NATIONAL EVALUATION OF THE FY 2003 EARMARKED ITS INTEGRATION PROJECT: SOUTHERN WYOMING, I-80 DYNAMIC MESSAGE SIGNS

FINAL PHASE III EVALUATION REPORT

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16. Abstract

This report presents the results for the national evaluation of the FY 2003 Earmarked ITS Integration Project: Southern Wyoming, I-80 Dynamic Message Signs. The I-80 Dynamic Message Signs project is a rural infrastructure deployment of ITS devices that were integrated with existing WYDOT transportation management systems. The devices include DMS, speed sensors, blank-out signs, Highway Advisory Radio (HAR), Environmental Sensor Stations (ESS), and Closed-Circuit Television (CCTV) camera systems, and the associated communications infrastructure necessary to operate these devices.
This report presents the findings of the system impacts and lessons learned for the ITS deployment on I-80 between Cheyenne and Laramie. The system impact study investigated the expected outcomes of the system in terms of safety, mobility, and customer satisfaction. The lessons learned were produced based on stakeholder experiences and are intended to be useful for other agencies developing a similar system.

Overall, the I-80 DMS Project has been found to result in several positive outcomes. The CCTV cameras have been very effective in improving WYDOT's ability to identify, verify, and respond to hazardous weather, road, and travel conditions. The DMS and other travel information dissemination sources appeared to be mostly effective in controlling traffic speeds, however, the effect on speeds appear to be dependent on a variety of factors (type of weather, road condition, how conditions are changing, type of vehicle, driver's perception of accuracy, message type, message consistency, etc.). The before and after comparison of crashes found that overall traffic crashes, injury crashes, and fatal crashes were reduced. Intercept surveys and local traveler panel surveys found that travelers appear generally satisfied with the understandability, usefulness, and availability of traveler information.

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FOREWORD

This National Evaluation of the FY 2003 Earmarked ITS Integration Project: Southern Wyoming, I-80 Dynamic Message Signs Final Phase III Evaluation Report presents the results and findings covering the period from January 1, 2002 through April 30, 2010. This report provides a comparison of the "before versus after deployment" system performance in terms of vehicle speeds, crashes, road closures, traffic volume, and road and weather conditions being investigated for the safety, mobility, customer satisfaction, and lessons learned evaluation.

The Southern Wyoming, I-80 Dynamic Message Signs (I-80 DMS) project is an effort led by WYDOT to improve the safety, mobility, and traveler satisfaction along the I-80 Summit Corridor between Cheyenne and Laramie. The project involves the deployment of ITS devices (DMS, speed sensors, blank-out signs, Highway Advisory Radio, Environmental Sensor Stations (ESS), and Closed-Circuit Television (CCTV) camera systems) and the associated communications infrastructure necessary to operate these devices.

This document does not supersede an earlier report on the subject.

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EXECUTIVE SUMMARY

This *Phase III Evaluation Report* presents the final results and findings for the national study of the *Southern Wyoming I-80 Dynamic Message Signs (I-80 DMS)* project. This evaluation was conducted in conjunction with the Federal Highway Administration's (FHWA) Integrated Intelligent Transportation Systems (ITS) Deployment Program. Interstate-80 (I-80) is a critical transportation corridor, not only within Wyoming, but also regionally and nationally. I-80 provides for major freight movement between the middle and western portions of the United States. Along I-80 in southern Wyoming, traffic travels through high mountain passes that are often closed due to weather and weather-related incidents. Over the 8-year period from 2002 to 2009, there have been 161 road closures, of which at least 89 were due to vehicle crashes. The evaluation of the I-80 DMS project focused on the summit corridor portion of I-80 between Laramie and Cheyenne, which is in the southeast portion of the State of Wyoming.

Overview of the Southern Wyoming I-80 DMS Project

The Southern Wyoming I-80 DMS project is a rural infrastructure deployment of ITS devices that were integrated with existing WYDOT transportation management systems. The integrated systems were used by WYDOT to provide credible and consistent information and support maintenance and operational requirements such as implementing road closures and variable speed limits in the Summit Corridor. The ITS devices deployed for this project included DMS, speed sensors, blank-out signs, Highway Advisory Radio (HAR), Environmental Sensor Stations (ESS), Closed-Circuit Television (CCTV) camera systems, and the associated communications infrastructure necessary to monitor and operate the devices.

WYDOT's outcome objectives for the I-80 DMS project as they relate to USDOT ITS strategic goal areas are shown in Table ES1.

Table ES1. Project Objectives by USDOT ITS Goal Areas

USDOT ITS Goal Area	I-80 DMS Project Objective
Safety	Reduce speeds under degraded roadway conditions
	Increase ability to obtain useful weather, road, traffic conditions
	Reduce overall rate of crashes, injury crashes, and fatal crashes
Mobility	Increase ability to respond to changes in weather, road, traffic conditions
	Reduce overall number and duration of road closures

USDOT ITS Goal Area	I-80 DMS Project Objective
Customer Satisfaction	Implement a useful automated road closure system
	Provide credible, consistent, useful messages/advisories that travelers will easily understand and act upon for safer travel
	Implement a project that will assist local travelers in making go/no go travel decisions

Overview of the Evaluation

To investigate the extent to which the project goals were met in deploying and operating such systems, the United States Department of Transportation (USDOT) contracted to conduct an independent evaluation of the I-80 DMS project. The evaluation consisted of a study of system impacts and the development of lessons learned. The system impact study investigated the expected outcomes of the system in terms of safety, mobility, and customer satisfaction. The lessons learned that were produced were based on stakeholder experiences and are intended to be useful for other agencies developing a similar system.

The evaluation was conducted as described in the *I-80 Dynamic Message Signs Final Detailed Test Plan.* Evaluation activities included the collection/analysis of both quantitative data (traffic speeds, crash records, traffic volumes, WYDOT Dispatcher/operator logs, DMS logs, intercept surveys, and panel surveys) and qualitative data (interviews, discussions, and, focus groups). The evaluation compared the system performance of I-80 between Cheyenne and Laramie, Wyoming before and after deployment. The "before" period included the 4-year period from January 1, 2002 to December 31, 2005. The "after" period included the 4 years from January 1, 2006, to December 31, 2009.

Conclusions of the Evaluation

This report presents the results, findings, and lessons learned for the evaluation of the Southern Wyoming I-80 DMS Project. The evaluation has resulted in a better understanding of the safety, mobility, and customer satisfaction impacts from the implementation, management, and utilization of the ITS technologies. The study of safety impacts found that the I-80 DMS project did have a positive impact on traveler safety in terms of reducing traffic speeds during hazardous travel conditions, enhancing the ability of WYDOT and WHP to obtain weather, road, and traffic condition information, and reducing the overall number of crashes, including injury crashes and fatal crashes. The study of mobility impacts found that the ITS deployment was viewed favorably by operations/maintenance/dispatcher staff and the traveling public for increasing their ability to identify and respond to changes in travel conditions. The improvements in identifying hazardous conditions led to more actions in response, which is supported by the increase in the number of road closures since ITS deployment. The study of customer satisfaction impacts found that travelers rated the understandability of the DMS messages and advisories very highly. They viewed the advisories as useful for making travel decisions and as a result felt that they had safer trips.

Conclusions for the key and secondary evaluation hypotheses are described below and reveal whether the evaluation found results that supported/contradicted the hypotheses or were inconclusive.

Key Hypothesis: The project will effectively reduce traffic speeds and variability in response to deteriorated roadway conditions (e.g., during incidents, inclement weather, etc.). *This hypothesis was supported with the results obtained from the quantitative data analysis.* The analysis of traffic speeds during 16 periods of adverse travel conditions revealed that the DMS advisories were often effective in reducing overall traffic speeds. This effect was most pronounced in the eastbound direction, which often showed average speeds decreasing from 5 to 10 mph depending on the advisory message and travel conditions. Also, it appears that a number of factors may influence the effectiveness of DMS advisories in reducing speeds, including the travel conditions, the type of message displayed, and the consistency of the messages across multiple DMS locations. The overall variability of the before and after hourly average speeds were very similar, both having an average standard deviation of about 7 mph.

Key Hypothesis: The project will increase the ability of operations, maintenance, and law enforcement to obtain useful weather, road surface, or traffic condition information on I-80 between Cheyenne and Laramie. *This hypothesis was supported with the results obtained from the interviews with WYDOT and WHP staff.* WYDOT and WHP stakeholders were in agreement that the implementation of ITS technology on the Summit Corridor greatly increased their ability to obtain weather, road, and traffic information. The CCTV cameras were clearly the favorite technology for obtaining information and were useful for operators to quickly obtain first-hand visual information to check and verify unconfirmed reports and (RWIS/speed/ice) sensor information.

Secondary Hypothesis: The project will result in a reduction in the overall rate of crashes, fatalities, and injuries. This hypothesis was supported with the results obtained from the quantitative analysis of crash records. The total number of crashes decreased from 1,155 in the pre-deployment period (2002 to 2005) to 1,025 in the post-deployment period (2006-2009). The number of crashes per vehicle miles traveled was also reduced for overall, injury, and fatal crashes during the after period. Overall, crashes per million vehicle miles traveled decreased from 1.63 (before) to 1.44 (after).

Fewer crashes involving injuries occurred during the post-deployment period (281) compared to the pre-deployment period (370). Comparison of injury crash rates supported these results as the injury crash rate decreased from 0.52 to 0.39 injury crashes per MVM. For fatal crashes, fewer crashes resulted in fatalities with 19 occurring before deployment and 10 occurring after deployment. The after period had a lower fatality crash rate, decreasing from 0.03 to 0.01 fatal crashes per MVM.

Secondary Hypothesis: The project will increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner. *This hypothesis was supported with the results obtained from interviews with WYDOT and WHP staff and traveler surveys.* Interviews with WYDOT and WHP staff revealed that they felt that the implementation of ITS technology on the Summit Corridor had greatly increased their ability to identify and respond to changes in weather, road, and traffic conditions. The colocation of WYDOT and WHP at the TMC in Cheyenne also improved the ability of both agencies to obtain weather, road, and traffic condition information; to speak directly to each other to share information; and to coordinate their efforts to perform their responsibilities during hazardous travel conditions.

Traveler perceptions from the surveys indicated that drivers want and use the available information to help in their decision making regarding safe travel. Survey respondents reported using the DMS, 511, and the Wyoming DOT Web site to gather information, especially to anticipate road closures and travel advisories. The DMS appeared to affect their behavior, as most reported that the information encouraged them to drive more carefully and slowly in response to the road conditions. Many also used the travel information to decide to postpone or cancel their trips.

Secondary Hypothesis: The project will result in a reduction in the overall number and duration of road closures. *This hypothesis was not supported with the results obtained from the quantitative data analysis.* In fact, it was found that after ITS deployment the number of road closures increased. However, given that WYDOT has (through the addition of ITS technologies) improved their ability to detect hazardous travel conditions, it seems reasonable that more road closings may result from better identification of hazardous conditions. Also, since road closings occur due to hazardous weather conditions, accidents, or both and are implemented to protect travelers from harm, these findings appear to be a positive result of ITS deployment. This is supported by the decrease in post-deployment-period crashes.

Key Hypothesis: The automated road closure system will be perceived as useful in closing and/or re-opening roadways. *This hypothesis is inconclusive as an automated closure system was not deployed in time for evaluation.* Consequently, an investigation of the usefulness was not conducted. The interviews with WYDOT ITS, maintenance, and operations staff found that several challenges related to safety slowed the implementation of a fully automated road closure system. The primary challenges included having several entry points onto I-80 within the eastside and westside road closure gate areas and the need to have WHP present at gates to enforce gate closures.

Key Hypothesis: The traveling public will be able to easily understand the messages and advisories enabled by the deployment of the project and will act upon this information to effect safer travel. *This hypothesis was supported with the results obtained from the quantitative data analysis of the local panel surveys and intercept surveys.* The surveys that were conducted showed that high proportions of travelers rated the usefulness, understandability, timeliness, and credibility of the sources very highly. The proportion who reported using the DMS was also high, with more than three-fourths of respondents saying they had read the signs. The usefulness of these information sources was borne out by the high proportion of travelers who reported the information encouraged them to take the action that was advised, helped them decide on trip actions, and made their trips safer.

Secondary Hypothesis: The project will be perceived as useful to assist local travelers in making go/no go travel decisions. *This hypothesis was supported with the results obtained from the quantitative data analysis of the local panel surveys.* Panelists showed a reliance on the information sources to help them determine if they should proceed with their planned trips. Less than 10 percent of these respondents reported they “ignored” the information they received, regardless of the source (or across all sources). Approximately one-third postponed their trips and approximately one in five reported they had cancelled a trip based on the information.

Figure ES1 highlights the overall benefits found during this evaluation. Overall, the I-80 DMS Project has been found to result in several positive outcomes. The CCTV cameras have been very effective in improving WYDOT’s ability to identify, verify, and respond to hazardous weather, road, and travel conditions. The DMS and other travel information dissemination sources appeared to be mostly effective in controlling traffic speeds; however, the effect on speeds appear to be dependent on a variety of factors (the type of weather, the road condition, how conditions are changing, the type of vehicle, drivers’ perception of the accuracy of the information, the type of message, the consistency of the message, etc.). The before and after comparison of crashes found that overall traffic crashes, injury crashes, and fatal crashes were reduced. Intercept surveys and local traveler panel surveys found that travelers appear generally satisfied with the understandability, usefulness, and availability of traveler information.

Summary of Overall Benefits

The ITS technologies deployed for the I-80 Summit Corridor between Cheyenne and Laramie were effective in:

- Improving identification of hazardous weather, road, traffic conditions
- Reducing traffic speeds during hazardous travel conditions
- Reducing the overall number of traffic crashes, injury crashes, and fatal crashes.

Figure ES1. Summary of Overall Benefits

Figure ES2 highlights the lessons learned during the evaluation of the I-80 DMS Project. The implementation of the technologies and operational experience has provided WYDOT with numerous lessons that will guide the agency through future enhancements. During the evaluation period, WYDOT has continued to improve their ability to increase traveler safety, mobility, and satisfaction by expanding ITS technology across Wyoming. Interstates 25, 80, 90 and numerous state roads now have Dynamic Message Signs, CCTV cameras, weather stations, and road sensors with travel condition information accessible from HAR, DMS, text message, 511, e-mail, and the WYDOT Web site.[1]

Summary of Lessons Learned

- Cameras are very useful for quickly observing and verifying travel conditions.
- Integrating information and colocating agencies improves agency coordination.
- DMS are often effective in controlling traffic speeds, but multiple factors influence that effectiveness.
- Consider the safety factors related to deploying a remotely operated road closure system.
- Travelers are most responsive to accurate, timely, and precise information.

Figure ES2. Summary of Lessons Learned

[1] See: Wyoming Department of Transportation, "Wyoming Travel Information Map," available at: Wyoming Travel Information Map (last accessed October 5, 2010).

