motorists of planned events and network issues. Three surveys were disseminated to the public. The first inquired about attitudes and responses to the VMS, the second asked motorists how they would respond to different VMS messages, and the third asked motorists how if they would divert to an "Immediate Warning" message. London residents believed that VMS could be useful and were in favor of investing in VMS. Using a logistic regression model confirmed that location of the incident and message positively reinforced motorists' willingness to divert. Finally, the actual results of diversion were roughly 20% of the rate predicted from stated preference survey data.

Benson (1996) performed a study involving 517 respondents in the Washington, D.C. area to determine attitudes and responses to VMS. This study reinforced the fact motorists prefer more detailed and up to date information that is reliable and easy to understand. The study also stated that demographic information had little to do with motorist attitudes on VMS, except in the case of education level.

Wang et al. (2009) investigated the effects of different messages displayed on DMSs in Rhode Island. A web based survey asked respondents about their preference of DMSs' display, frame changes and graphic integration. It also asked the respondents what caused them to slow down. Speeds were collected and analyzed 5 minutes before and after messages were displayed on I-95. This data revealed that drivers slowed down in more than half the cases, especially when a danger message was displayed. The survey concluded that elder drivers were more likely to slow down in response to DMSs, and text-only messages were preferred over graphic-integrated and graphic-aided messages.

To summarize, the above studies have performed a variety of unique DMS studies using a variety of methods. Some studies have utilized t-tests to determine the effect of DMS on speeds, used methods such as logistic regression and fuzzy sets to analyze survey data, and both stated and revealed preference studies on the diversion rate effects of DMS. The study locations reported in the literature have been predominantly from urban areas.

4. RESULTS OF STUDY TASKS

Task 4.1. Survey of Motorists in the Study Corridor

Formulation of Survey

Four methods of distributing surveys are commonly used in transportation studies - mail-back, telephone, web-based, and on-site (in-person). The on-site survey option was preferred over the other three types in order to obtain the perceptions of both local residents and visitors who travel on the study corridors. Also, commercial vehicle drivers may not reside in the study area and hence may be missed in any mail-back/telephone surveys of households in the area. The benefits of an on-site survey include lower cost and a high sampling rate. On-site surveys also offer the benefit of obtaining a high response rate and also the option of interacting with the respondents (e.g., providing further clarification on a question).

Thus, an on-site survey was designed to reveal insights into how motorists perceive the usefulness of DMS. First, motorists were prompted to answer questions involving gender, age, residency, vehicle type, and trip purpose. These questions helped to identify specific driver behavior among each group. Second, nine questions specific to DMS were presented to motorists based on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." Likert scales and demographic based questions are commonly used in many transportation surveys (Peeta et al. 2001, Edwards and Young 2009, Mounce et al. 2007, Tennessee DOT 2011). The questions are listed below.

1. The signs were clearly readable.
2. The information provided was easy to understand
3. The information provided was accurate
4. I had the opportunity to perform the action provided by traveler information.
5. The information provided was specific enough for you to make better decisions.
6. I feel that the information provided for better overall safety.

7. I am satisfied with the information provided by the dynamic message signs.
8. I reduced my speed when the sign warned me of a safety concern.
9. I had to slow down to be able to read the message.

The final portion of the survey asked motorists if they took the action advised by the DMS sign. If they had, they were given the option of "Slow Down," Change Lane," "Divert Route," or "Other."

Surveys were deployed on August 11th, 2010 at two different locations along Interstate 55 in the study area. The first location was a gas station located at the Perryville Exit 129 off I-55, and the second location was at Exit 91 just south of Cape Girardeau near Cape Girardeau Regional Airport.

Since this was a qualitative survey determining the minimum sample size for the survey was not pursued. Typically, for minimum sample size computations value of the standard deviation of the measured variable is needed along with the acceptable standard error. The intent of the survey was to obtain the perception of motorists and not to measure the value of any specific variable. Therefore, the minimum sample size computations could not be computed for this survey. Instead, a sample size of 200 was chosen based on the resources available in the project. Based on the reviewed literature this number was reasonable.

A team of four members, two at each location, had a total of 200 surveys to distribute between these two locations. A total of 74 surveys were collected at the Perryville exit, while 124 were collected at the Cape Girardeau exit. A total of 198 surveys were analyzed for this project. Not all 198 surveys were used in each group analysis because some questionnaires were not fully completed. For example, some respondents chose to not answer their age or residency. It is also noted that on average 1 out of 4 private vehicle drivers that were approached responded to the survey and 1 out of every 3 commercial vehicle (truck) drivers responded to the survey. Therefore, the number of people that were asked to complete the survey was three to four times higher (between 600 and 800 people).

Survey Results

The survey responses were analyzed to gain insights into the driver perceptions of DMS. Mean values of responses were computed and cross-tabulated for different subgroups. In table 1, the survey data is summarized into four subgroups – gender, trip purpose, vehicle type, and residency. The mean overall score for each question are also reported in the last column of the table.

Table 1 shows that the difference in means is more evident in the "Vehicle Type" (between trucks and private vehicles) and "Trip Purpose" (between work and recreation) subgroups. There is quite a difference among the "Signs Readable, "Easy to Understand," and "Accurate" questions. The work trips and truck drivers tended to be more critical of these three questions. This could be due to an increased attention toward the sign when the motorist is driving on official business and in a time critical situation such as meeting a time deadline. Since most commercial truck drivers are working when they are in their trucks, there is likely a large correlation between these two subgroups.

One interesting finding is the number of respondents that took the action provided by the DMS. The compliance rate seems exceptionally high, and a revealed preference study would help to confirm or deny the stated answers.

Table 1. Mean responses for all subgroups and DMS action responses

Survey Questions	**Gender**		**Trip Purpose**		**Vehicle Type**		**Residency**		**Overall**
	Male	Female	Work	Recreation	Truck	Private	Local	Visitor	Total
Signs Readable	4.58	4.38	4.51	4.68	4.46	4.63	4.60	4.52	4.55
Easy to Understand	4.50	4.43	4.44	4.66	4.38	4.60	4.58	4.42	4.49
Accurate	4.37	4.28	4.29	4.57	4.18	4.51	4.43	4.29	4.36
Opp. To Perform	4.21	4.05	4.14	4.28	4.11	4.22	4.16	4.20	4.17
Better Decisions	4.45	4.33	4.39	4.58	4.37	4.50	4.43	4.45	4.40
Better Safety	4.54	4.40	4.48	4.62	4.45	4.57	4.50	4.56	4.51
Satisfied w/ Info	4.41	4.23	4.35	4.47	4.32	4.44	4.41	4.35	4.37
Reduced Speed	4.51	4.38	4.48	4.55	4.48	4.53	4.50	4.52	4.49
Slowed to Read	2.67	2.85	2.65	2.77	2.56	2.79	2.64	2.74	2.69
Statistics	**Gender**		**Trip Purpose**		**Vehicle Type**		**Residency**		**Overall**
	Male	Female	Work	Recreation	Truck	Private	Local	Visitor	Total
Took Action	94%	95%	96%	89%	98%	92%	94%	94%	94%
Total Surveys	156	40	141	53	82	112	104	89	198

*Highlighted numbers indicate results were significant at a 10% significance level

Overall, the mean response score was extremely high. Motorists seem to be very satisfied with how MoDOT is utilizing their rural DMS. It must also be mentioned that the “Slowed to Read” question is much lower than the other scores. Since slowing down to read information on a DMS is not desirable, a lower score on this question (1 being strongly disagree and 5 being strongly agree) is indicative of drivers not having to slow down just to read the sign. The results of Mann-Whitney U test (Washington et al. 2011) indicated that only the question on accuracy of information provided was significant for vehicle type and trip purpose subgroups at a 10% significance level.

Task 4.2. Evaluation of Driver Response to DMS Upstream of a Work Zone

State DOTs strive to improve the safety at construction work zones on roadways. Informing motorists about an upcoming work zone would increase the alertness of drivers and hence improve the safety of both motorists and workers. Two case studies were conducted to measure the driver response to DMS alerting them of an active work zone at a downstream location. Vehicle speeds were measured before and after drivers read the DMS. Depending on the message that is being displayed, drivers will react differently toward different DMS messages (Benson 1996, Chatterjee et al. 2002, Wang et al. 2009). Statistical tests were used to test the significance of the observed changes in speeds resulting from DMS use.

Figure 3. DMS used at the Perryville site

Data was collected at two locations along the I-55 corridor. The first data collection date was on Friday, June 25th, 2010. A permanent DMS was located at mile marker 129.6 on I-55 near Perryville, Missouri and displayed the message "ROAD WORK AT MM 117 EXPECT DELAY" (see Figure 3). The second data collection date was Tuesday, August 10th, 2010. A portable DMS (PCMS) was placed at mile marker 119.5 displaying the message "TWO WAY TRAFFIC AHEAD / USE CAUTION." The posted speed limit was 70 mph at both sites.

Table 2. Mile markers for speed measurement devices

	Date	Upstream MM	Downstream MM
Case study 1	6/25/2010	134.8	129.6
Case study 2	8/10/2010	120.9	119.5

At each site, two cameras, one upstream of the DMS and one immediately after the DMS, were set up to capture speeds before and after the DMS. The first camera captured speeds before the DMS was visible, and the second camera captured speeds after the drivers saw the DMS and had the opportunity to react after reading the message on the DMS.