CHAPTER 1. INTRODUCTION

1.1 Background

Wyoming is the ninth largest state in the United States, covering 97,814 square miles. One of three states bounded by straight lines, the distance from the north border to the south border is 276 miles (444 km) and the distance from the east to west border is 375 miles (603 km).[2] The state is located in the Rocky Mountain portion of the western United States, with the Continental Divide passing from the northwest to the south central border. Situated between Colorado and Montana where the Great Plains meets the Rocky Mountains, the state is a great plateau broken by a number of mountain ranges.[3] As such, Wyoming has the second highest mean elevation in the United States at 6,700 feet above sea level.[4]

The climate is semiarid, but because of the topographical diversity, it is also varied. Annual precipitation varies from as little as 5 inches to as much as 45 inches a year. In winter, Wyoming is often beneath the jet stream, or north of it, resulting in frequent strong winds, blasts of arctic air, and precipitation. In the summer, a typical day will start out bright and sunny, and around noon, clouds will appear on the western horizon, with thunderheads developing by mid-afternoon. Scattered, isolated thundershowers will dot the landscape in late afternoon and early evening. Some storms can be severe and produce strong winds and hail.[5]

Cheyenne (the State Capital) and Laramie are the gateway cities for visitors entering the State from the southeast on I-80. The prairies of southeast Wyoming support farming and ranching, where herds of cattle and sheep and vast stretches of wheat fields populate the landscape. The plains give rise to mountain ranges, where the I-80 cuts through the Laramie Mountains and the Medicine Bow Range (known locally as "the Snowy Range"[6]). The mountainous corridors can be difficult to travel, especially during adverse weather conditions that produce precipitation,

[2]"About Wyoming, A Narrative About Wyoming," State of Wyoming Web site, available at: State of Wyoming website (last accessed October 19, 2010).

[3]Ibid.

[4]U.S. Department of the Interior, U.S. Geological Survey.

[5]*Wyoming's Weather & Climate*, Wyoming Travel & Tourism Web site, available at: Wyoming Office of Tourism (last accessed October 19, 2010.)

[6] Ibid.

blowing snow, and high winds that impact traveler safety and challenge road maintenance operations.

1.2 Statement of the Problem

The I-80 is a critical transportation corridor not only within Wyoming, but also regionally and nationally. The I-80 corridor provides for major freight movements between the middle and western portions of the United States. Along I-80 in southern Wyoming, traffic travels through high mountain passes that are often closed due to weather and weather-related incidents. Over the 8-year period from 2002 to 2009, there have been 161 road closures, of which at least 89 were due to vehicle crashes.

Due to the high incidence of crashes on I-80 between mile posts 325 and 335 (known locally as "the Summit"), the Wyoming Department of Transportation (WYDOT), in conjunction with the FHWA and Tabler & Associates, conducted a safety improvement study[7] for the Transportation Commission of Wyoming. This Summit Corridor, the highest elevation along the entire length of I-80, often experiences intensely hazardous road weather conditions, including wind speeds exceeding 60 mph, snow, ice, and fog. The study investigated crashes occurring from January 1996 through August 2001 to identify the contributing factors and recommend safety improvements that could reduce crash incidence. Icy road conditions were reported for 74 percent of all crashes and blowing snow was identified as the main cause of icy roads. Based on the analyses and field observations, the study's safety improvement objectives included: immediate detection of changes in weather, road, or traffic conditions requiring maintenance or traffic control response; reduction in traffic speeds; reduction in blowing snow; and improvements in roadway delineation. The I-80 Dynamic Message Signs (DMS) project is a part of this safety improvement effort and includes non-ITS (but equally effective) solutions such as snow fencing and improvements to roadway delineation. In addition, WYDOT has implemented advisory speed limits along the Summit Corridor based on weather, road, and/or traffic conditions to reduce vehicle speeds during hazardous travel conditions.

1.3 Overview of the I-80 DMS Project

The I-80 DMS project is a rural infrastructure deployment of ITS devices that were integrated with existing WYDOT transportation management systems. The integrated systems were used by WYDOT to provide credible and consistent information and support maintenance and

[7] Tabler, R.D., *Safety Improvement Study: Interstate-80 Mile 325-335*, prepared for the Transportation Commission of Wyoming, Project No. NH-I080-05(145), July 31, 2002.

operational requirements such as implementing road closures and variable speed limits in the Summit Corridor. WYDOT has conducted the I-80 DMS project in conjunction with two other stakeholders: the Wyoming State Highway Patrol (WYSHP) and the Wyoming Office of Homeland Security, Department of Criminal Investigation.

The ITS devices deployed for this project included DMS, speed sensors, blank-out signs, Highway Advisory Radio (HAR), Environmental Sensor Stations (ESS), Closed-Circuit Television (CCTV) camera systems, and the associated communications infrastructure necessary to monitor and operate the devices. The ITS devices covering the Summit Corridor are monitored by WYDOT Operators in the WYDOT Traffic Management Center (TMC) in Cheyenne. The Operators can monitor the traffic, road, and weather conditions on I-80 between Cheyenne and Laramie using the ESS information and CCTV. The Operators can provide information to travelers using the blank-out signs, HAR system, WYDOT Web site, and broadcast media.

The map in Figure 1 shows both the portion of the I-80 across southern Wyoming under evaluation and the I-80 DMS project instrumentation for the Summit Corridor between Cheyenne and Laramie. The camera symbols in the figure indicate the locations of CCTV cameras, the black boxes with arrows identify DMS locations and direction of vehicle travel, and the white boxes with red thermometers show the location of weather stations.

Wyoming DOT

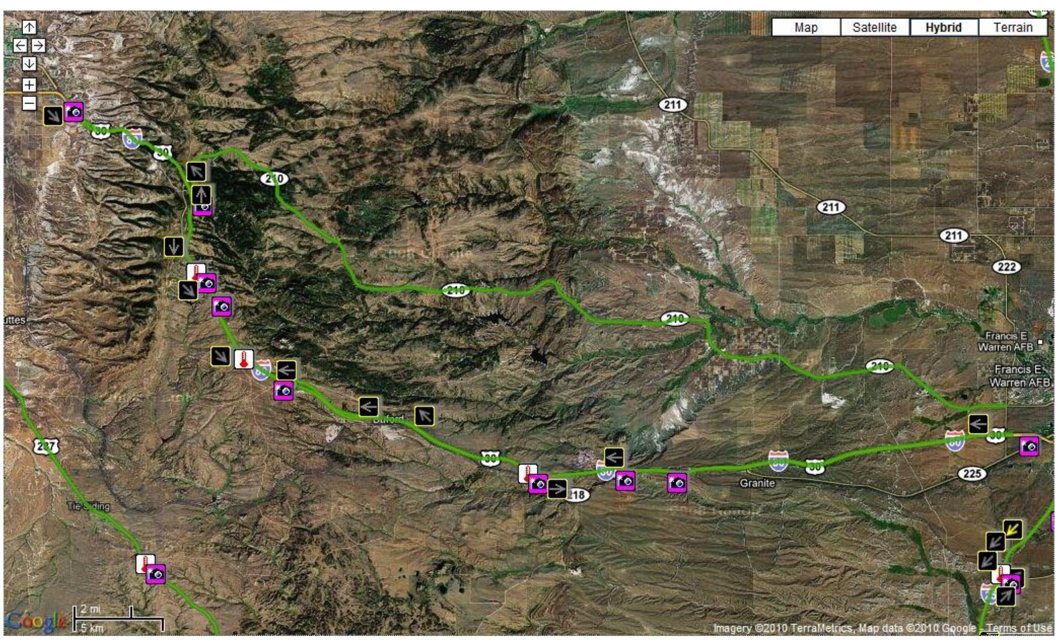


Figure 1. Map of I-80 through Southern Wyoming

1.4 Overview of I-80 DMS Evaluation

The Intelligent Transportation Systems (ITS) integration component of the Federal Highway Administration's (FHWA) ITS Deployment Program was conducted to accelerate the integration and interoperability of ITS in metropolitan and statewide settings. Projects approved for funding have been assessed as supporting the improvements of transportation efficiency, promoting safety, increasing traffic flow, reducing emissions, improving traveler information, enhancing alternative transportation modes, building on existing ITS projects, and promoting tourism. From among the population of ITS Integration Program projects earmarked for Fiscal Year (FY) 2003, a small number of projects were selected as candidates for national evaluation. The Southern Wyoming I-80 Dynamic Message Signs (I-80 DMS) project is one of them.

An Evaluation Team, under direction from the U.S. Department of Transportation (USDOT) ITS Joint Program Office (JPO), was selected to conduct a national evaluation of the I-80 DMS project. The following four areas were investigated as part of this evaluation:

- Safety Impacts.
- Mobility Impacts.
- Customer Satisfaction.
- Lessons Learned.

The purpose of this evaluation was twofold: to determine whether the safety, mobility, and customer satisfaction goals of the project were met and to develop a set of lessons learned to assist others who may be considering similar deployments. A description of the national evaluation was presented in the document titled: *National Evaluation of the FY 2003 Earmarked ITS Integration Project: Southern Wyoming, I-80 Dynamic Message Signs Evaluation Plan*. The subsequent document entitled *National Evaluation of the FY 2003 Earmarked ITS Integration Project: Southern Wyoming, I-80 Dynamic Message Signs Final Detailed Test Plan* complemented the Evaluation Plan by providing a detailed description of how the four areas would be investigated for this evaluation. This Final Phase III Evaluation Report presents the findings of the system impacts and lessons learned for the ITS deployment on I-80 between Cheyenne and Laramie.

1.5 Document Organization

The remainder of this Evaluation Report is organized as follows:

- **Section 2** describes the evaluation approach.
- **Section 3** discusses the safety, mobility, and customer satisfaction impacts of the deployed system.

- **Section 4** identifies various lessons learned based on the evaluation results, focus group discussions, and interviews/discussions with WYDOT and WHP.
- **Section 5** describes the conclusions of the evaluation.

CHAPTER 2. EVALUATION APPROACH

A structured approach was used in developing the methodology for evaluating the I-80 DMS project. Project documents (earmark funds application, WYDOT-sponsored research reports, maps, etc.), site visits and meetings, and follow-up discussions with project management and staff were used to develop the evaluation plan. The *I-80 Dynamic Message Signs Final Evaluation Plan* provided a roadmap for the evaluation and built upon both the Evaluation Team's initial technical proposal and its preliminary assessment of available data. After review and approval of the evaluation plan, a detailed test plan, the *Southern Wyoming I-80 Dynamic Message Signs Final Detailed Test Plan,* was developed to provide a more detailed description of the evaluation methodology, schedule, reporting requirements, organization, and staffing.

In general, the I-80 DMS project evaluation consisted of a study of system impacts and the development of lessons learned. The system impact study measured or confirmed the expected outcomes of the system in terms of the safety, mobility, and customer satisfaction impacts. The lessons learned have been based on the stakeholders' experiences, and are intended to be useful for other agencies in developing a similar system. In summary, the intent of the evaluation has been to:

- Examine the project's impact on managing vehicle speeds, on reducing the number of crashes and delays, and on contributing to more effective road closure decisions;
- Gain insight into road closure decisions and best practices in the use of the automated road closure systems through interviews of operations, maintenance, and law enforcement personnel;
- Investigate traveler perceptions and satisfaction with the project; and
- Document lessons learned from the planning, implementation, and operations of the project.

The following sections provide a description of the evaluation objectives, approach, and study areas.

2.1 Evaluation Objectives

The project objectives listed in Table 1 were the starting point for developing the evaluation study areas and hypotheses. Using the project objectives, a series of hypotheses were developed and shared with the WYDOT stakeholders at the Kick-Off Meeting held on August 25, 2006. Based on the discussions with WYDOT, four key hypotheses and four secondary hypotheses of interest were identified. The key hypotheses were those related to changes in traffic speeds resulting from DMS advisories, the understandability of messages and advisories, the ability to obtain useful weather, road, or traffic information, and the usefulness of the automated road closure system.

Table 1 shows the project goals and objectives and the related hypotheses.

Table 1. Project Goals, Objectives, and Related Hypotheses

Goal Area	Project Objective	Key or Secondary	Hypothesis
Safety	Use DMS, HAR, and other traveler information resources to reduce speeds under denigrated roadway conditions and even allow travelers to defer unsafe trips entirely.	Key	The project will effectively reduce traffic speeds and variability in response to deteriorated roadway conditions (e.g., during incidents, inclement weather, etc.).
	Increase ability to obtain useful information concerning weather, road surface, or traffic conditions on I-80 between Cheyenne and Laramie.	Key	The project will increase the ability of operations, maintenance, and law enforcement to obtain useful weather, road surface, or traffic condition information on I-80 between Cheyenne and Laramie.
	Reduce the overall rate of crashes, fatalities, and injuries.	Secondary	The project will result in a reduction in the overall rate of crashes, fatalities, and injuries.
Mobility	Increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner.	Secondary	The project will increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner.
	Reduce the overall number and duration of road closures.	Secondary	The project will result in a reduction in the overall number and duration of road closures.
Customer Satisfaction	Implement an automated road closure system that will be useful to WYDOT.	Key	The automated road closure system will be perceived as useful in closing and/or re-opening roadways.
	Provide credible, consistent, and useful messages and advisories that the traveling public will be able to easily understand and will act upon to achieve safer travel.	Key	The traveling public will be able to easily understand the messages and advisories enabled by the deployment of the project and will act upon this information to effect safer travel.
	Implement a project that will assist local travelers in making go/no go travel decisions.	Secondary	The project will be perceived as useful to assist local travelers in making go/no go travel decisions.

2.2 Evaluation Methodology

The evaluation consisted of four study areas: safety, mobility, customer satisfaction, and lesson learned. Safety, mobility, and customer satisfaction areas were based on the project goals and objectives. The lessons learned study area focused on lessons learned with respect to the planning, implementation, and operations of the project. The following provides a synopsis of the approach and data collection activities for each of the study areas. Additional details about the study areas can be found in the *Southern Wyoming I-80 Dynamic Message Signs Final Detailed Test Plan*.

2.2.1 Safety Study

The safety study investigated the impacts of the I-80 DMS project along the Summit Corridor in terms of changes in vehicle speeds, ability to obtain useful weather, road, and traffic information, and crash rates.

This study utilized three types of measures to investigate the hypotheses: 1) vehicle speeds from road-side sensors; 2) operations, maintenance, and law enforcement opinions and perceptions; and 3) crash records along the I-80 Summit Corridor. Table 2 shows the hypotheses, measures, data sources, and analysis methods used for the safety study. The safety study required collecting before and after data (January 1999 through December 2005 and January 2006 through April 2010, respectively). The project's impacts on vehicle speeds and crashes were assessed using before and after comparisons. Since vehicle speeds were not available until after deployment of the road side speed sensors, before and after comparisons were made by recording vehicle speeds upstream/downstream of DMS locations. Comparisons of crashes consisted of examining 1999 to 2005 crash records (before) with 2006 to 2010 records (after). Impacts on opinions and perceptions were collected periodically after the 2006 deployment of the system.

Table 2. Safety Study: Evaluation Approach

Hypothesis	Measures	Data Sources	Analysis
The project will effectively reduce traffic speeds and variability in response to deteriorated roadway conditions (e.g., during incidents, inclement weather, etc.).	Vehicle speed (mean and standard deviation).	Speed sensor data, DMS logs, RWIS data, and dispatcher logs.	Comparison of vehicle speeds upstream and downstream of the DMS by time of day/time of year, weather, road, and DMS MSG conditions.

Hypothesis	Measures	Data Sources	Analysis
The project will increase the ability of operations, maintenance, and law enforcement to obtain useful weather, road surface, or traffic condition information on I-80 between Cheyenne and Laramie.	Operations, maintenance, law enforcement perceptions.	Interviews with operations, maintenance, and law enforcement perceptions, and comments.	Analysis of operations, maintenance, and law enforcement perceptions of ability to detect changes in weather, traffic conditions, and road surface conditions.
The project will result in a reduction in the overall rate of crashes, fatalities, and injuries.	Crashes, fatal crashes, and injury crashes.	Corridor crash data, traffic counts/volume by vehicle type, DMS logs, RWIS data, dispatcher logs.	Before and after comparison of crashes, fatal crashes, and injury crashes by TOD/TOY, weather, road, and DMS MSG conditions.

2.2.2 Mobility Study

The mobility study examined the ability of both public and private entities to respond to changes in weather, road, and traffic conditions, and investigated whether or not there was a reduction in the overall number and duration of road closures.

This study employed three measures: 1) operations, maintenance, and law enforcement opinions and perceptions; 2) local traveler perceptions; and 3) the number and duration of road closures. Table 3 summarizes the hypotheses, measures, data sources, and analysis methods used for the mobility study.

The ability of the public and private entities to respond to changes in weather, road, and traffic conditions were examined by collecting information about road closures and travel advisories; by conducting interviews with operations, maintenance, and law enforcement personnel; and by conducting traveler surveys and focus groups to obtain local traveler perceptions. To explore the reduction in the overall number and duration of road closures, the number and duration of road closures were examined by collecting and analyzing the DMS logs, RWIS data, and dispatcher logs. The analyses consisted of before and after comparisons of the road closures, statistical analysis of the survey data, and review/summarization of expressed opinions and perceptions.

Table 3. Mobility Study: Evaluation Approach

Hypothesis	Measures	Data Sources	Analysis
The project will increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner.	Operations, maintenance, law enforcement perceptions. Traveling public perceptions.	Operations, maintenance, law enforcement perceptions and comments from interviews. Local Traveler Surveys and Focus Groups.	Analysis of operations, maintenance, law enforcement perceptions. Analysis of periodic surveys via e-mail/ phone, focus group meetings.
The project will result in a reduction in the overall number and duration of road closures.	Number of road closures, duration of road closure.	DMS logs, RWIS data, and dispatcher logs.	Before and after comparison.

2.2.3 Customer Satisfaction Study

The customer satisfaction study investigated: (1) perceptions and attitudes of operations, maintenance, and law enforcement personnel with the automated road closure system; (2) perceptions and behaviors of the traveling public about the DMS messages and advisories; and (3) the perceptions of credibility, consistency, and usefulness of the project to assist local travelers in making go/no go travel decisions.

This study used three types of measures: 1) operations, maintenance, and law enforcement opinions and perceptions; 2) traveler perceptions; and 3) local traveler perceptions. Table 4 shows the hypotheses, measures, data sources, and analysis methods. Interviews were conducted to investigate operations, maintenance, and law enforcement insights into the automated road closure system. Intercept surveys of travelers to investigate the insights of the traveling public were conducted at the I-80 summit corridor rest stops. In addition, a panel of local travelers (i.e., travelers who regularly traveled the Summit Corridor between Cheyenne and Laramie) were established and periodic surveys were distributed to obtain their perceptions and self-reported changes in travel behaviors. Finally, a focus group with drivers who frequently traveled between Cheyenne and Laramie was held to obtain feedback on the understandability of different DMS, 511, and HAR messages.

Table 4. Customer Satisfaction: Evaluation Approach

Hypothesis	Measures	Data Sources	Analysis
The automated road closure system will be perceived as useful in closing and/or re-opening roadways.	Operations, maintenance, and law enforcement perceptions.	Operations, maintenance, and law enforcement perceptions and comments from interviews.	Analysis of operations, maintenance, law enforcement perceptions.
The local traveling public will be able to easily understand the messages and advisories enabled by the deployment of the project, and will act upon this information to effect safer travel.	Traveler perceptions. Local traveler panel perceptions.	Intercept surveys of travelers at rest stops, DMS logs, RWIS data, dispatcher logs, Cheyenne/Laramie travel times. Periodic surveys via E-mail/phone, and focus group meetings.	Analysis of traveler intercept surveys, local traveler surveys, and focus group meetings.
The project will be perceived as credible, consistent, and useful to assist local travelers in making go/no go travel decisions.	Local traveler panel perceptions.	Periodic surveys via e-mail/phone and focus group meetings.	Analysis of local traveler surveys and focus group meetings.

2.2.4 Lessons Learned

The lessons learned effort documented experiences and suggestions that will be useful to other stakeholders and were derived from the project stakeholders' planning, implementation, and operations experiences.

While documenting lessons learned, the Evaluation Team sought answers to general questions such as: "What was done right?"; "What would one do differently?"; "How could one be more effective in the future?"; and "What experience ('lesson learned') would one pass on to his or her peers?" Some of the specific questions included:

- What are some best practices in the use of an automated road closure system?
- Does the 511 system reduce the workload on operations and maintenance staff?
- What are the most effective sets for DMS advisories, 511, and HAR?
  - How do you warn people of conditions miles ahead?
  - Do the needs and perceptions of CVO differ from operators of passenger vehicles?
    - If so, how?
  - Is the posting of travel times relevant in rural locations?
- What is the value of CCTV cameras?

- Can speed advisories or variable speed limits allow roads to remain open longer?
- How to determine safe vehicle speeds.
- How to operate the various elements of the system in an integrated, effective fashion.
- What infrastructure do you need to support effective use of variable message signs and DMS?
  - What is the required sign spacing?
- How effective are DMS advisories versus Variable Speed Limit (VSL)?
- Can we actually cause motorists to defer trips by providing more detailed weather information?

The majority of the data collection activities for the development of lessons learned occurred during the course of discussions and interviews with WYDOT, WYSHP, and travelers.

CHAPTER 3. SYSTEM IMPACTS

3.1 Safety Impacts

The safety impacts study investigated the following hypotheses:

- The project will effectively reduce traffic speeds and variability in response to deteriorated roadway conditions (e.g., during incidents, inclement weather, etc.).
- The project will increase the ability of operations, maintenance, and law enforcement to obtain useful weather, road surface, or traffic condition information on I-80 between Cheyenne and Laramie.
- The project will result in a reduction in the overall rate of crashes, fatalities, and injuries.

The following sections describe the analyses that were conducted to investigate the impact on traffic speeds, ability to obtain useful weather, road, and traffic condition information, and the overall crashes, injuries, and fatalities.

3.1.1 Impact on Reducing Overall Traffic Speeds

The analysis of traffic speeds during periods of deteriorating travel conditions and DMS advisories found that a majority of overall average speeds decreased. This effect was most pronounced in the eastbound direction, which often showed average speeds decreasing from 5 to 10 mph depending on the advisory message and travel conditions. To investigate the impact on traffic speeds, WYDOT's road-side vehicle-speed sensors captured and archived data along I-80 between Cheyenne and Laramie. Both eastbound and westbound speeds were examined for the period from 5/27/08 to 3/17/2010. During this period, 9 dates yielded 16 events that were examined. Each event was selected because DMS speed advisory messages were displayed to drivers due to adverse road/weather conditions. Table 5 shows the dates, road/weather condition, and direction and type of adverse travel events that were examined for this analysis. The types of adverse conditions affecting travel included: limited visibility due to fog (shown in Figures 2 and 3) or blowing snow (shown in Figure 4); slick road due to icy, snowy, wet road (shown in Figure 5); and/or strong winds.

The following sections describe the results and findings for before and after comparisons of traffic speeds.

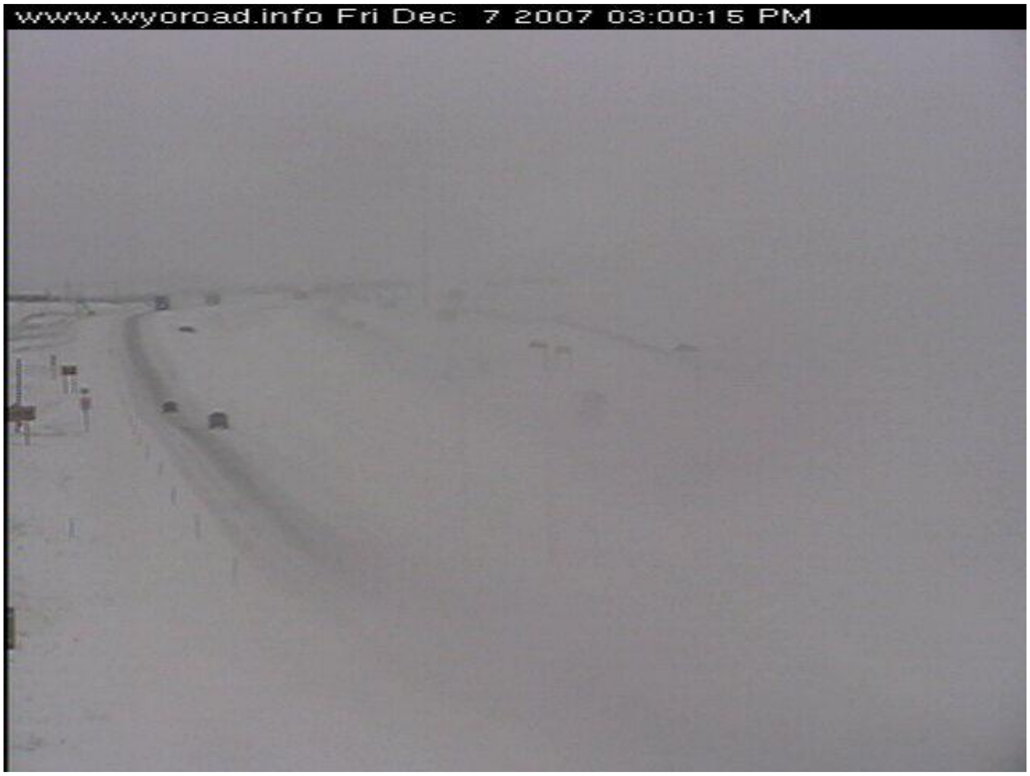
Table 5. Adverse Travel Events

Event #	Date	Road/Weather Condition	Direction and Type of Event
1 2	May 27, 2008	Fog	WB: Heavy Fog Limited Visibility EB: Heavy Fog Limited Visibility
3 4	Oct. 12, 2008	Snowfall, Icy Road	WB: Icy Road Snowfall EB: Icy Road Snowfall
5 6	Nov. 23, 2009	Strong Wind, Blowing Snow, Slick Road	WB: Slick Road Strong Wind Blowing Snow EB: Slick Road Blowing Snow
7 8	Dec. 1, 2009	Fog, Blowing Snow, Slick Road	WB: Dense Fog Reduced Visibility Slick Road Snow Blowing EB: Slick Road Snow Blowing
9	Mar. 23, 2010	Blowing Snow, Poor Visibility, Slick Road	EB: Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH
10	Mar. 24, 2010	Slick Road	WB: Slick Road Advise 45/55/60/65 MPH
11 12	Apr. 2, 2010	Blowing Snow, Poor Visibility, Slick Road	WB: Advise 40 MPH Slick Road Poor Visibility EB: No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH
13 14	Apr. 7, 2010	Snow, Slick Spots, Wet Road	WB: Wet Road Snow Reduce Speed EB: I-80 Closed & Slick Spots Snow Reduce Speed
15 16	Apr. 17, 2010	Fog	WB: Dense Fog Poor Visibility Reduce Speed EB: Dense Fog Poor Visibility Reduce Speed

Legend: WB = Westbound, EB = Eastbound

Wyoming DOT

Figure 2. Limited Visibility Conditions on I-80



Wyoming DOT

Figure 3. Foggy Conditions on I-80

Wyoming DOT

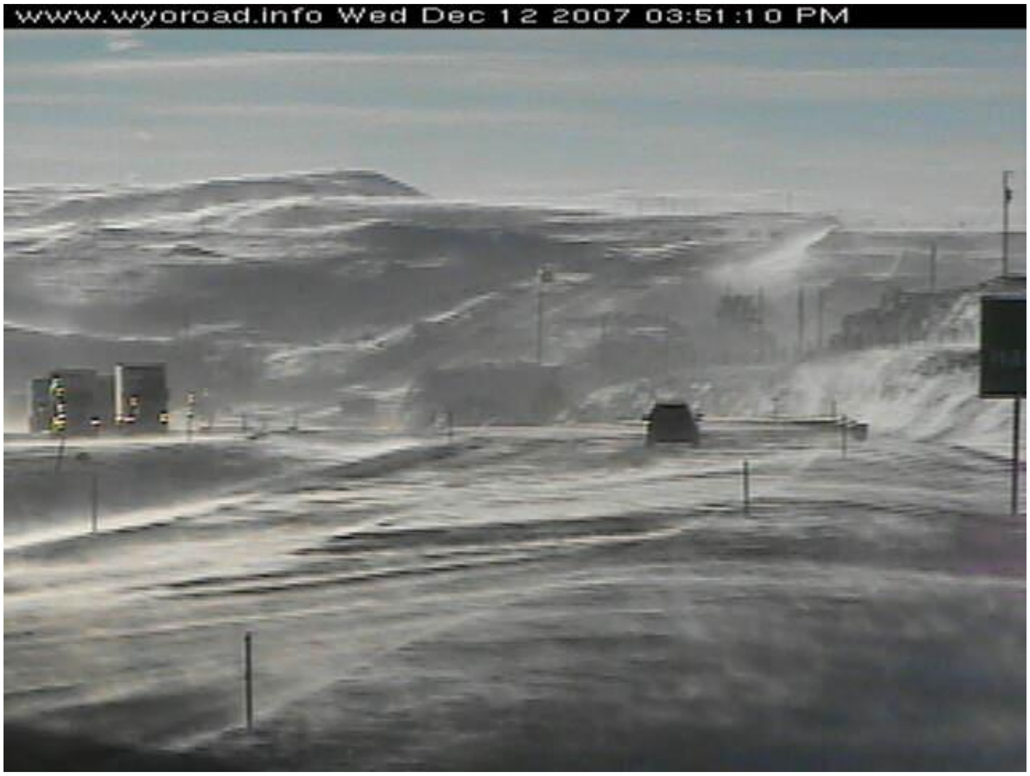
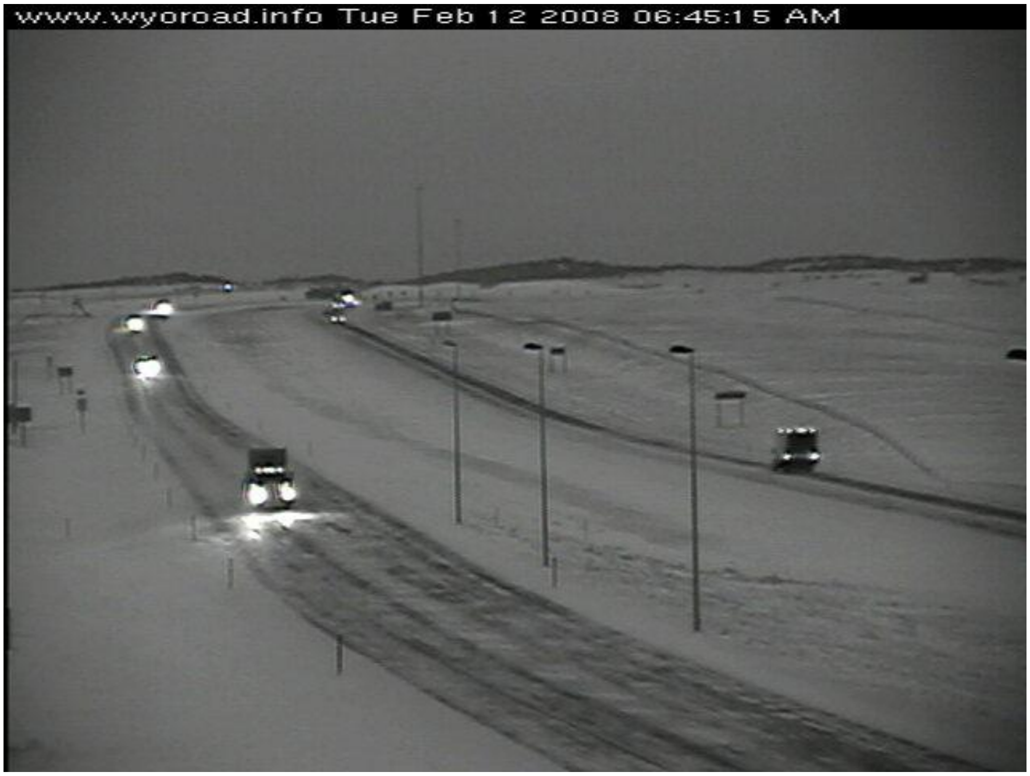