The placement of cameras for collecting speed data are shown in Table 2. Note the mile markers are much closer for August 10th. This should not affect the data because the upstream cameras were both far enough away from the DMS. The MoDOT DMS policy guide (MoDOT 2010) and MUTCD (FHWA 2009) state that for a 55 mph speed zone or higher, the sign should be visible from 0.5 miles and legible from at least 800 feet for normal daylight conditions. The upstream speeds were measured at 1.4 miles (7392 feet) away from the DMS, thus drivers were uncertain of the message displayed. Although one may argue that if drivers noticed the presence of the sign it could have had an early impact on their speed.

A radar speed gun was used to collect a sample of speed data at both upstream and downstream locations. This sample data was used for calibrating the speed extraction process from video data. Speeds were derived from the video using forty-foot long virtual speed traps derived from known distances recorded on video. The recorded temporal resolution was high and involved 29.97 frames per second or 0.0334 seconds between frames.

A total of 101 minutes were recorded at the first date and included 975 vehicles upstream and 962 vehicles downstream. The second date included 167 minutes of video, and 1137 upstream vehicles and 1132 downstream vehicles. This provided a sufficiently high sample for analysis using both t-tests and F-tests (Washington et al., 2011).

Table 3 presents the number of vehicles, average speeds for each vehicle type, truck percentage, and p values for both t-tests and F-tests for each date. Except for trucks viewed in isolation on June 25, there was a statistically significant drop in average speeds for private vehicles, trucks, as well as the combined case (private vehicles and trucks). For the combined case, the speed decrease of 3.64 mph on June 25th was more pronounced than the 1.25 mph decrease witnessed on August 10th. These results indicate that DMS has a positive effect on drivers' speeds upstream of work zones on rural uncongested four-lane interstates.

Table 3. Speed statistics for the work zone case studies

Speeds and Variance by Vehicle Type, Truck %, and Vehicle Totals for Case Study 1

Upstream Average Speeds, Variance, and Truck %

Truck Average Speed =	71.75 (32.8)*	Mph	Truck % =	15.90%
Private Vehicle Avg. Speed =	75.07 (34.5)	Mph		
Combined Average Speed =	74.62 (35.5)	Mph	Veh. Total =	962

Downstream Average Speeds, Variance, and Truck %

Truck Average Speed =	70.63 (33.9)	Mph	Truck % =	14.30%
Private Vehicle Avg. Speed =	71.04 (24.5)	Mph		
Combined Average Speed =	70.98 (23.0)	Mph	Veh. Total =	975

Vehicle	P Value		
	t-test	F-test	Speed Diff.
Trucks	0.113	0.113	1.12
Private	0.000	0.000	4.03
Combined(Trucks + Private)	0.000	0.000	3.64

Speeds and Variance by Vehicle Type, Truck %, and Vehicle Totals for Case Study 2

Upstream Average Speeds, Variance, and Truck %

Truck Average Speed =	67.20 (17.30)	Mph	Truck % =	22.90%
Private Vehicle Avg. Speed =	71.73 (19.73)	Mph		
Combined Average Speed =	70.69 (22.80)	Mph	Veh. Total =	1132

Downstream Average Speeds, Variance, and Truck %

Truck Average Speed =	64.75 (16.48)	Mph	Truck % =	23.10%
Private Vehicle Avg. Speed =	70.89 (19.53)	mph		
Combined Average Speed =	69.44 (25.62)	mph	Veh. Total =	1137

Vehicle	P Value		
	t-test	F-test	Speed Diff.
Trucks	0.000	0.000	2.45
Private	0.000	0.005	0.84
Combined (Trucks + Private)	0.005	0.000	1.25

*Variances are presented in parenthesis

Task 4.3. Evaluation of DMS Effects in a Full Freeway Closure Project

One objective of this study is to evaluate the impact of DMS in diverting traffic to detour routes in the event of downstream incidents, lane closures, or congestion. The low traffic volumes in the rural study corridors means that most of the capacity reductions (due to incidents, lane closures) does not necessitate traffic to divert to other routes. This is a key difference between DMS evaluations in urban and rural areas. For example, Table 4 shows the low average daily volumes in Southeast Missouri for the busiest day, Friday. Finding events that necessitate traffic diversion is more challenging in rural areas than in urban areas.

Table 4. Average daily traffic (ADT) in the study area (on a Friday in June 2010)

Freeway	County	Average Daily Traffic (ADT) (06/12/2010)
I-55 NB (MM 105.7)	Cape Girardeau	10,479
I-55 SB (MM 91.8)	Cape Girardeau	10,488
I-55 NB (MM 2.8)	Pemiscot	11,861
I-55 SB (MM 205.5)	Pemiscot	9,634
I-57 NB (MM 7.5)	Mississippi	9,033
I-57 SB (MM 11.5)	Mississippi	9,261

One event that would require traffic to divert to alternate routes is a full freeway closure. In that event, drivers do not have a choice but to divert to a detour route to reach their destinations. One such event occurred during the study period. The Illinois DOT decided to close Interstate 57 crossing over the Mississippi river in Missouri for a period of 3 days from August 16, 2011 to August 18, 2011. All lanes on the bridge were closed to traffic in both directions. The full closure provided an efficient way for the contractor to make bridge repairs. A map of the location of the bridge closure is shown in Figure 4.

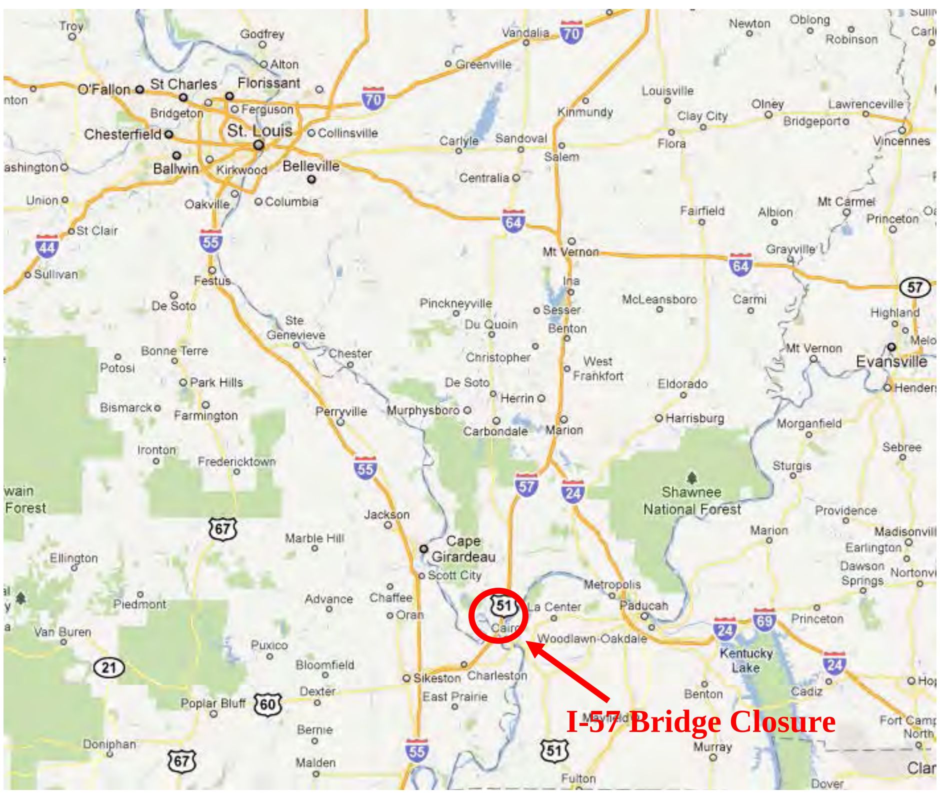


Figure 4. Location of I-57 Bridge Closure Project

The bridge closure project impacted traffic from and to Missouri. MoDOT developed an advanced notification plan informing motorists more than two weeks prior to the planned bridge closure. Figure 5 shows the two signs used by MoDOT (one permanent DMS and one temporary PCMS) for alerting motorists. Media outlets such as news releases were also issued two weeks before the bridge closure.

On the days of bridge closure, MoDOT implemented an incident response plan (see Figure 6). The plan included the use of permanent DMS located on the study routes (I-55, I-57, US 60), temporary PCMS, and static signs. Clear instructions on the detour route were provided at several key locations through these signs thus providing sufficient advance notice for en route drivers.