Figure 4. Blowing Snow on I-80



Wyoming DOT

Figure 5. Slick Road on I-80

3.1.1.1 Traffic Speed Changes By Direction

The analyses of traffic speeds involved examining the eastbound and westbound directions separately because of differences in road grade, location of speeds sensors, and placement of DMS. For the westbound direction, the analyses focused on the segment of I-80 approaching the summit at milepost 323.1. Figure 6 depicts the location of speed sensors and DMS for westbound I-80 between mileposts (MP) 339 and 321. The road surface is depicted as the horizontal gray area separated by dashed lines. Speed sensors are shown roadside with the milepost location underlined (e.g., s330 indicates a speed sensor at milepost 330). Additional sensors (not shown in the figure) were also located at 336.5, 335.5, and 326.9. The black numbered boxes show the location of the DMS (e.g., box 331 means the DMS is located at milepost 331). Along the top of the figure are milepost designations to provide an indication of the figure scale. When traveling westbound (right to left in the figure), vehicles are headed towards the summit (and Laramie) and for the most part experience a gradual upgrade climb until near the summit pass.

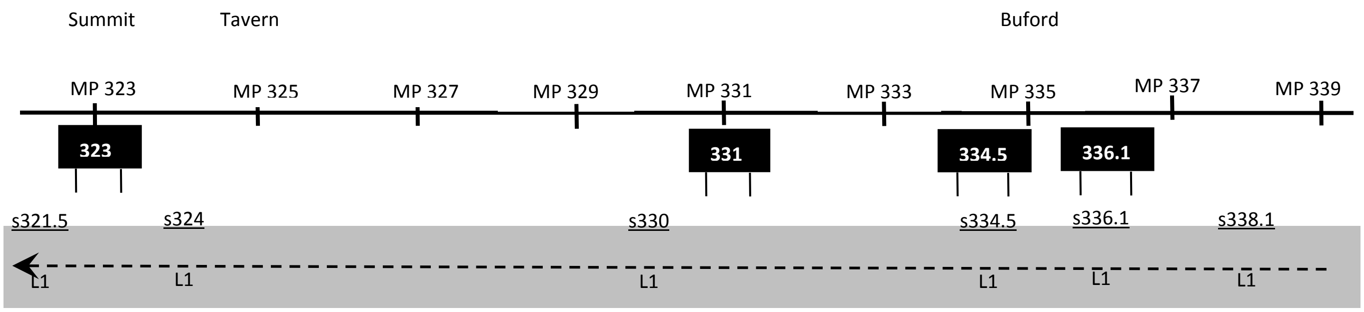


Figure 6. Speed Sensors and DMS on Westbound I-80 between MP 339 and 321

The speed sensors aggregated individual vehicle speeds into 1 minute averages, which were then recorded and subsequently used to calculate hourly average speeds. To investigate overall changes in westbound vehicle speeds the average speed for the 1 hour before a DMS advisory was compared to the average speed for the first hour after a DMS was continuously displayed. Overall, the variability of the before and after hourly average speeds were very similar, with both having an average standard deviation of about 7 mph.

Figure 7 shows the change in average speeds for the eight westbound travel events described in Table 6 above. The bold horizontal line represents difference (or change) in speed between the before and after periods (i.e., change of zero miles per hour). Data points above the bold line indicate an increase in speed and those points below show decreases in speeds. Speed changes are not available at every sensor location because each adverse travel event (i.e., date) had unique circumstances and DMS advisories may have been displayed at different milepost locations. As such, comparison of speeds across the entire road segment for every event was not examined.

The results in Figure 7 show that about two-thirds (23 of 34) of the changes in speed were decreases with just under one-third (10 of 34) showing decreases of more than 5 miles per hour. The largest speed change decreases (on 4/17/2010) occurred when a blank DMS (i.e., no message displayed) during the before period was changed to display “Dense Fog Poor Visibility Reduce Speed.” As a result, drivers decreased their speed from about 68 mph to 54 mph (13.5 mph decrease) at milepost 336.1 and from 62 mph to 48 mph (14 mph decrease) at milepost 330. The largest speed change increases resulted from two factors: an improvement of travel conditions and a small number of speeds (i.e., small sample size) contributing to the average. For example, the large increases for 3/24/2010 occurred when I-80 was closed in the before period, resulting in only a few vehicles driving at a low speed past the sensors (at milepost 338.1 one vehicle drove past at 33 mph). In the after period, the road was opened and 98 vehicles traveling west drove past the sensor averaging about 52 mph (the DMS displayed “Slick Road

Snow Advise 45 MPH). Similar situations also explain the increases found on 4/2/2010 and 11/23/2009. In both cases traffic speeds were slowed during the before period because of crashes. During the after period, travel conditions improved and as a result average speeds increased.

Discounting the cases with large increases in speeds, it appears that the DMS advisories were effective in decreasing average speeds in a majority of cases when DMS advisories were used.

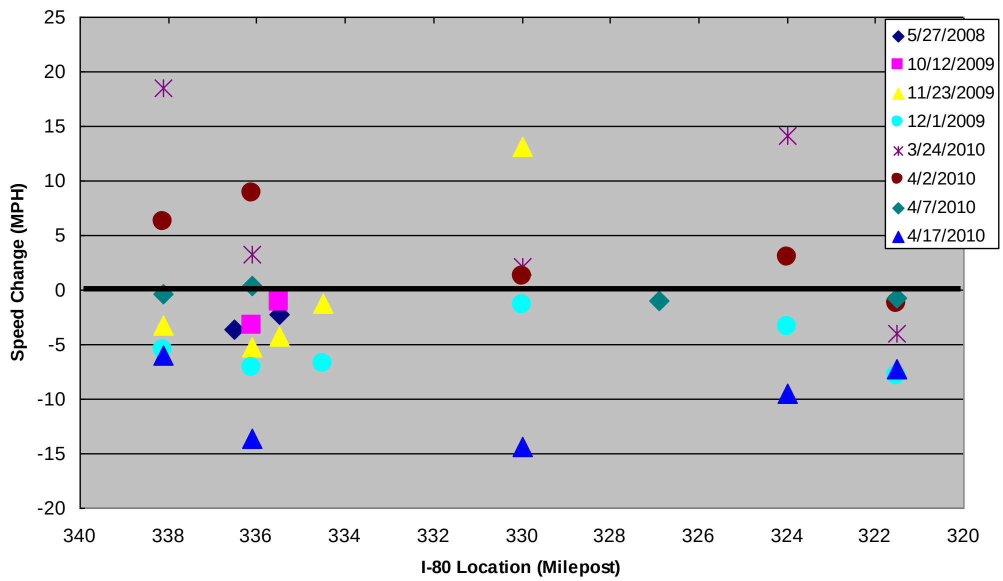


Figure 7. Westbound Change in Average Speeds

Figure 8 shows the location of speed sensors and DMS for eastbound I-80 between milepost 317 and 330. When traveling in the eastbound direction, vehicles are headed away from Laramie (left to right in the figure) and after crossing the summit (near milepost 323.1) experience a downgrade down the summit then a gradual downgrade to Cheyenne.

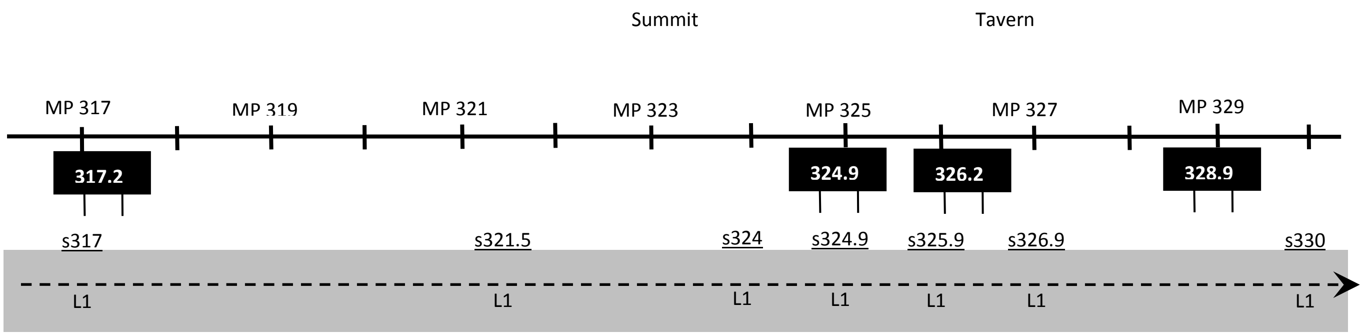


Figure 8. Speed Sensors and DMS on Eastbound I-80 between MP 317 and 330

A similar, more prominent trend was found for eastbound vehicle speeds. Using the same method to investigate overall changes in eastbound vehicle speeds, most average speeds decreased. As shown in Figure 9, the change in average speeds for the eight adverse travel events show that about three-fourths (32 of 43) of the changes in speed were decreases with about 44 percent (19 of 43) showing decreases of more than 5 miles per hour.

The large speed change increase on 11/23/2009 occurred when there was a crash in the before period (slowing traffic) and in the after period travel conditions improved (increasing traffic speeds). On 5/23/2008, average speeds during the before period were about 43 mph (the DMS displayed “Click-it Don’t Risk It Please Buckle Up”) but increased to about 51 mph when the DMS was changed to “Heavy Fog Limited Visibility Speed Limit 45 MPH.”

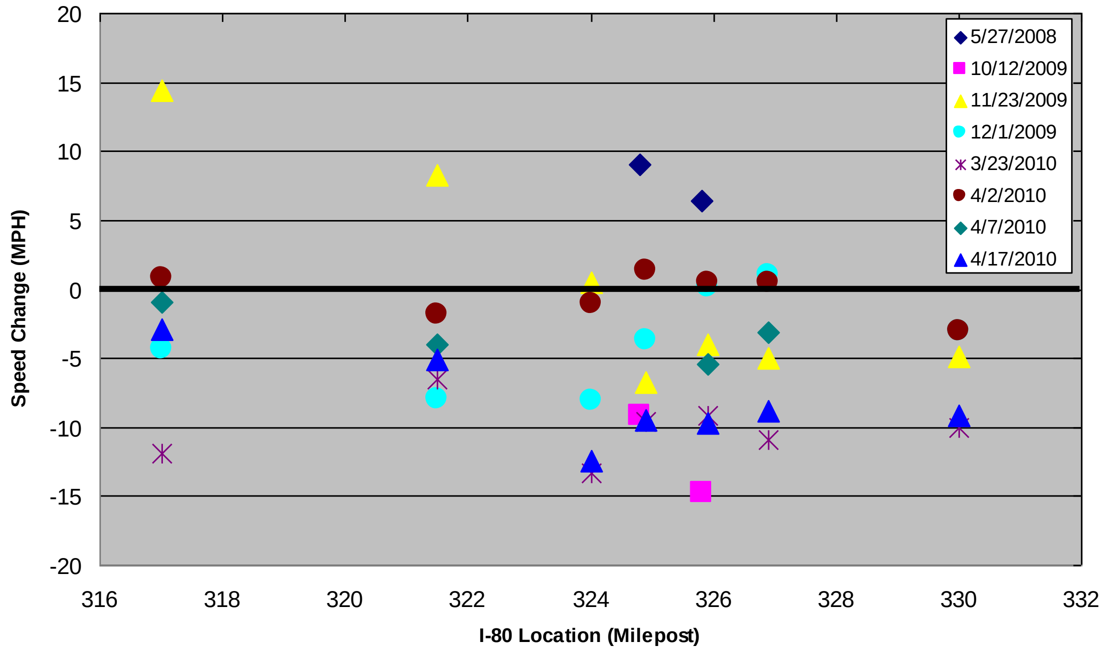


Figure 9. Eastbound Change in Average Speeds

For both the westbound and eastbound directions, the overall variability in before and after speeds were very similar (both averaged about 7 mph) and the largest decreases in speeds occurred when there were reduced visibility due to fog or blowing snow. For example, Figure 10 shows the average speeds by milepost location and before and after time period for westbound travel on 4/17/2010. The large speed reductions resulted when, during the before period, no messages were displayed on the DMS and drivers were provided no warnings or limitations on their speeds. During this before period (shown as white circles in the figure), average speeds ranged from 70 miles per hour at milepost 338.1 to 60 miles per hour at MP 324. In the first hour after (and over the next four hours), the DMS messages at 336.1, 334.5, 331.0, and 323.0 (depicted as the vertical bars) all displayed "Dense Fog Reduced Visibility Reduce Speed." The result (shown as red boxes in the figure) was a large reduction in speeds (5 to 15 miles per hour) during the first hour after the advisories. The speed reductions continued into the second and third hours afterwards. During the fourth hour, speeds rose at MP 338.1 from about 52 miles per hour and continued to increase through MP 321.5 to speeds equivalent to the before period.

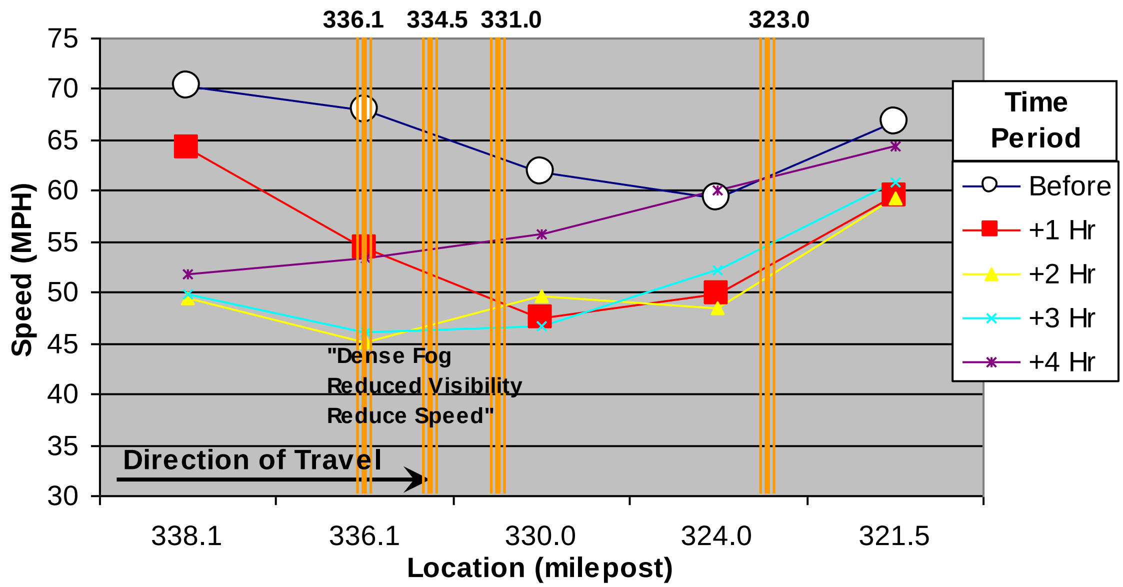


Figure 10. Westbound 4/17/2010 Change in Average Speeds

The circumstances where average speeds increased occurred during times of improving travel conditions when the before speeds were lower due to poor conditions and the after period speeds increased with improved travel conditions. For example, in Figure 11 the before hour speeds (white circles) for westbound travel on 3/24/2010 were based on speeds during a road closure. Once the road was reopened, the DMS at MPs 336.1, 334.5, and 331.0 displayed "Advise 45 MPH" advisories. When comparing the before and after average speeds, the before period speeds increased due to better travel conditions. In Figure 11, this is clearly depicted as with each successive hour the DMS message advises higher speeds and average speeds also increase accordingly.

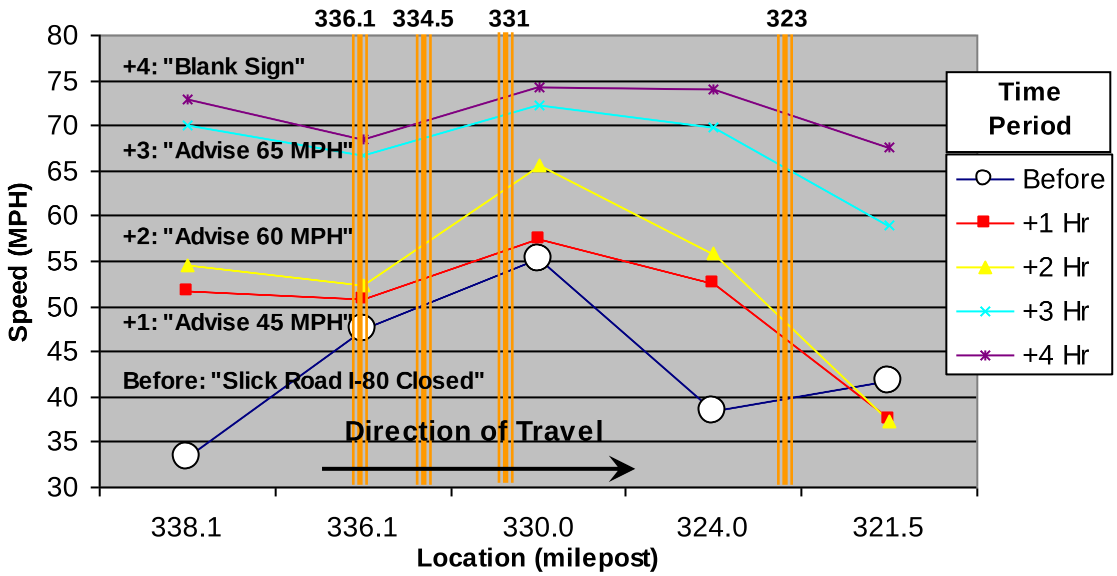


Figure 11. Westbound 3/24/2010 Change in Average Speeds

The large increases in speeds for westbound travel on 11/23/2009 were based on speeds during which I-80 was closed due to a wreck. Shown in Figure 12, the before hour speeds (white circles) at MPs 317 and 321.5 were 52 and 48 miles per hour, respectively. Once the road was reopened, the average speeds at milepost 317 were about 65 miles per hour. Consequently, when comparing the before and after average speeds at milepost 317, the difference in before and after speeds shows a large increase due to higher speeds when the road was reopened.

The other portion of Figure 12 (on right side of the figure between mileposts 324.9 and 330) provides an example of the effect of two different DMS advisory messages on traffic speeds. During the before period, the DMS at MPs 324.9, 326.2, and 328.8 displayed “Reduce Speed” advisories and speeds (depicted as white circles) decreased after each sign from about 60 mph at milepost 324 to about 48 mph at milepost 330. During the after period, the DMS messages were changed to “Advise 45 MPH” and average speeds decreased further to about 43 mph. In addition, the speeds during the first hour after (red boxes) were 5 mph to 8 mph lower than the before (white circles) period between milepost 324.9 and 330. Therefore, it appears that when repeatedly advised to reduce speeds, average traffic speeds continued to decrease, however, repeated “Advise 45 MPH” advisories appear to be more effective and reduced average speeds 5 to 8 mph below the “Reduce Speed” average speeds.

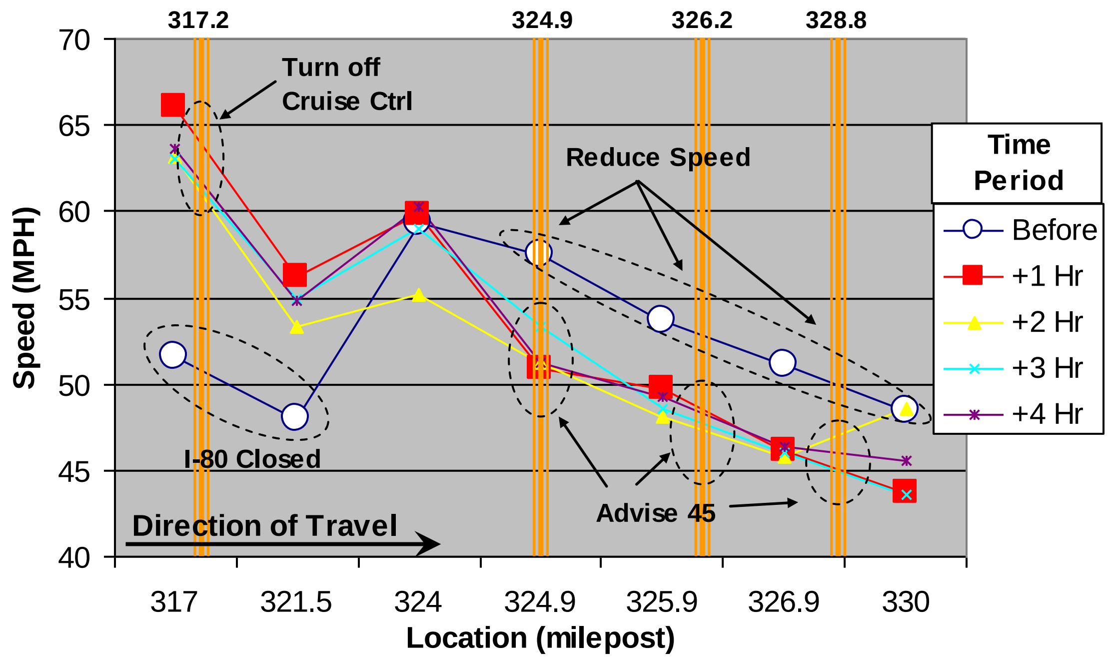


Figure 12. Eastbound 11/23/2009 Change in Average Speeds

These results illustrate several factors that appear to influence the effectiveness of DMS advisories in modifying traffic speeds. The travel conditions (road and weather conditions), type of advisory message (e.g., Reduce Speed versus Advise X MPH), consistency of messages across consecutive DMS, and average vehicle speeds before the advisories all appear to affect whether or not vehicle speeds change.

When travel conditions are improving, average speeds tend to increase, and DMS advisories can be used to guide the rate of increase over several hours. It was also found that advisories were very effective in reducing speeds when travelers encountered limited or poor visibility conditions due to fog or blowing snow.

The type of advisory message also appeared to influence vehicle speeds, but this seemed to be related to vehicle speed before the advisory and travel conditions. In several instances, “Advise 45 MPH” was more effective at decreasing speeds than “Reduce Speed” or “Turn-off Cruise Control.” In general, when the before speed was 65 mph or more, speeds often decreased by about 10 mph. A second or third identical DMS advisory could result in additional decreases or would reinforce the continuation of lower travel speeds. Appendix A provides additional tables of the DMS messages by time and location as well as figures of the corresponding average speeds by hour and location.

Summary: These analyses of vehicle speeds from 16 events found that the DMS advisories were often effective in reducing overall traffic speeds during adverse travel conditions. However, it appears that a number of factors may influence the effectiveness of DMS advisories in reducing speeds, including travel conditions, type of message, and consistency of messages over several DMS locations.

3.1.2 Impact on Ability to Obtain Weather, Road, and Traffic Conditions

As part of the USDOT national evaluation of the Southern Wyoming I-80 DMS earmark project, WYDOT and WHP stakeholders were interviewed to obtain first-hand experiences and opinions regarding: (1) whether or not they felt they obtained useful weather, road surface, and/or traffic condition information; and (2) whether or not they felt they were able to respond to changes in weather, road, and traffic conditions due to the project's ITS improvements. They were also asked whether they had any suggested improvements and the level of impact they felt the project had on their ability to do their jobs, making decisions, and managing road closures These stakeholders included representatives from WYDOT operations and maintenance and WHP.

3.1.2.1 Ability to Obtain Information and Responding to Changing Conditions.

WYDOT and WHP stakeholders were in agreement that the implementation of ITS technology on the Summit Corridor has greatly increased their ability to obtain weather, road, and traffic information and respond to changes in conditions. The CCTV cameras were clearly the favorite technology for obtaining information. The use of cameras to obtain weather, road, and traffic conditions were viewed very favorably by both WYDOT and WHP stakeholders. The cameras were used for checking and verifying unconfirmed reports and (RWIS/speed/ice) sensor information. This enabled operators to obtain first-hand visual information to confirm sensor reports of icy road conditions such as shown in Figure 13.

Wyoming DOT

Figure 13. Icy Road Surface on Bridge near I-80 Summit

Cameras were also used to monitor remote portions of I-80 quickly and at any time, such as the snowy road conditions in Figure 14. Without the cameras operators would be required to rely on in-person reports of conditions to obtain status reports and monitor changes. Sometimes this would mean having to send a person out during hazardous conditions to check a situation and report back via cell phone. For the Summit corridor, the roughly 40 mile distance between Cheyenne and Laramie could mean making a 20 mile trip (one-way) and waiting over 20 minutes to have an area visually checked. Using the cameras, operators and WHP can now choose a camera location; adjust the east/west view, zoom level, etc.; and in a matter of seconds look at the conditions. If needed, they can quickly convey what they see to plow drivers or the Highway Patrol so that action can be taken. Of course, there are limitations depending on weather conditions and lighting; nevertheless, the cameras have, in many situations, expanded the stakeholders' ability to view distant areas quickly.

Wyoming DOT

Figure 14. Night View of Road Conditions on I-80 near MP 327

Finally, the cameras were also useful for identifying changing traffic conditions such as for the tractor trailer accident shown in Figure 15. Depending on the severity and expected duration of the accident, road closures due to crashes or adverse weather events can last for several hours (over 4 hours on average). The impact of long closures can result in long back-ups upstream. In the winter, having thousands of stranded travelers on the road can be dangerous. If the closure is in the evening or at night, the number stranded travelers can quickly exceed the number of vacancies in nearby hotels/motels. Consequently, operators can use the DMS to display road closure advisories to forewarn upstream drivers and discourage them from traveling into the area and becoming stranded on the roadway.

Wyoming DOT

Figure 15. Monitoring Traffic after I-80 Accident on 5/22/2008 East of Laramie

Although not part of the original I-80 Dynamic Message Sign project, the colocation of WYDOT and WHP at the TMC in Cheyenne has also improved the ability of both agencies to obtain weather, road, and traffic condition information and to coordinate/perform their respective missions. The TMC is two adjacent secure areas for the WYDOT statewide traffic management center and the WHP command center. Although each center operates independently, their close proximity, common interest in traveler safety, similar information needs, and frequent reliance/coordination during incidents made colocating a win-win situation. For example, sharing camera and weather sensor information to identify blowing snow, high winds, and traffic back-ups due to crashes allows WHP dispatchers and WYDOT operators to speak directly to each other, improving the response planning process and enabling them to direct deployment of the resources that are most appropriate, to improve activities coordination, and to mitigate the hazard for travelers.

3.1.2.2 Suggested Improvements

In terms of suggested ways to improve weather, road, and traffic information and respond to adverse traveler conditions, several items were mentioned: improvements to speed sensors, additional DMS, more technology beyond the Summit Corridor, and a better system for communicating. Originally, the speed sensors were hoped to be used as a real-time traffic monitoring sensor to supplement the CCTV camera imagery and to provide an indication of where hazardous areas were developing. However, shortly after initial implementation it became clear that the speed sensors and software were not as useful as hoped. Several sensors malfunctioned, adverse weather conditions would cause some sensors to fail, and the software that collected and displayed the speed data to the operators was not presenting information to support the needs of the operators. Consequently, WYDOT has made necessary repairs to get the system operational, has upgraded the software, and has recently begun to use the speed data in their efforts to improve traffic monitoring on I-80.