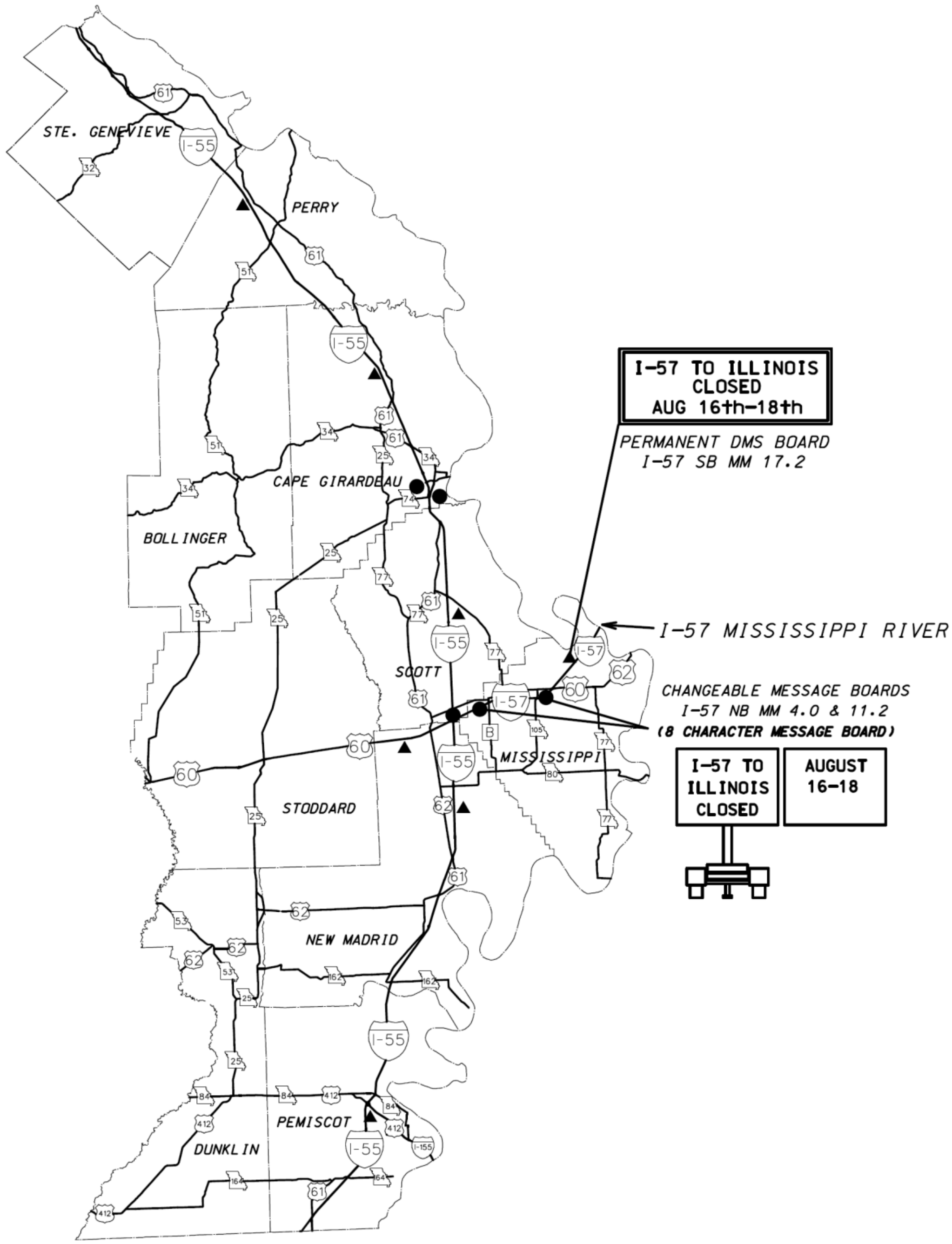


Figure 5. Map showing the DMS use for advanced notification of the I-57 bridge closure

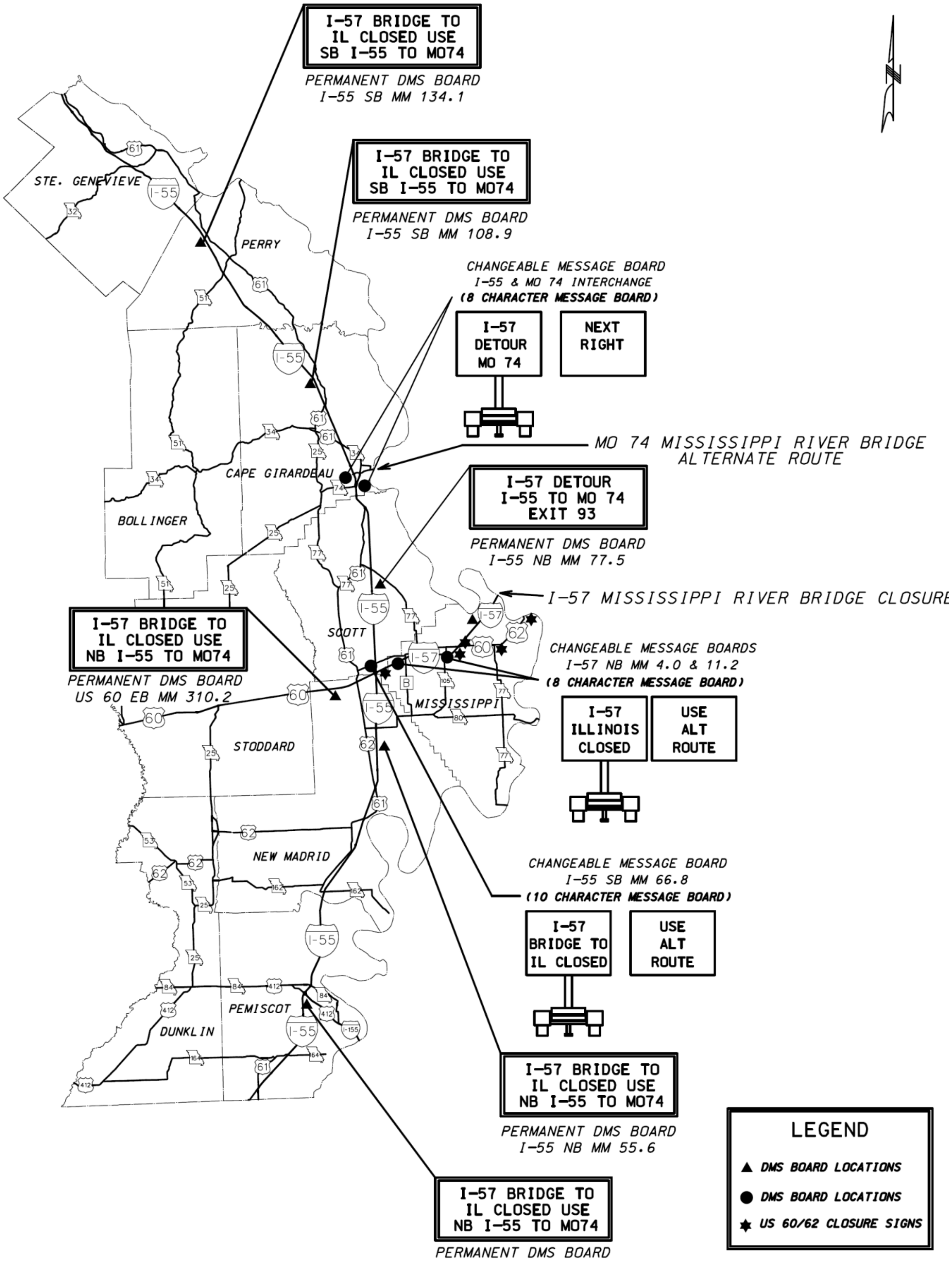
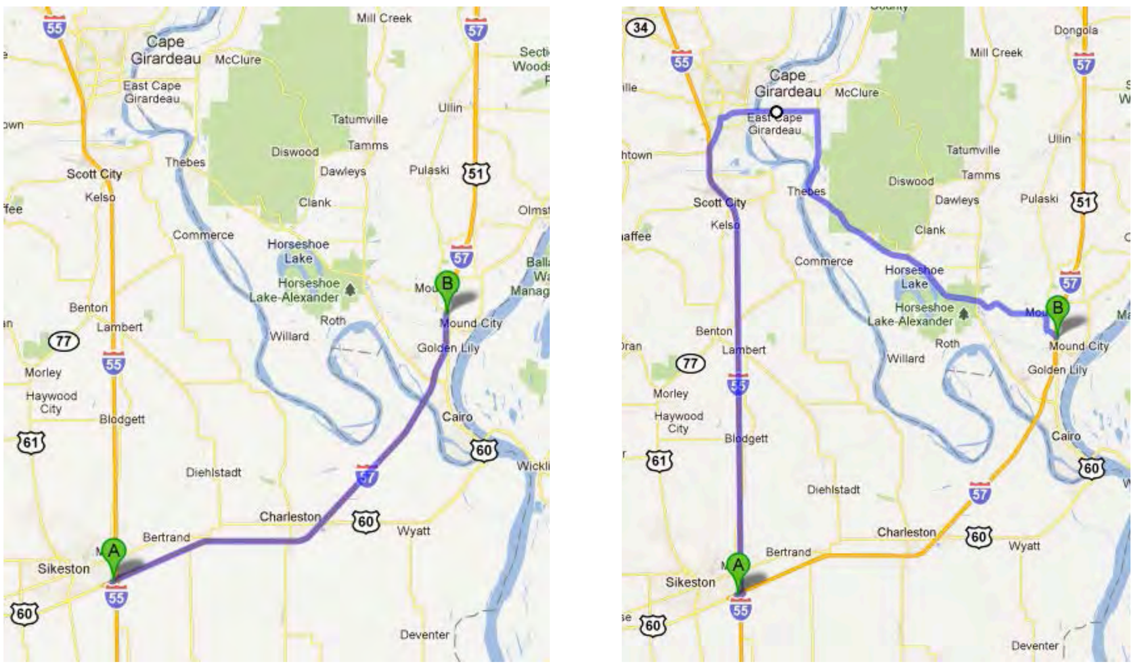


Figure 6. MoDOT's incident response plan for the I-57 bridge closure

Figure 7 compares the I-57 route and the detour route recommended by MoDOT for a trip between Sikeston, Missouri, and Mound City, Illinois. With the detour, the northbound traffic on I-55 that would normally use I-57 to travel to Illinois would continue north to Cape Girardeau and take MO-74, then IL-146, and IL-3 to I-57. Same detour route (in the opposite direction) is used by the southbound traffic coming from Illinois. The detour route adds about 38 miles to the trip length. This route was the best available alternative for traffic. Expecting an increase in traffic volumes on the detour route, MoDOT encouraged drivers to consider other alternate routes. However, there were not many additional options available for motorists. One other option encouraged by MoDOT in the news release was taking the Dorena-Hickman Ferry to cross the Mississippi river. This option, however, was not believed to be chosen by many motorists given that they did not have any en route navigation guidance. The pre-trip and en route information was focused on the official detour route described earlier.