Stakeholders also mentioned additional DMS and more technology beyond the Summit Corridor as desired improvements. They felt that supplementing the existing technology in the corridor would help WYDOT inform travelers of localized (smaller scale) hazards (such as fog or icy/slick sections) that may develop. With vast sections of the terrain susceptible to rapidly changing conditions due to storms and winds that cause drifting snow, additional technologies to monitor and disseminate condition information may be useful. Also, adding technology to expand the monitoring capabilities beyond the corridor would benefit WYDOT by providing advance warning of storms approaching the corridor. DMS outside the corridor would also benefit travelers approaching the Summit Corridor. If WYDOT provided travelers with advance warning of road closures or hazardous conditions, it could reduce congestion on I-80 and allow travelers to seek out accommodations away from the affected area.

Finally, improvements to the communications system were strongly suggested. During major storm events, radio traffic gets frenzied as different WYDOT crews and staff within the state try to communicate. Although each department has its own radio band, trying to call and hear each other can be difficult and very frustrating. Consequently, crews and staff have also relied on Citizen Band (CB) radios and cell phones for direct communication or when they cannot get on the WYDOT radio.

3.1.3 Impact on Overall Rate of Crashes, Fatalities, and Injuries

Vehicle crash data were obtained with the help of the staff at the WYDOT Highway Safety Program. The crash data included all reported crashes that met the Wyoming Accident Reporting System (WARS) reporting threshold of $1,000 damage, injury, or death. All crashes occurred on the I-80 Summit Corridor between mileposts 317.42 and 356.74 between January 2002 and April 2010. The crashes were categorized into two evaluation periods: before and after ITS deployment along the I-80 Summit Corridor. The before period included all crashes from January 2002 to December 2005. The after period included crashes from January 2006 to April 2010. In addition to dates and times, the data also contained information about: number of injuries/fatalities, road/weather/lighting condition; first harmful event; primary cause; number of drivers involved; vehicle type; driver age and gender.

The following sections describe the results and findings for before and after comparisons of crashes by year, time of year (month, winter driving season), type of crash (injury, fatality), time of day, road condition, weather condition, and other factors (lighting, age, gender).

3.1.3.1 Occurrence of Crashes by Year and Before and After Time Period

Examining the number of crashes by year found a trend indicating crashes decreased from 2002 through 2009. There were a total of 2,180 reported crashes between January 1, 2002 and December 31, 2009, or about 273 crashes per year based on the 8 calendar year period. The number of crashes per year is shown in Figure 16. The highest number of crashes, 317, occurred in 2004, while 2009 had the fewest with 206 crashes. The trend line shows the linear correlation of the number of crashes to year. The proportion of total variation in crashes accounted for by year (R^2 = 0.40) indicated that year "explains" about 40 percent of the variability in number of crashes.

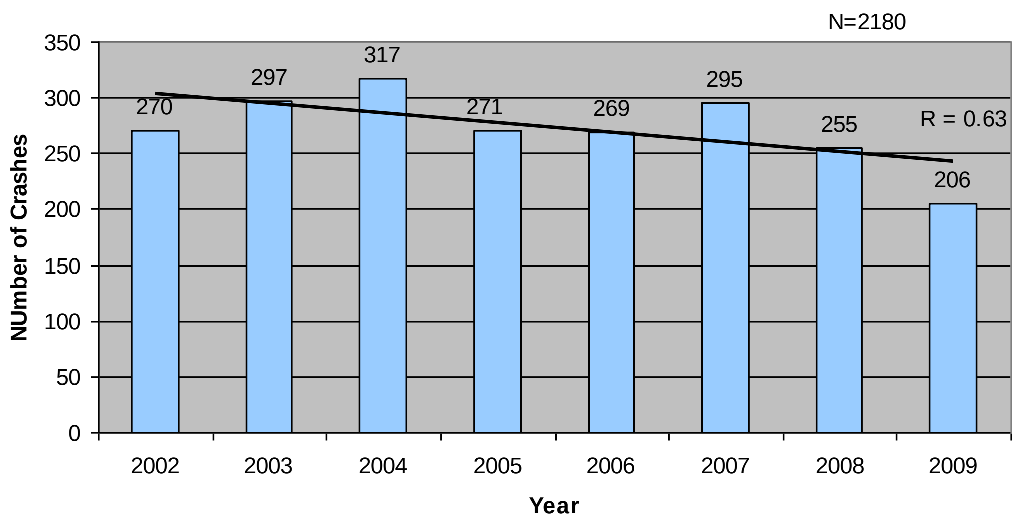


Figure 16. Overall Number of Annual Crashes for 2002 through 2009

Comparison of Crashes by Year and Before and After Time Period

Comparing before and after crashes over the 8-year period found that the total number of crashes decreased about 12.7 percent after ITS deployment. A total of 1,155 crashes occurred during the 4-year period before ITS deployment (2002-2005) versus 1,025 total crashes for the 4-year period after ITS deployment (2006-2009). This 11 percent decrease in crashes was found to be statistically reliable (Z=-2.784, p<0.005).

Summary: The analyses of total number of crashes by year and before and after time period support the hypothesis that the project would result in a reduction in the overall rate of crashes.

3.1.3.2 Crash Rates by Vehicle Miles Traveled

The crash rate analyses found that the crashes per vehicle miles traveled also indicated a reduction in overall, injury, and fatal crashes during the after period. Although the occurrence of crashes was useful for showing the overall trends over time, crash rates were examined to ensure the results were not biased due to changes in the volume of vehicles. As such, vehicle miles traveled based on I-80 traffic counts collected by the WYDOT Transportation Survey staff were used to allow equivalent comparison of before and after crash rates. The data consisted of daily traffic counts of vehicles on I-80 west of Cheyenne from January 2002 through December 2009.

Overall, there were a greater number of vehicles during the after period (18,255,840) than the before period (18,209,850 total vehicles). The annual traffic volumes are shown in Figure 17. The years to the left of the vertical dashed line (2002 – 2005) represent the before time period and years to the right (2006 – 2009) are the after time period. The before years had volumes ranging from 4.435 to 4.716 million vehicles per year. The after years had volumes from 4.371 to 4.811 million vehicles per year.

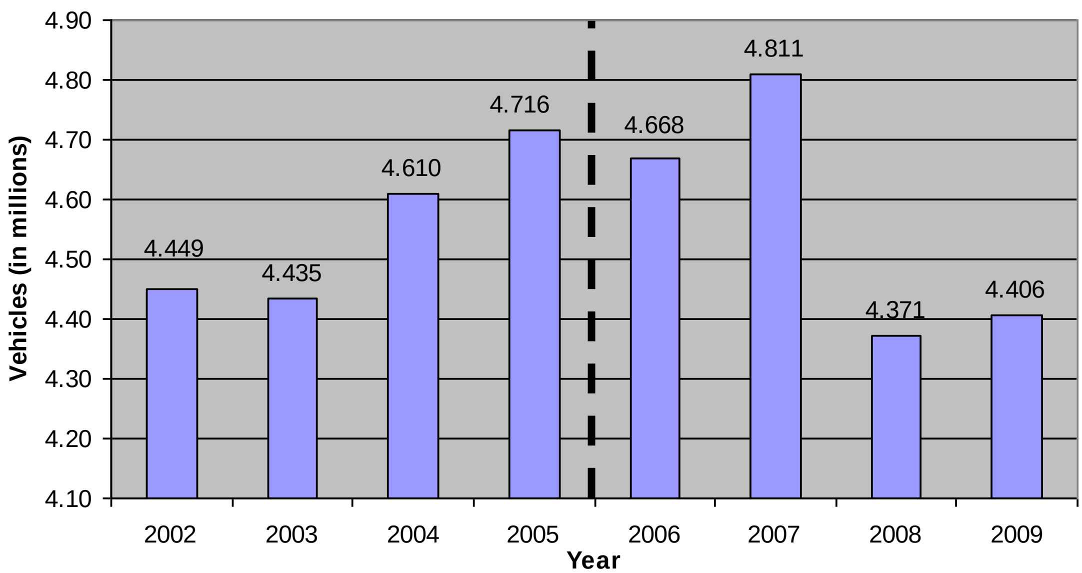


Figure 17. Annual Traffic Volume

Overall Crashes per Vehicle Miles Traveled

To examine crash rates using vehicle miles traveled, traffic volumes were multiplied by the 39-mile distance of the Summit Corridor between Cheyenne and Laramie (from MP317 to MP356).

The overall number of crashes, injury crashes, and fatal crashes were examined using annual crash rates and overall crash rates for the before and after time period. Figure 18 presents the annual crash rates per million vehicle miles (MVM) traveled. The trend line in the figure indicates that 2002 through 2005 had a higher crash rate compared to 2006 through 2009.

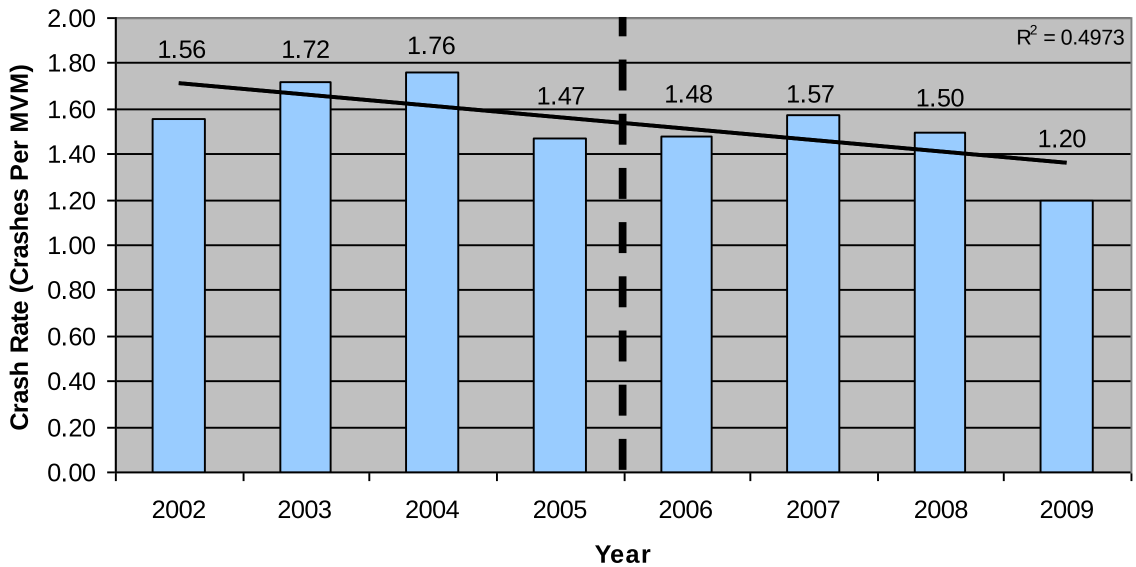


Figure 18. Annual Crash Rates

Combining the years into before and after periods also showed the after period had a lower crash rate per MVM. Table 6 presents the before and after total vehicle miles traveled, number of crashes, and crashes per MVM traveled. During the after period, the crash rate decreased about 13.1 percent, from about 1.63 to 1.44 crashes per MVM.

Table 6. Before and After Crash Rates

Year	VMT	Crashes	Crashes Per MVM
2002-2005	710,184,150	1,155	1.63
2006-2009	711,977,760	1,025	1.44

Summary: The results from the data analysis support the hypothesis that the project would result in a reduction in the overall rate of crashes. The overall number of crashes and crash rate per MVM shows about 13 percent fewer crashes between the before and after time periods.

3.1.3.3 Accident Types – First Harmful Event

The analysis of accident types examined the before and after changes in occurrence for five categories to identify where changes occurred. The accident types were based on the first harmful event recorded in Wyoming accident records. Table 7 shows the first harmful event[8] categories, the number of before and after occurrences (for all but nine crashes in the after period that were missing data), and the amount of change.

Table 7. First Harmful Event

	Before	After	Change	% Change
MV-MV Collision	283	252	-31	-11.0%
Collision w/ Fixed Object	355	294	-61	-17.2%
Overturn Vehicle	317	239	-78	-24.6%
Other Non-Collision	122	156	+34	+27.9%
Collision w/ Animal	78	75	-3	-3.8%

Comparing the before and after first harmful events found that accidents involving collisions (with other motor vehicles, fixed objects, or animals) and overturn vehicle accidents decreased during the after period. Motor vehicle to motor vehicle (MV-MV) collisions decreased about 11 percent (from 283 to 252), MV collisions with fixed objects (guardrails, posts, fences, etc.) decreased about 17 percent (355 to 294), collisions with animals decreased about 4 percent (from 78 to 75), and overturned vehicle accidents decreased about 25 percent (317 to 239). However, the decreases in collision accidents were partially offset by other non-collision accidents (i.e., jackknife, fire, run off road, etc.) which increased about 28 percent (from 122 to 156).

In terms of statistical reliability, the Chi-Square test indicated statistically reliable before and after differences ($\chi^2(5) = 24.022$, $p<0.001$) for two categories: the decrease in overturned vehicles and the increase in other non-collision accidents.

Summary: Investigating the before and after first harmful events found fewer accidents involving overturned vehicles and more non-collision accidents (i.e., jackknife, fire, run off road, etc.) during the after period.

[8] The purpose of the classification is to describe road vehicle accidents in terms of the first harmful event that occurred. For more information, see ANSI D16.1-2007 *Manual on Classification of Motor Vehicle Traffic Accidents*, American National Standard, 2007.

3.1.3.4 Comparison of Injury Crashes by Year and Before and After Time Period

Fewer crashes resulted in injuries during the 2006-2009 after deployment period (281 or 27.4 percent) compared to the 2002-2005 before period (370 or 32 percent). Figure 19 shows the comparison of injury to non-injury crashes for before and after periods. The comparison indicates a statistically significant, reliable difference in injury occurrences between the two time periods ($\chi^2(1) = 5.534$, $p<0.05$).