(A) – with bridge open **(B) – with bridge closed (MoDOT detour)**

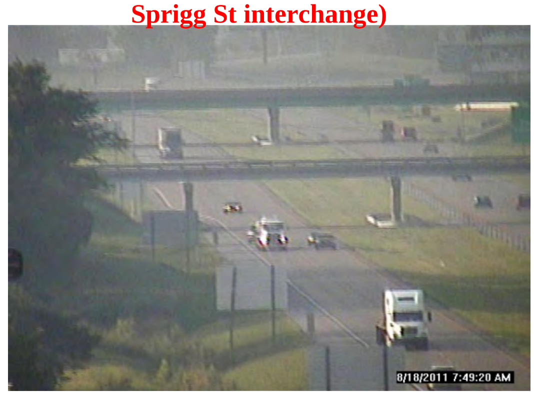
Figure 7. Travel routes with and without I-57 bridge open

In order to capture the regional traffic patterns, MoDOT's CCTV cameras at four locations were recorded on multiple days when the bridge was open and when it was closed. The days without bridge closure were used as the control data whereas the days with bridge closure were used as the treatment data. The four locations, as shown in Figure 8, were: 1) I-55/US 60 interchange (exit 66), 2) I-55/US 62 interchange (exit 67), 3) I-55/Rt. AB camera viewing the Sprigg St. interchange (exit 93), and 4) I-55/MO 74 interchange (exit 95).

(A) –US 60/I-55

(C) – I-55/Rt. AB (viewing Sprigg St interchange)

(B) – US 62/I-55



(D) – I-55/MO 74

Figure 8. CCTV Camera Views Monitored

As previously mentioned in the incident response plan, MoDOT used a combination of static and dynamic message signs to alert motorists during the I-57 bridge closure project. Whereas the static signs only provided information on the bridge being closed without detour information, the DMSs provided specific information on the detour route (see Figure 9).

Figure 9. Sample signage deployed during the I-57 bridge closure

Survey of motorists during the I-57 bridge closure

A second survey on the DMS signs was deployed during the days of bridge closure. The purpose of this survey was to obtain a better understanding of travelers' perceptions and responses to detour routes provided by DMS. In addition to the demographic, trip purpose, vehicle type questions the following DMS related questions were asked.

1. Have you seen a message regarding the I-57 bridge closure similar to the right?

2. Were you clearly aware of the I-57 bridge closure before you drove on I-55 today?
3. Were you happy with the means used to inform the public of the closure?
   Please circle the means you used: television radio DMS newspaper other
4. Were the dynamic message signs enough to inform you of the closure before it began?
5. Do you trust the accuracy of detours labeled on the dynamic message signs?
6. Will you utilize the recommendations provided by the dynamic message signs?
7. Did the messages on the dynamic message signs provide sufficient detour information?
8. Were you planning on crossing the Mississippi River today? If so, were you planning on using I-57 if there were no message signs?

A five-point Likert scale with 1 being "strongly disagree" and 5 being "strongly agree" was used. The survey was deployed at a truck stop off of Exit 91 close to the Cape Girardeau Regional Airport. Four personnel interviewed 151 motorists on August 17th 2011 when the I-57 bridge closure was in place. The results of the survey are summarized and presented in Table 5.

Table 5. Average scores (out of 5) on each question for different classification types

Classification			Average Scores					
		Number	Clearly Aware	HappyWithMeans	DMS Alone	TrustDetours	UtilizeRecs	SufficientInfo
Combined		151	3.50	3.84	3.64	3.99	3.97	4.05
Trip Purpose	Work	118	3.58	3.96	3.74	4.10	4.08	4.20
	Recreation	17	3.06	3.53	3.18	3.41	3.29	3.47
	p value		0.134	0.085	0.082	0.109	0.014	0.015
Residency	Local	90	3.88	3.93	3.60	3.96	3.97	3.94
	Visitor	47	2.77	3.79	3.67	3.96	3.93	4.29
	p value		0.001	0.574	0.755	0.861	0.867	0.064
Vehicle Type	Commercial	75	3.64	4.13	3.95	4.34	4.25	4.43
	Private	73	3.30	3.54	3.36	3.65	3.69	3.68
	p value		0.066	0.001	0.003	0.000	0.001	0.000
Gender	Male	122	3.63	3.94	3.74	4.09	4.06	4.10
	Female	23	2.83	3.55	3.30	3.65	3.68	4.05
	p value		0.035	0.246	0.142	0.284	0.394	0.995

*Highlighted numbers indicate results were significant at a 10% significance level

The average score for each question was computed by averaging the scores of all survey respondents. These values are indicated in the row titled ‘Combined’ in the table. The average score on every question exceeded 3.5 which was between the ‘neutral’ and ‘somewhat agree’ with most of them being closer to ‘somewhat agree’. The highest average rating was observed for the question on whether the DMS provided sufficient detour information.

Work-related trip makers agreed more than the recreational trip makers on every survey question. This result is desirable since delay costs associated with work trips are higher than non-work trips. The maximum difference in the average scores was witnessed for the amount of trust in the suggested detours, utilization of the DMS recommendations, and sufficiency of the information.

More local motorists indicated that they were aware of the bridge closure compared to the visiting population. This makes sense given that the bridge closure information was disseminated through news and media releases locally. In terms of the sufficiency of information provided on DMS, visitors were slightly more favorable than locals. The responses of both visitors and locals were similar for the other questions.

Commercial vehicle drivers (truck drivers) tended to be more satisfied with the overall information dissemination process. Their average rating for every question was higher than the private vehicle drivers. Noteworthy among the responses was their high rating for the amount of trust in the suggested detours, utilization of the DMS recommendations, and sufficiency of the DMS information.

Only 16% of the respondents were females. The average score for each question was higher for males than females. However, the statistical test indicated only a significant difference for the question on awareness of the bridge closure.

Traffic data collection and analysis

Traffic data was collected for both with and without bridge closure scenarios. Three methods were used to collect data: 1) the research team deployed cameras at the interchange locations to measure traffic flows for critical movements, 2) MoDOT's CCTV cameras at the interchanges shown in Figure 8 earlier were processed for traffic flows, and 3) MoDOT deployed pneumatic tube counters at certain mainline locations prior to entrance and exit ramps.

As previously mentioned, the bridge closure project was considered to be an excellent case study for evaluating DMS given the rural nature of the study area. Therefore, the research team ensured that they had more than one way to capture the traffic data for the closure. This provided for some contingency in case one of the traffic monitoring devices was not functioning properly. Due to the large number of movements (fifteen) for which traffic flows were needed, only the evening peak hour data from 4:30 pm to 5:30 pm was analyzed from the recorded videos from MoDOT cameras. The evening peak was chosen, because it produced the highest flows based on the hourly flow data provided by the MoDOT traffic management system (TMS) archive. The tube counters only captured about four of the fifteen movements of interest. However, they provided hourly volumes for the entire day during each day they were deployed. These hourly volumes were used in conjunction with the peak hour volumes obtained from CCTV cameras in building the simulation models.

The traffic flows and percentage changes presented in Tables 6 and 7 indicate that the bridge closure had an impact on several of the movements for both passenger vehicles and trucks. In this context, trucks refer only to commercial trucks and not pickups. Traffic data collected at I-55 and US 62 interchange did not reveal any trends probably because the US 62 Mississippi Bridge had already been closed for several months. The traffic flows at that interchange remained relatively unchanged with or without the I-57 bridge closure project. Thus, this location is not discussed in the tables and the report. The findings at other three interchange locations are discussed next.

Table 6. Peak hour traffic flows at the three interchange locations

		Peak Hour Traffic Flows (veh/hr)					
		I-57 Bridge Closed (Treatment)			I-57 Bridge Open (Control)		
Location	**Movements**	**Passenger**	**Truck**	**Total**	**Passenger**	**Truck**	**Total**
I-55 @ US 60 (Exit 66)	**I-55 NB**	449	221	670	379	127	506
	I-55 SB	366	240	605	355	267	622
	I-55 NB to US 60 EB	47	44	91	60	160	220
	I-55 SB to US 60 EB	50	16	66	58	8	65
	US 60 EB	427	52	479	444	55	498
	US 60 WB	198	35	233	341	202	543
	US 60 EB to I-55 NB	219	31	250	193	17	209
I-55 @ Sprigg St (Exit 93)	**I-55 NB**	1385	289	1674	1360	172	1532
	I-55 SB	1648	262	1910	1524	176	1700
	I-55 NB to MO 74	55	29	83	57	21	77
I-55 @ MO 74 (Exit 95)	**I-55 NB**	1153	181	1334	1092	145	1236
	I-55 SB	750	147	896	739	147	885
	I-55 NB to MO 74	225	90	315	196	9	204
	I-55 SB to MO 74	127	14	141	139	17	156
	MO 74 to I-55 SB	589	94	683	492	12	503

Table 7. Percent change in the peak hour traffic flows

		Percent change in hourly flows (treatment-control)/control		
Location	**Movements**	**Passenger**	**Truck**	**Total**
I-55 @ US 60 (Exit 66)	**I-55 NB**	18% ↑	75% ↑	33% ↑
	I-55 SB	3% ↑	-10% ↓	-3% ↓
	I-55 NB to US 60 EB	-22% ↓	-73% ↓	-59% ↓
	I-55 SB to US 60 EB	-13% ↓	107% ↑	1% ↑
	US 60 EB	-4% ↓	-5% ↓	-4% ↓
	US 60 WB	-42% ↓	-83% ↓	-57% ↓
	US 60 EB to I-55 NB	14% ↑	85% ↑	19% ↑
I-55 @ Sprigg St (Exit 93)	**I-55 NB**	2% ↑	69% ↑	9% ↑
	I-55 SB	8% ↑	49% ↑	12% ↑
	I-55 NB to MO 74	-4% ↓	39% ↑	8% ↑
I-55 @ MO 74 (Exit 95)	**I-55 NB**	6% ↑	25% ↑	8% ↑
	I-55 SB	1% ↑	0%	1% ↑
	I-55 NB to MO 74	15% ↑	959% ↑	54% ↑
	I-55 SB to MO 74	-9% ↓	-21% ↓	-10% ↓
	MO 74 to I-55 SB	20% ↑	717% ↑	36% ↑

<u>Traffic flow changes at the I-55 @US 60 (Exit 66) interchange</u>

Traffic flow in the northbound (NB) direction of I-55 increased by 33% (18% passenger vehicles and 75% trucks) during the bridge closure days. This was expected because traffic could not exit onto US 60 to reach Illinois and instead continued north on the I-55 detour route. Accordingly, the traffic flow from I-55 NB to eastbound (EB) US 60 decreased by 59% during the bridge closure.

Traffic flow on I-55 SB mainline was relatively unchanged (3% change) during the bridge closure days. This occurred because the traffic counter was located south of the interchange accounting for traffic merging from US 60 WB as well. Therefore, the sum of traffic heading south on I-55 upstream of the interchange plus the US 60WB entrance ramp traffic remained constant. Traffic entering I-55 NB from US-60 EB also increased by 19% during bridge closure since additional detour traffic was using I-55 NB to access the detour route.

Traffic flow on US-60 WB mainline was significantly higher by 57% when the bridge was open as traffic from Illinois could travel through US 60 WB to access I-55. The US 60 EB traffic flow remained constant (only a 4% change) as the traffic counter was located prior to the exit ramp to I-55 NB (the detour route).

Traffic data collected at I-55 and US 62 interchange did not reveal any trends. The traffic flows remained relatively unchanged with or without the I-57 bridge closure project. Thus, this location is not discussed any further in this report.

Traffic flow changes at the I-55 @Sprigg St. (Exit 93) interchange

Three movements were measured at the I-55 93A interchange: I-55 NB and I-55 SB mainline flows, and I-55 NB to MO 74 ramp. Both I-55 NB and I-55 SB mainline traffic flows increased during the days of bridge closure indicating the use of detour route. As shown in the table, the increases were more significant for trucks than passenger vehicles. To access MO 74 some traffic exited at Exit 93A and used Kingshighway to reach to MO 74 (Shawnee Parkway). This trend was observed more for trucks than passenger vehicles. Also, as will be discussed later, the major access point to MO 74 was the immediately downstream exit ramp at Exit 95.

Traffic flow changes at the I-55 @MO 74 (Shawnee Parkway) (Exit 95) interchange

The traffic flow on the exit ramp from I-55 NB to MO 74 increased significantly (959%) for trucks due to the bridge closure. This increase is attributed to the use of detour route. Similarly, the entrance ramp to I-55 SB from MO 74 also carried significant higher flow (717%), since the detour traffic was using the ramp during bridge closure days. Fluctuations in mainline flows on I-55 SB and NB are attributed to day-to-day and seasonal variations and locations where these flows were measured were devoid of any detour traffic.

The I-55 SB to MO 74 traffic decreased slightly during bridge closure. This movement was expected to remain roughly the same since this movement should not have been affected by the I-57 bridge closure. One reason for the slight decrease was that the traffic that regularly used this route was aware of the detour days and hence wanted to avoid traveling on the route.

To account for the day-to-day variability of travel demand, the ratio of ramp flow and mainline flow was computed for every exit and enter ramp. Table 8 shows such ratios and confirms the fact that the percent changes shown in Table 7 are not mainly due to day-to-day demand variations but to traffic re-routing. For example for the I-55NB to MO74 movement at Exit 95, the ratio increased by 27% for trucks corresponding to the 959% increase in flows. For the Mo 74 to I-55 SB movement at Exit 95, the ratio increased by 32% for trucks corresponding to the 717% increase in flows. For the I-55NB to US 60 EB- movement at Exit 66, the ratio decreased by 18% for the total traffic corresponding to the 59% decrease in flows.

A proportion test was conducted to test the statistical significance of the results. In Table 8, the proportions for both treatment and control cases are shown. The last columns indicate the p-value with the highlighted cells indicating significance at 90% confidence level. For most movements, the trends are in agreement with those previously reported in Table 7. Movements that had statistically significant difference in proportions confirmed the preceding discussions of Table 7 findings. The total proportion differences for only two movements were found to not be statistically significant: I-55 SB to US 60 EB at Exit 66 and I-55 NB to MO74 at Exit 93. This provides support that the 1% increase observed in the total traffic flow exiting I-55 SB to US-60 EB (see Table 7) was perhaps a result of the daily variation in demand and not significant.

Table 8. Changes in ramp traffic proportions with and without bridge closure

Location	Ramp movement	Ramp Proportions (ramp flow/mainline flow)						Significance (p-value)		
		I-57 Bridge Closed (Treatment)			I-57 Bridge Open (Control)					
		Passenger	Truck	Total	Passenger	Truck	Total	Passenger	Truck	Total
I-55 @ US 60 (Exit 66)	I-55 NB to US 60 EB	9%	17%	12%	14%	56%	30%	0.002	0.000	0.000
	I-55 SB to US 60 EB	14%	6%	11%	16%	3%	10%	0.090	0.003	0.619
	US 60 EB to I-55 NB	51%	59%	52%	43%	30%	42%	0.000	0.000	0.000
I-55 @ Sprigg St (Exit 93)	I-55 NB to MO 74	4%	10%	5%	4%	12%	5%	0.341	0.160	0.500
I-55 @ MO 74 (Exit 95)	I-55 NB to MO 74	16%	33%	19%	15%	6%	14%	0.127	0.000	0.000
	I-55 SB to MO 74	17%	9%	16%	19%	12%	18%	0.091	0.172	0.059
	MO 74 to I-55 SB	44%	39%	43%	40%	7%	36%	0.002	0.000	0.000

Simulation of DMS impact on traffic diversion

In order to build a simulation model of the region relevant to the I-57 bridge closure, field traffic data and survey results were used as inputs. Comparing the traffic counts from 4:30pm to 5:30pm on August 17th (one of the bridge closure days) and 31st (bridge open), the traffic flow on the ramp connecting I-55 NB to US 60 EB was 160 vehicles less on the 17th than the 31st flow. Similarly, the traffic flows on ramps from US 60 EB to I-55 NB and US 62 EB to I-55 NB were 30 vehicles and 10 vehicles more than 31st flows as shown in Table 9. Thus, a possible total of 200 vehicles (160+30+10) detoured during the peak hour on the 17th that would have otherwise used the I-57 bridge on normal days. These motorists could have received the bridge closure and detour information through one or more means such as TV, radio, newspaper, and DMS. Since it was not possible to measure directly the percentage of drivers that detoured solely due to the DMS information, the simulation of several percentages were carried out and DMS benefits estimated. Six different percentages of the detour traffic were simulated: 10%, 30%, 50%, 80%, 90%, and 100%.

Of the 109 motorists who responded to the bridge survey question on how they knew about the bridge closure, 62 answered DMS, 38 TV, 15 radio, 12 newspaper, and 11 other means. Note that some respondents checked more than one option (e.g., DMS and newspaper). Further analysis revealed that 45 respondents checked ONLY DMS as the means used to learn about the bridge closure. Therefore, about 41% (45/109) of the driving population were aware of the bridge closure only through DMSs.

Table 9. Peak Hour Traffic Count Difference between August 17th (treatment) and 31st (control)

Location	Movements	Volume Difference (treatment - control)		
		Passenger Car	Truck	Total
I-55@ US 60	I-55 NB to US 60 EB	-19	-141	-160
I-55@ US 60	US 60 EB to I-55 NB	20	10	30
I-55@ US 62	US 62 EB to I-55 NB	3	7	10

As previously mentioned, the hourly counts were only available at a few locations where the tube counters were deployed. However, the peak hour flows (4:30 to 5:30 pm) were available for all 15 movements upon processing the CCTV camera recordings. To generate the hourly volumes for all movements, the average hourly factors were computed using the tube counts and then the peak hour flows were multiplied by these factors to obtain flows for non-peak hours. Average hourly factor is computed by dividing the hourly volume during a 1-hour interval with the peak hour volume. For example, say the average hourly volume for 11:00 am to 12:00 pm is 1,100 and the peak hour volume (4:30 pm to 5:30 pm) is 1,400, the average hourly factor for 11:00 am to 12:00