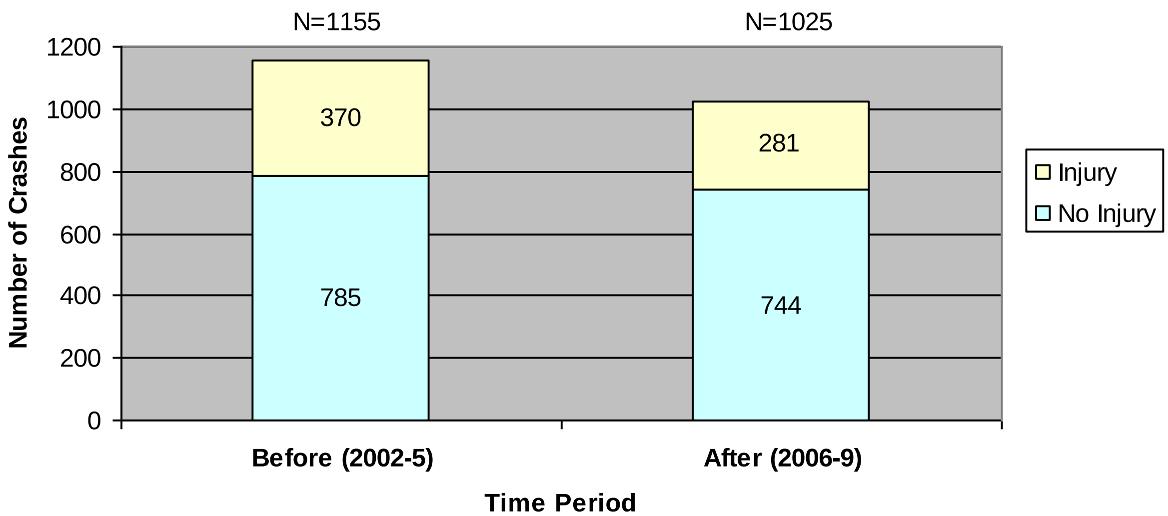


Figure 19. Number of Injury Crashes by Evaluation Time Period

Injury Crashes per Vehicle Miles Traveled

Injury crash rates by year were examined to compare annual rates for the before and after years. Table 8 presents the annual injury crash rates per MVM traveled. The injury crash rates show that 2002 through 2005 had more years with higher crash rates compared to 2006 through 2009. The before years had the first, third, fourth, and fifth highest rates for the entire eight year period. Whereas, in the after years, three of the four years (2007, 2008, and 2009) had the lowest overall injury crash rates.

Table 8. Annual Injury Crash Rates

Year	VMT	Injury Crashes	Injury Rate Per MVM
2002	173,524,650	89	0.513
2003	172,955,250	86	0.497
2004	179,788,050	116	0.645
2005	183,916,200	79	0.430

Year	VMT	Injury Crashes	Injury Rate Per MVM
2006	182,065,650	99	0.544
2007	187,617,300	80	0.426
2008	170,464,125	53	0.311
2009	171,830,685	49	0.285

A comparison of before and after injury crash rates also found the after period rate had decreased from 0.52 to 0.39 injury crashes per MVM. Table 9 shows the before and after injury crash rates per MVM.

Table 9. Before and After Injury Crash Rates

Year	VMT	Injury Crashes	Injury Rate Per MVM
2002-2005	710,184,150	370	0.52
2006-2009	711,977,760	281	0.39

Summary: This analysis supports the hypothesis that the project would result in a reduction in the overall rate of injury crashes.

3.1.3.5 Comparison of Fatal Crashes by Year and Before and After Time Period

As shown in Table 10, fatal crashes decreased from 19 (1.6 percent) before deployment to 10 (1.0 percent) after deployment. However, due to the infrequent nature of fatal crashes, the number of fatal crashes in the after period was not statistically reliable.

Table 10. Fatal Crashes by Evaluation Time Period

Fatal Crash	Time Period	
	Before	After
No	1136	1015
	98.4%	99.0%
Yes	19	10
	1.6%	1.0%
Total	1155	1025
	100%	100%

Fatal Crashes per Vehicle Miles Traveled

Fatality crash rates by year were examined to compare annual rates for the before and after years. Table 11 shows the annual fatality crash rates per MVM traveled. The fatality rate during

2002 through 2005 ranged from 0.01 to 0.05 per MVM compared to 0.00 to 0.02 for 2006 through 2009.

Table 11. Annual Fatal Crash Rates

Year	VMT	Fatal Crashes	Fatality Rate Per MVM
2002	173,524,650	8	0.05
2003	172,955,250	2	0.01
2004	179,788,050	5	0.03
2005	183,916,200	4	0.02
2006	182,065,650	4	0.02
2007	187,617,300	0	---
2008	170,464,125	3	0.02
2009	171,830,685	3	0.02

Combining the years into before and after periods showed the after period had a lower fatality crash rate (0.03 to 0.01 fatal crashes) per MVM. Table 12 shows the before and after fatal crash rates per MVM.

Table 12. Before and After Fatal Crash Rates

Year	VMT	Fatal Crashes	Fatality Rate Per MVM
2002-2005	710,184,150	19	0.03
2006-2009	711,977,760	10	0.01

Summary: The analysis of overall number and rate of fatality crashes shows a trend of fewer crashes in the after deployment period. However, the lack of statistical reliability does not support the hypothesis that the project would result in a reduction in the overall number and rate of fatality crashes per MVM.

3.1.3.6 Crashes by Time of Year: Month and Winter Driving Season

When the crashes for 2002 to 2009 were categorized by month, the number of crashes was found to be considerably higher during the winter driving months as compared to the spring, summer, and fall seasons. The winter driving season typically encompasses October through April; spring from May through June; summer includes July and August; and fall includes September. The 7-month winter driving season accounted for about 74 percent of crashes annually. The other 5 months encompassing the spring, summer, and fall seasons comprised considerably fewer crashes (about 26 percent) annually. This trend is shown in Figure 20, with the months of October through April ranging from 185 to 289 crashes overall, and May through September ranging from 106 to 121 total crashes.

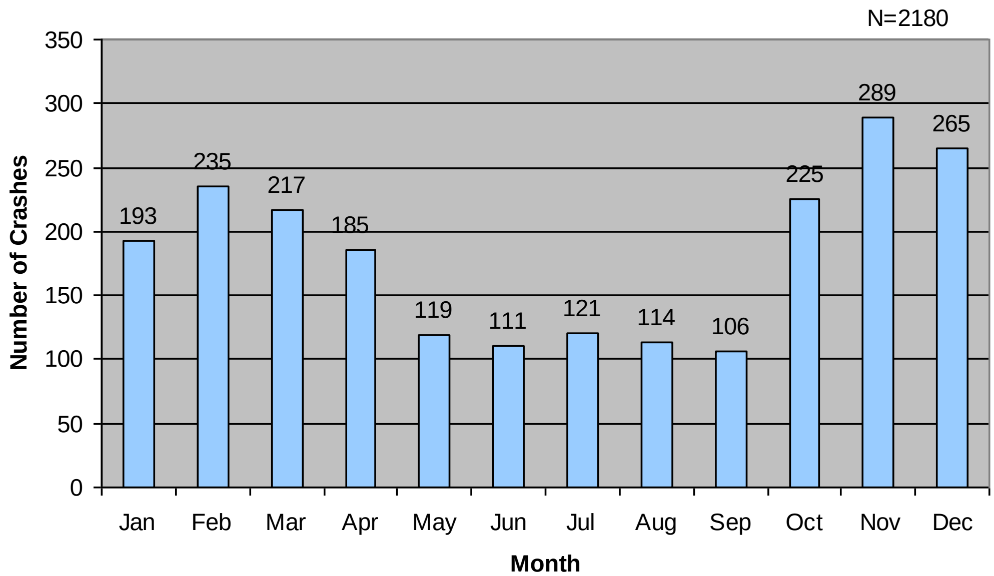


Figure 20. Number of Crashes by Month for January 2002 to December 2009

Comparison of Before and After Crashes by Month

A comparison of the number of before and after crashes by month was examined to determine if the changes in overall crashes were identifiable at the month level. The comparison found that some months had higher or lower numbers of crashes than others. As shown in Figure 21, April and November show very large decreases in crashes after deployment and September and December show large increases. Although these differences between before and after time periods were large enough to be statistically reliable ($\chi^2(11) = 69.292$, $p<0.01$), recognizing an overall association between before and after crashes and month is difficult to identify. Consequently, the next analysis will explore before and after crashes by winter driving seasons.

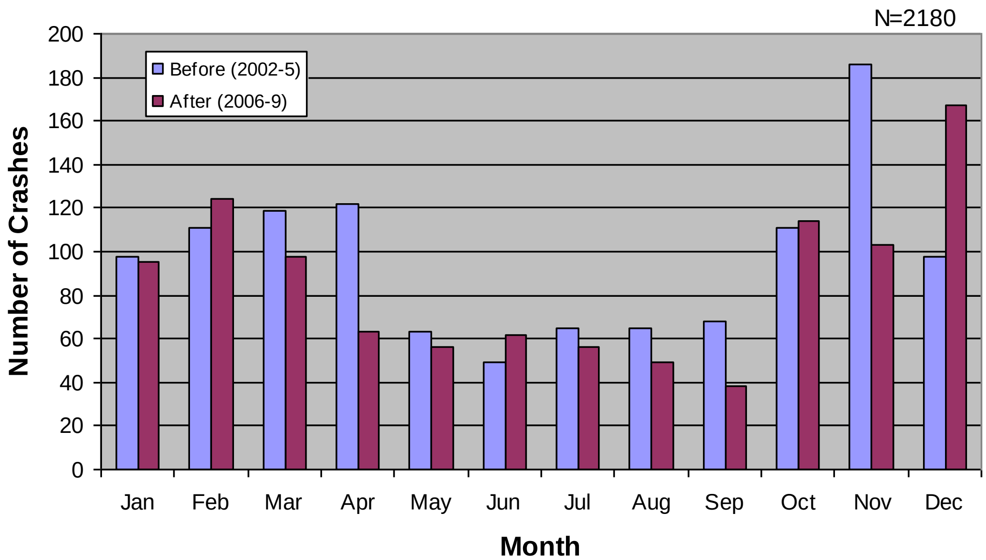


Figure 21. Before and After Crashes by Month for 2002-5 and 2006-9.

3.1.3.7 Comparison of Before and After Crashes by Winter Driving Season

There were 817 winter season crashes during the before period and 816 during the after period, but the difference was not statistically significant, as (Z=-0.024, p=0.492). Comparison of winter driving seasons (October through April) found a trend towards fewer crashes after ITS deployment, although the association is very weak (R=0.3285). Figure 22 shows the number of crashes that occurred during each winter driving seasons from 2002-10. The vertical dashed line separates the winter seasons before and after ITS deployment. The solid line indicates the trend line of the linear correlation of the number of crashes to winter season. The slope of the trend line indicates slightly fewer crashes after ITS deployment.

Figure 23 shows the (winter driving season) monthly number of crashes for the before and after time periods. The results are similar to Figure 21 above and statistically reliable differences between certain months ($\chi^2(6) = 43.134$, $p<0.001$) were found between the before and after periods in November and December.

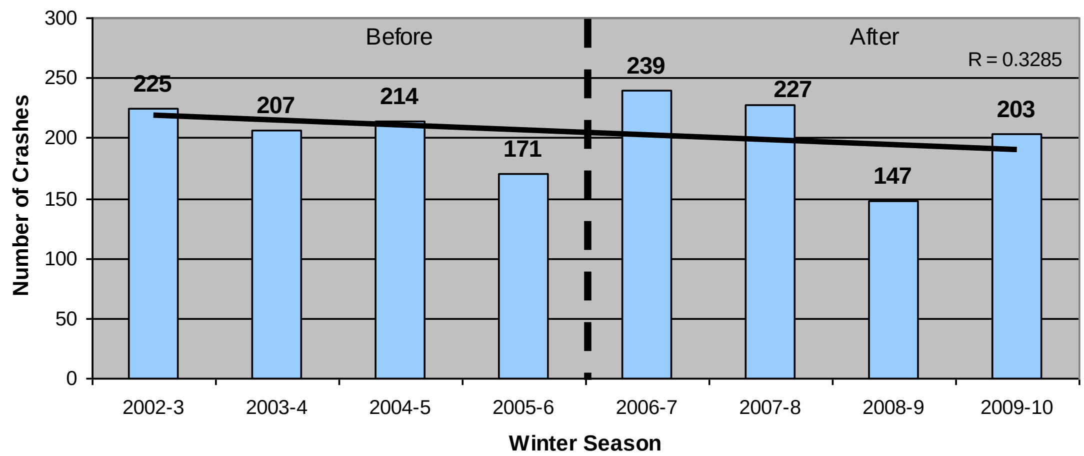


Figure 22. Number of Winter Season Crashes for 2002-03 through 2009-10

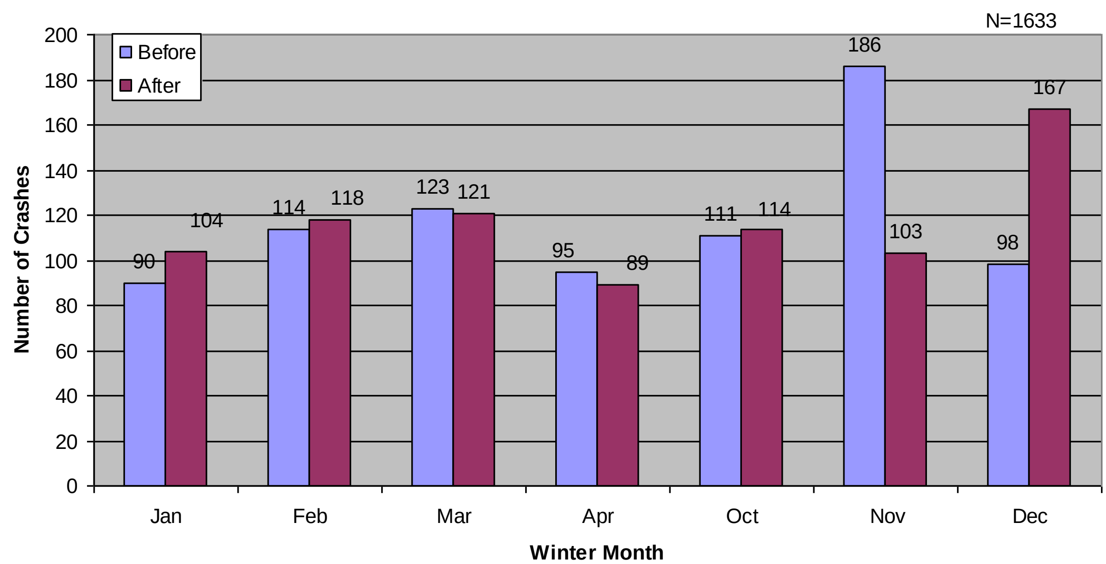


Figure 23. Number of Before and After Winter Season Crashes for 2002-05 and 2006-09

Summary: The analysis of the number of crashes between months or winter seasons did find before and after differences for certain months and a slight trend toward fewer after period winter season crashes; however, the results do not consistently indicate an overall reduction of crashes on a winter-to-winter or month-to-month basis.

3.1.3.8 Comparison of Before and After Injury/Fatal Crashes by Winter Season

Comparison of before and after winter driving season injury crashes found fewer injury crashes in the winter driving seasons after ITS deployment. As shown in Figure 24, the number of winter season injury crashes before deployment was 243 and decreased to 213 after deployment. The fewer injury crashes in the after period approaches statistical significance but does not reach the p<0.05 level ($\chi^2(1) = 2.688$, p=0.101).