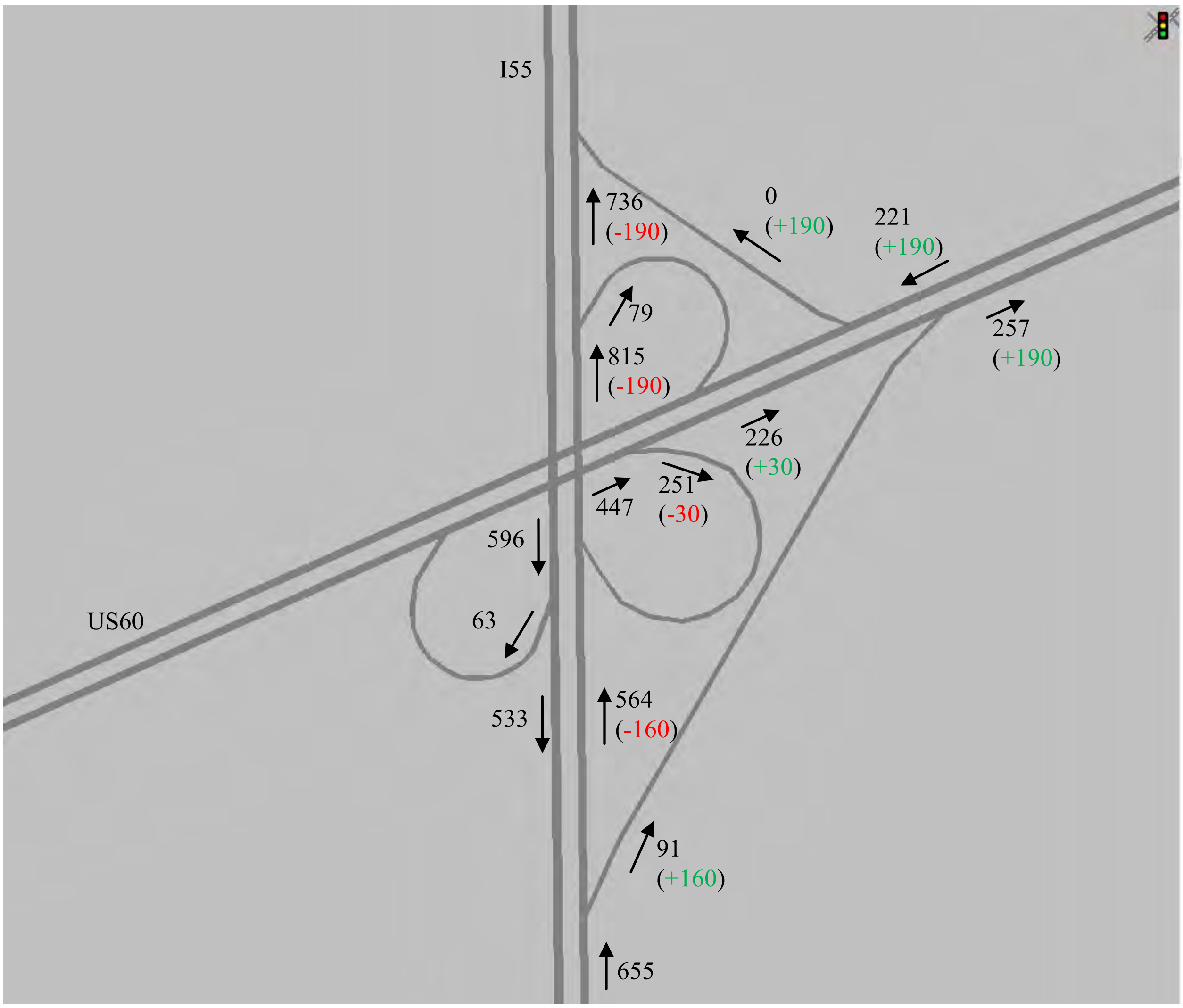
pm is 1,100/1,400 = 0.78. The average hourly factors computed using tube counter data at mile marker 91.2 on both I-55 SB and NB are shown in Table 10.

Table 10. Average Hourly Factors

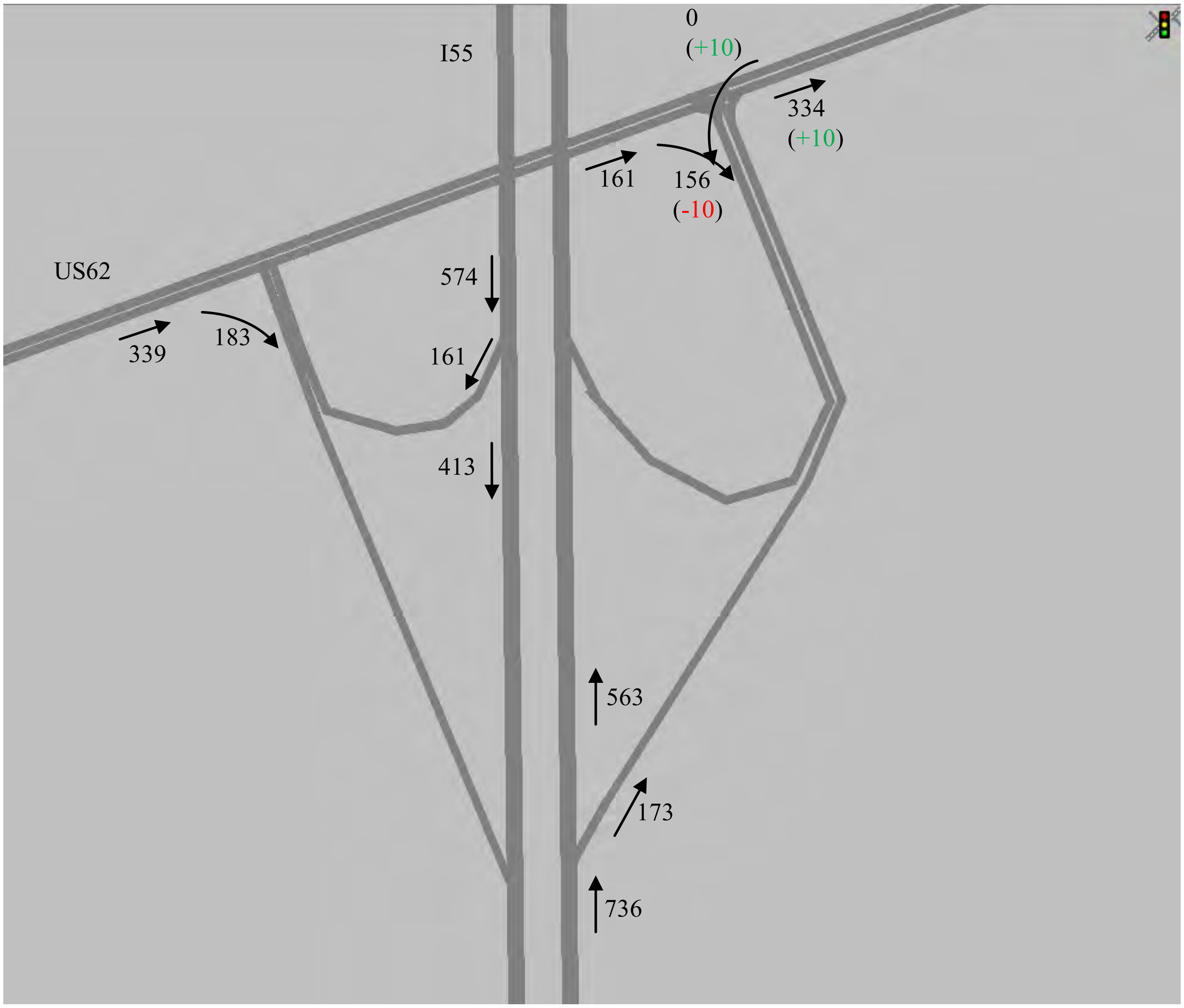
Time	I55NB	I55SB	Average
0:00am-1:00am	0.17	0.13	0.15
1:00am-2:00am	0.14	0.11	0.13
2:00am-3:00am	0.12	0.10	0.11
3:00am-4:00am	0.14	0.12	0.13
4:00am-5:00am	0.19	0.14	0.17
5:00am-6:00am	0.38	0.28	0.33
6:00am-7:00am	0.66	0.44	0.55
7:00am-8:00am	1.09	0.63	0.86
8:00am-9:00am	0.93	0.59	0.76
9:00am-10:00am	0.92	0.58	0.75
10:00am-11:00am	0.89	0.69	0.79
11:00am-12:00pm	0.96	0.74	0.85
12:00pm-1:00pm	0.99	0.80	0.90
1:00pm-2:00pm	1.01	0.80	0.90
2:00pm-3:00pm	1.02	0.87	0.94
3:00pm-4:00pm	1.05	0.92	0.99
4:00pm-5:00pm	1.03	1.02	1.03
5:00pm-6:00pm	0.97	0.98	0.97
6:00pm-7:00pm	0.84	0.76	0.80
7:00pm-8:00pm	0.60	0.60	0.60
8:00pm-9:00pm	0.51	0.49	0.50
9:00pm-10:00pm	0.42	0.39	0.40
10:00pm-11:00pm	0.32	0.29	0.31
11:00pm-12:00pm	0.24	0.23	0.23

These hourly volumes were then coded into VISSIM simulation program as vehicle inputs. Routing decisions (paths for vehicles) were defined for both with DMS and without DMS scenarios. The 'with DMS' scenario routes all vehicles to the detour route as observed on the days of bridge closure. For the 'without DMS' scenario a certain proportion of the detouring traffic is believed to have been informed about the bridge closure and also follow the detour route. As these drivers are assumed to solely rely on DMS, without DMS they would have continued towards the closed route (US 60 EB or US 62 EB) until they see the static bridge closure signs and made an U-turn by taking the immediate next exit to return to the detour route. The additional distance and travel time experienced by this proportion of vehicles gives an estimate of the amount of savings obtained through DMS use. Recognizing that the static signs only provided the bridge closure information but did not provide detour information it is possible that some drivers may even get lost or have a hard time finding the detour route. In this project, it was assumed that all drivers who turned back would get back onto the detour route. Additional costs for any driver inconveniences were not included in the analysis, thus the estimation of DMS benefits was conservative.

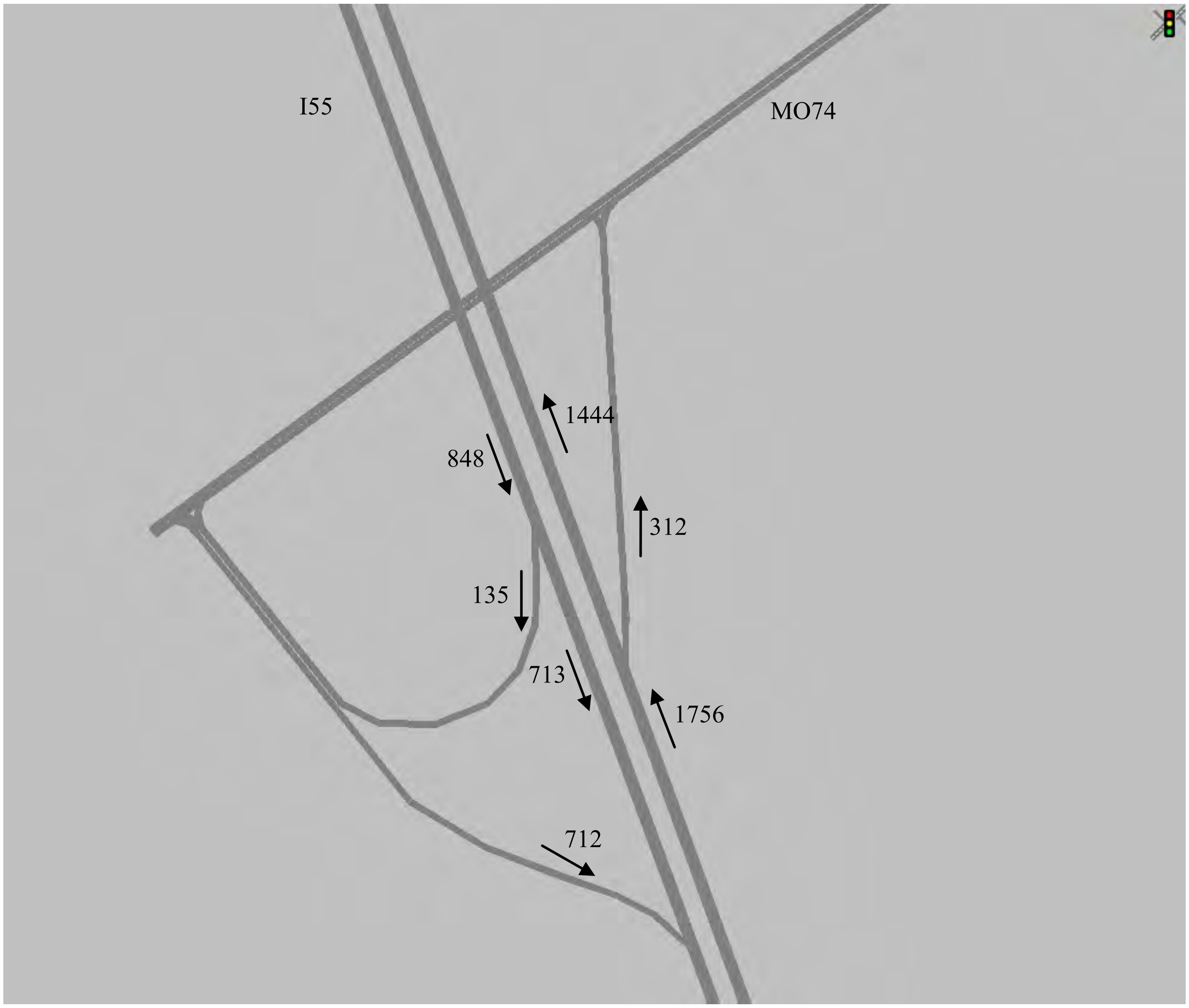
As an example, the turning volumes for the evening peak hour are shown in Figure 10 for I-55@US 60, I-55@US 62, and I-55@MO 74 interchanges. The values outside parenthesis indicate the flows 'with DMS' and values inside parenthesis denote the increase (+) or decrease (-) in traffic flows 'without DMS'. When the flow did not change with DMS only one value is shown. For example, Figure 10(a) shows 190 vehicles that were not aware of the closure, and ended up being forced to turn back on US60.



(a) Interchange of I55 and US60



(b) Interchange of I55 and US62



(c) Interchange of I55 and MO74

Figure 10. Peak-hour Traffic Volume Inputs for Network with DMSs (a, b, and c)

Using this vehicle input and routing decision information, simulations were performed for the entire 24 hour period. The results of simulation for various percentages of the detour traffic were obtained. Travel time and distance measures were extracted from the results. The total and average travel times and travel distances for 'with DMS' and 'without DMS' scenarios are reported in Table 11. For example, 'without DMS 80%' denotes the scenario in which 80% of those that detoured did that solely due to DMS. Table 11 shows the travel savings varies between 20.20 seconds/vehicle and 1.82 seconds/vehicle, and between 393.41 total hours and 35.44 total hours depending on the percentage of DMS compliance.

Table 11. Performance measures from simulations and estimated benefits

	With DMS	Without DMS (100%)	Without DMS (90%)	Without DMS (80%)	Without DMS (50%)	Without DMS (30%)	Without DMS (10%)
Number of vehicles	70,278	70,278	70,278	70,278	70,278	70,278	70,278
Total travel time (hr)	17,503	17,897	17,856	17,801	17,681	17,619	17,538
Average travel time (min/veh)	14.9	15.3	15.2	15.2	15.1	15.0	15.0
Total travel distance (mi)	1195500	1222747	1219941	1216229	1207890	1203543	1198063
Average travel distance (mi/veh)	17.0	17.4	17.4	17.3	17.2	17.1	17.0
SAVINGS							
Total travel time saving (hr)		394.4	353.2	298.6	177.8	116.4	35.4
Average travel time saving (sec/veh)		20.2	18.1	15.3	9.1	6.0	1.8
Total travel distance saving (mi)		27247.3	24441.3	20728.5	12389.6	8043.0	2563.0
Average travel distance saving (ft/veh)		2047.1	1836.23	1557.3	930.8	604.3	192.6

Chapter 5 of the AASHTO Redbook (User and Non-user Benefit Analysis for Highways) (2010) provides information on value of time and fuel consumption that can be used to evaluate the travel time and fuel savings resulting from DMS. These values are shown in Table 12. These values were used in producing the benefits resulting from the travel time and fuel consumption savings as reported in Figure 11. The total savings per day range from $1,721 to $18,643 depending on the proportion of drivers who chose to divert solely based on DMSs. The bridge closure was in place for three days resulting in a total savings per a 3-day project of $5,163 to $55,929.

Table 12. AASHTO recommended values of value of time and fuel consumption

	Average wage or compensation ($/hr)	Percentage of average wage	Fuel consumption (gal/mi)	Passenger occupancy
Trucks	20.23	100%	0.158	1.05
Passenger Cars	18.56	50%	0.039	1.5

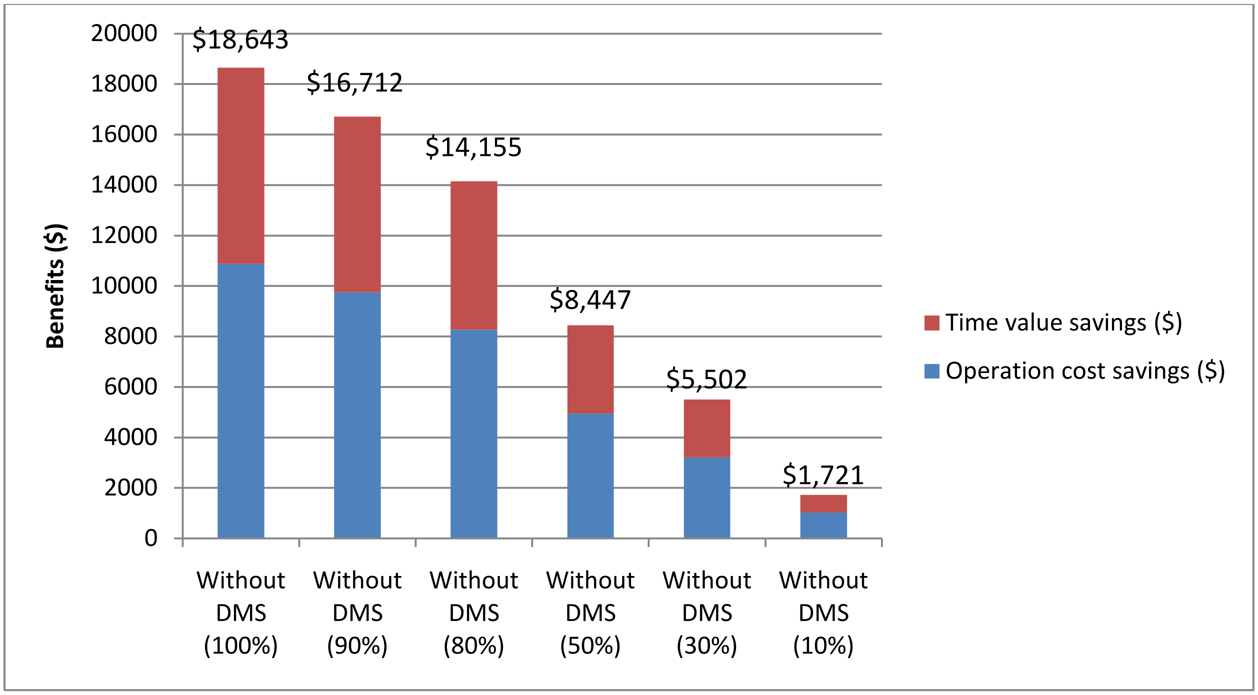


Figure 11. Monetary value of travel time and operation cost savings per closure

Task 4.4. Analysis of Crashes in the Study Region before and after DMS

DMSs are mainly intended for traveler information purposes. They are not a safety treatment although they could contribute to the reduction in secondary incidents by providing timely information about primary incidents. Previous research did not show any unanticipated negative safety impacts when MUTCD and state-specific guidelines were followed about the messages.

Crash data was obtained for the I-55, I-57, and US 60 corridors that were part of the DMS deployment (Figure 2 in section 1 shows boundaries of each corridor). The DMSs were fully operational in 2010. Therefore, only one year of after DMS data for 2010 could be included in the crash analysis. The before period consisted of five years - 2005 to 2009.

Given the limited amount of after period data available for the study the findings in this section must be considered as preliminary. In the future, crash analysis must be revisited when multiple years of after period data becomes available.

Since the study area was rural, DMS deployment could help improve safety during incidents such as during inclement weather or at construction work zones. Therefore, two sets of crash data were analyzed – 1) work zone related crashes and 2) inclement weather related crashes. From the crash database, the Missouri Uniform Crash Records (MUAR) was helpful in determining the cause of each incident. These two groups were analyzed because they included incidents that could potentially be avoided if DMS alerted motorists. Of course, not all work zone crashes could be prevented just by using DMS.

The extent of the study corridors included 157.5 miles of I-55, 161 miles of US 60, and 22 miles of I-57. Due to the variability of AADT over these extended segment lengths, it was not possible to compute crash rates (crashes/AADT). The number of work zones and inclement weather events most likely differ from one year to another and could have a significant impact on the number of crashes that occur. Unfortunately, this data was not available to incorporate into the analysis.

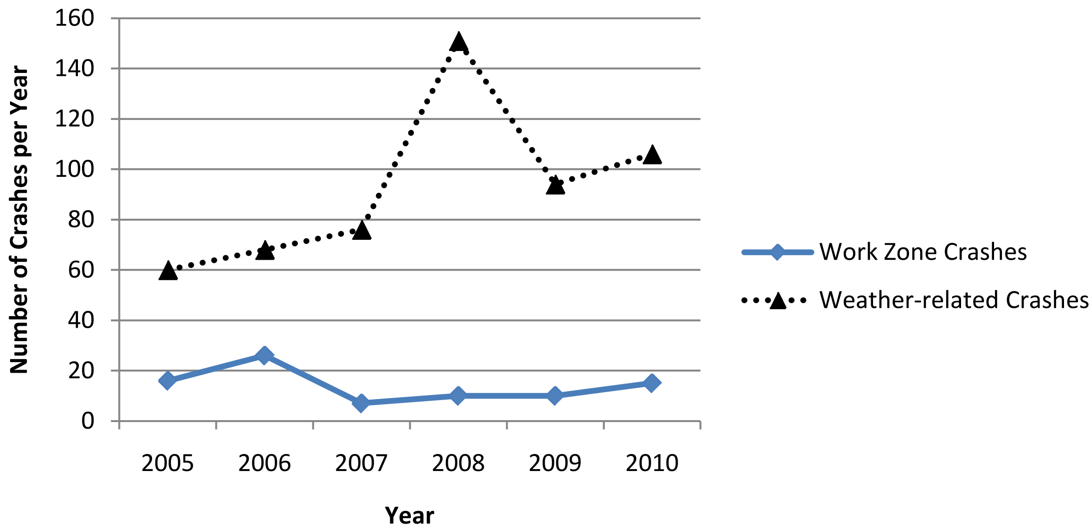


Figure 12. Number of work zone and weather–related crashes on study corridors

In Figure 12, the work zone and weather-related crashes are plotted for each year. Weather-related crashes show an increasing trend from 2005 to 2010 with a sudden spike in 2008. Work zone crashes dropped from 2006 to 2007 after which they steadily increased.

A simplified before-after analysis (Hauer, 1997) was conducted with the crash data. The naïve before-after method is frequently encountered in safety literature and it can act as a useful upper bound because the statistical precision is unsurpassed (Hauer, 1997). The terminology used in the before-after study is defined as follows:

$\gamma =$ The sum of crashes occuring at all treatment sites j in the after period

$$\gamma = \sum L(j)$$

Where,

j – Entity receiving treatment

L(j)- number of crashes occurring at a treatment site *j* in the after period

$$VAR\{\gamma\} = \sum L(j)$$

$\pi =$ Equivalent number of crashes before sites j were treated

$$\pi = \sum r_d(j)K(j)$$

Where,

$$r_d(j) = \frac{\text{Duration of after period for site } j}{\text{Duration of before period for site } j}$$

$K(j) =$ The number of crashes at site j before it was treated

$$VAR\{\pi\} = r_d^2 \sum K(j)$$

$\delta =$ Reduction of crashes in the after period

$$\delta = \pi - \gamma$$

$$VAR\{\delta\} = VAR\{\pi\} + VAR\{\gamma\}$$

The reduction in crashes in the after period (δ) and its variance ($VAR(\delta)$) were computed using the above formulas for both work zone and weather-related crashes. The results of mean, standard deviation and 95% confidence interval are shown in Table 13. The mean values for work zone and weather related crashes were both negative indicating an increase in the number of crashes in the after period. This finding could be attributed to a number of confounding factors that were not accounted for in this research due to lack of data. For example, factors such as the increase in number of work zones, greater number of inclement weather events, increase in traffic levels in the study corridors, during the after period may have contributed to the observed increases. As discussed earlier, DMSs are primarily intended for traveler information and not as an active safety treatment.

Table 13. Changes in crash rates (crashes/year) on the study corridors

Crash Type	Before Period	After Period	Mean (δ)	Std. dev. (√VAR(δ))	95% Conf. Int.
Work Zone	5 Years	1 Year	-1.2	4.21	(-9.46, 7.06)
Weather Related	5 Years	1 Year	-16.2	11.13	(-38.02, 5.62)

5. CONCLUSIONS

Dynamic message signs on freeways in rural areas were evaluated in this research project. A three-step approach was used for the evaluation. First, motorist surveys were conducted to obtain the perception of both commercial vehicle (truck) drivers and personal vehicle (e.g., passenger car) drivers towards DMSs. Motorists were highly favorable towards DMSs responding with very high scores on survey questions. Motorists seemed to be very satisfied with how MoDOT was utilizing their rural DMS. When motorists were separated into subgroups for analysis, there were some differences in mean scores in the "Vehicle Type" (between trucks and private vehicles) and "Trip Purpose" (between work and recreation) subgroups. There were significant differences among the "Signs Readable, "Easy to Understand," and "Accurate" questions. The work trips and truck drivers tended to be more critical of these three questions. This could be due to the increased attention toward DMSs when motorists were driving on official business and were in time critical situations such as in meeting arrival times. Since most commercial truck drivers work when they are in their trucks, there is likely a large correlation between these work trips and truck drivers. A very high proportion (~90%) of the surveyed motorists said they took the action provided by the DMS.

Second, field studies were conducted to assess the impact of DMSs in alerting drivers of an upcoming work zone. Two construction work zones on I-55 within the study area were selected. One site consisted of a permanent DMS upstream of the work zone and the other site consisted of a portable DMS (or PCMS) upstream of the work zone. Both DMSs displayed messages alerting drivers of the upcoming work zone. Average speed of vehicles were measured before and after the DMS to ascertain if drivers adjusted their speeds in response to the displayed message. At both sites, speeds dropped after the DMSs indicating a positive safety effect. Speed decreases of 3.64 mph and 1.25 mph observed at the first and second sites were also statistically significant. These findings indicate that DMS has a positive effect on drivers' speeds upstream of work zones on rural uncongested four-lane interstates.

Third, the effectiveness of DMSs in diverting traffic to a detour route during a full freeway closure was investigated. The I-57 bridge crossing the Mississippi river was closed for three days in order to repair the bridge. Due to the bridge closure traffic traveling on I-57 between the states of Missouri and Illinois had to detour. Motorist surveys were conducted in the affected area to discover if motorists were aware of the bridge closure and detour and to what extent they relied on DMSs to obtain traveler information. Overall, motorists said they were satisfied with traveler information provided by MoDOT through DMSs, they trusted the accuracy and sufficiency of detour information provided on DMS, and they utilized the recommendations provided by the DMSs during the bridge closure project. Commercial vehicle (truck) drivers were more satisfied with the overall information dissemination process. Their average rating for every question was higher than the private vehicle drivers. Noteworthy among the responses was their high rating for the amount of trust in the suggested detours, utilization of the DMS recommendations, and sufficiency of the DMS information.

Traffic data collected before, during, and after the bridge closure were compared at several key locations in the road network. Overall, there was a significant increase in traffic flow on the detour route (and corresponding decrease on US 60/I-57) during the bridge closure project. Motorists who chose to detour could have received the bridge closure and detour information through one or more means such as TV, radio, newspaper, and DMS. Since it was not possible to measure directly the percentage of drivers that detoured solely due to the DMS information, the simulation of several percentages were carried out and DMS benefits estimated. Depending on the proportion of drivers who chose to divert solely based on DMSs, total travel time savings ranged between 394.4 hours and 35.4 hours. These savings translated to monetary benefits ranging between $55,929 and $5,163 for the 3-day bridge closure project. The motorist survey revealed that 41% of drivers relied solely on DMSs to get the traveler information. At this market penetration level, potential benefits of $21,365 are realized for the 3-day project. The estimated range of savings may seem low at first glance, but DOTs are increasingly conducting full freeway closures to expedite construction and maintenance activities. These benefits can easily multiply over the life of DMS equipment. However, it is not possible to estimate the overall benefits of DMS without knowing the number of full freeway closures conducted by a DOT. For example, five full closure projects in one year could result in benefits ranging from $25,815 to $279,645. It is also noted that DMS are not only beneficial during full freeway closures; they provide tangible benefits during work zones, incidents, and inclement weather conditions. In urban areas due to the significantly higher ADT and hourly traffic volumes than rural areas, the benefits accrued from travel time and fuel savings are also typically higher.

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