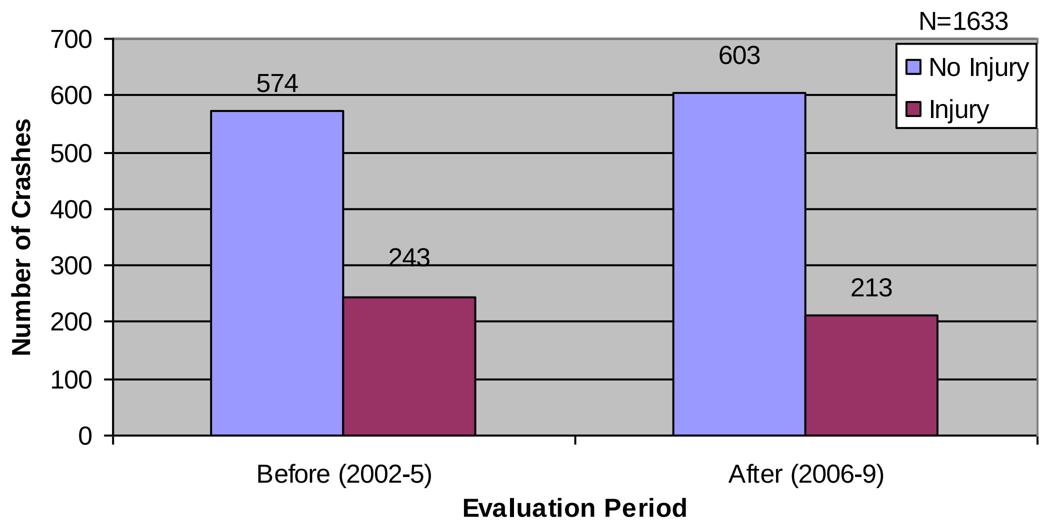


Figure 24. Number of Injury Crashes by Evaluation Period for Winter Seasons

A similar trend was found when examining the winter season fatality crashes, where fatalities decreased from 9 crashes (about 1.1 percent) before deployment to 7 (about 0.9 percent) after deployment. However, the decrease was not large enough to be a statistically significant reduction.

Summary: The analysis of before and after injury and fatal crashes during the winter driving season did show fewer injury and fatality crashes during the after period; however, the results were not large enough to be statistically reliable.

3.1.3.9 Crashes by Time of Day

An analysis by time of day was also conducted to investigate the before and after distribution of crashes for different periods of the day. The purpose was to identify unique time-of-day categories that may have had differences greater than an estimate of expected frequencies. The Chi-square test was used to investigate differences. Chi-square obtains expected frequencies by multiplying the corresponding marginal row (time of day category) and column (before and after period) totals and dividing by the total number of crashes.

Six time-of-day categories were used: Early AM (midnight to 5 AM); AM (5 to 10 AM); Noon (10 AM to 3 PM); PM (3 to 8 PM); and Evening (8 PM to midnight). As shown in Figure 25, when crashes were categorized by time of day, the percentage of crashes were found to be higher (about 23 to 28 percent) during the AM, Noon, and PM periods than the Early AM or Evening periods.

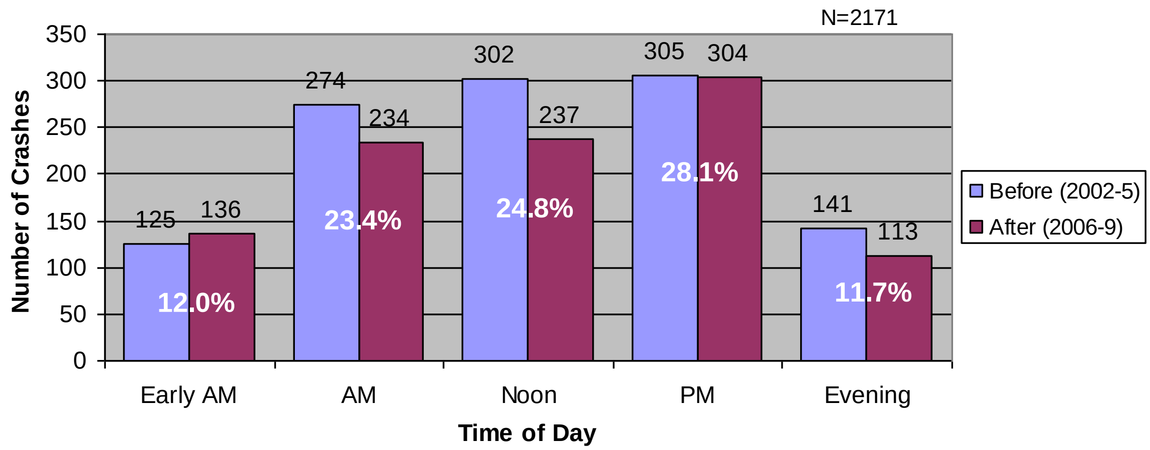


Figure 25. Before and After Crashes by Time of Day

Table 13 shows the number of before and after crashes and the change in number and percentage. Although some time of day categories showed differences between before and after periods, none of the differences were large enough to be statistically different from the expected values ($\chi^2(4) = 7.596$, p=0.108).

Table 13. Time of Day Crashes by Time Period

	Before	After	Change	%Change
Early AM	125	136	11	8.8%
AM	274	234	-40	-14.6%
Noon	302	237	-65	-21.5%
PM	305	304	-1	-0.3%
Evening	141	113	-28	-19.9%

Summary: The analysis of before and after crashes for time of day did find before and after differences for certain time of day categories; however, the differences were not large enough to be statistically different from the expected proportions.

3.1.3.10 Crashes by Road Condition

The crashes by road condition analyses investigated what road conditions may have had before and after differences greater than would be expected based on the proportion of occurrence. The road condition at the time of the crash was recorded in the crash records. Six categories were used: icy, dry, snow/ice/frost, wet, slush, and unknown. Because the ice and snow/ice/frost categories overlap, these two categories were combined in the analyses. From January 2002 through December 2009 there were a total of 2,180 crashes, 1,155 (53 percent of total) in the before period (January 2005 through December 2005) and 1,025 (47 percent of total) in the after period (January 2006 through December 2009).

Comparison of Before and After Crashes by Road Condition

Figure 26 shows the number of crashes by road condition for the before and after deployment periods. Snow/ice/frost on the road was the most common road condition, with 674 instances in the before period decreasing to 640 instances in the after period. Dry roads were the second most common condition with 352 before period crashes decreasing to 273 after period crashes. The wet roads category showed crashes decreasing from 94 (before) to 88 (after) and slushy roads crashes decreased from 33 (before) to 21 (after). Although some road condition categories showed differences between before and after periods that approached significance, none of the changes were large enough to be statistically different ($\chi^2(3) = 5.861$, $p=0.119$).

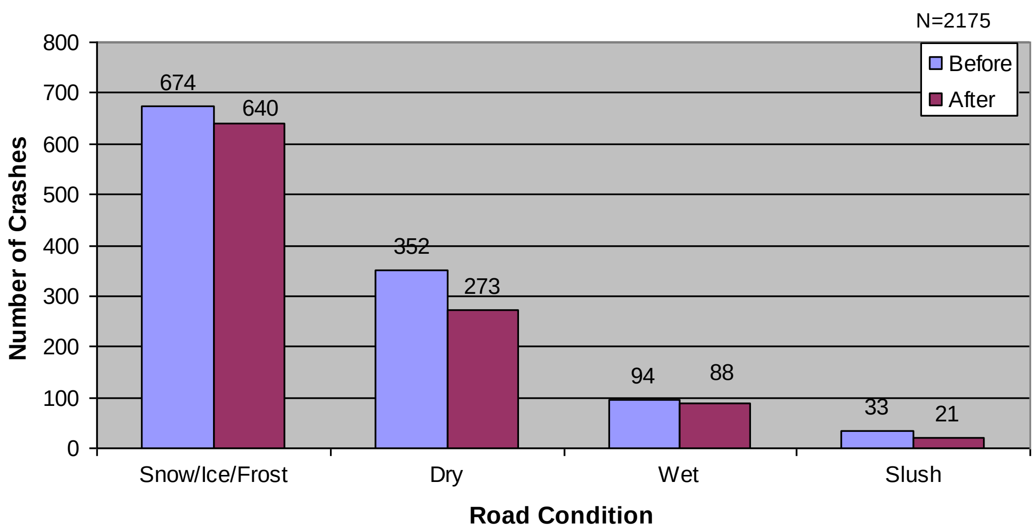


Figure 26. Number of Crashes by Road Condition

However, collapsing road conditions into two categories, dry and not dry, did reveal larger than expected differences between the number of dry/not dry road crashes and the time period ($\chi^2(1) = 3.92$, $p<0.05$). Table 14 shows the number of before and after crashes for Dry/Not Dry road conditions and the change in number and percentage. The test results indicated that for dry roads the after period crashes decreased more than expected (statistically) and for not dry roads the after period crashes did not decrease by as much as would be expected (statistically).

Table 14. Before and After Crashes for Dry/Not Dry Roads

Road Condition	Before	After	Change	% Change
Dry	352	273	-79	-22.4%
Not Dry	803	752	-51	-6.8%

Summary: The number of crashes by road condition found that in every category the number of after period crashes decreased. However, only when road conditions were collapsed into two categories, dry and not dry, were the before and after differences statistically reliable.

Comparison of Before and After Injury/Fatal Crashes by Road Condition

Comparing before and after injury crashes found that there were fewer total injury crashes after ITS deployment. As shown in Table 15, the number of after period injury crashes for all road conditions decreased. However, the before and after injury crash differences was not found to be statistically different ($\chi^2(3) = 5.219$, p=0.156) than what is expected based on the proportions. Also, collapsing road conditions into two categories, dry and not dry, did not reveal any unique differences between the number of dry/not dry road injury crashes and the time period ($\chi^2(1) = 2.269$, p=0.132). As such none of the after period road conditions can be identified as particularly better than the others in terms of injury crash reductions.

Table 15. Injury Crashes by Road Condition

Road Condition	Before	After	Change	%Change
Snow/Ice/Frost	192	169	-23	-12.0%
Dry	118	77	-41	-34.7%
Wet	50	32	-18	-36.0%
Slush	9	3	-6	-66.7%
Total	**369**	**281**		

Comparing before and after fatality crashes also found fewer total fatality crashes after ITS deployment. However, none of the after period road conditions could be identified as particularly better than the others in terms of fatal crash reductions ($\chi^2(2) = 4.003$, p=0.135). Collapsing road conditions into two categories, dry and not dry, also did not reveal an association between the number of dry/not dry road fatal crashes and the time period ($\chi^2(1) = 3.052$, p=0.081). Table 16 shows the number of fatality crashes by road condition and the change before and after deployment.

Table 16. Fatal Crashes by Road Condition

Road Condition	Before	After	Change	%Change
Dry	10	2	-8.000	-80.0%
Snow/Ice/Frost	6	7	1.000	16.7%
Wet	3	1	-2.000	-66.7%
Total	**19**	**10**		

Summary: Although the total number of injury and fatality crashes decreased after ITS deployment, statistical analyses did not indicate any unique road categories that differed more than others. This was also true after combining road conditions into two categories: dry and not dry.

3.1.3.11 Crashes by Weather Condition

Like the previous analyses, the weather condition analysis investigated what weather conditions may have had a difference in the after period that was greater than expected. The purpose was to identify specific weather condition categories that may have had differences greater than an estimate of expected frequencies based on the proportion of crashes in each category.

Weather conditions at the time of each crash were recorded in the crash records. The weather conditions were grouped into six categories: clear, snowing/blizzard, strong wind, raining, sleet/hail, and fog. For the 8-year period from January 2002 through December 2009 there were 2,174 crashes with weather condition information recorded, with 1,153 of these crashes occurring before ITS deployment and 1,021 occurring after ITS deployment.

Comparison of Before and After Crashes by Weather Condition

Figure 27 shows the number of crashes by weather condition for the before and after deployment periods. The majority of crashes occurred during two types of weather conditions—snow/blizzard and clear weather. Snow/blizzard weather had the greatest number of crashes (425 before and 475 after, for a total of 900) followed by clear weather (498 before and 387 after, for a total of 885). Far fewer crashes occurred during strong wind, raining, sleet/hail, or foggy weather conditions.

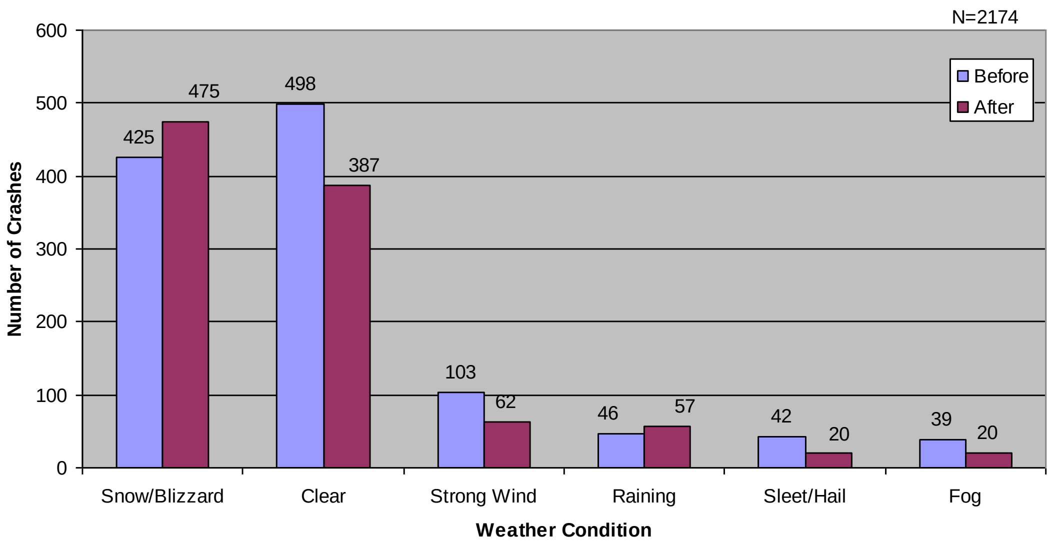


Figure 27. Before and After Crashes by Weather Condition.

A comparison of the number of before and after crashes for each category, shown in Table 17, found that crashes increased for two weather conditions: snow/blizzard and raining, and decreased in four categories: clear, strong wind, sleet/hail, and fog. A greater than expected difference (increase) in before and after crashes was found for snow/blizzard weather. A greater than expected difference (decrease) was also found for clear, strong wind, sleet/hail, and fog weather conditions ($\chi^2(5) = 34.099$, $p<0.005$). This finding complements the previous road condition analysis, which found the not dry roads had higher than expected crashes.

Table 17. Before and After Crashes by Weather Condition

Weather Condition	Before	After	Change	%Change
Snow/Blizzard	425	475	50	11.8%
Clear	498	387	-111	-22.3%
Strong Wind	103	62	-41	-39.8%
Raining	46	57	11	23.9%
Sleet/Hail	42	20	-22	-52.4%
Fog	39	20	-19	-48.7%

Comparison of Before and After Injury/Fatal Crashes by Weather Condition

Table 18 shows the number of before and after injury crashes by weather condition. Comparing the number of crashes within each category found injury crashes decreasing for clear (162 before versus 104 after), raining (25 versus 24), strong wind (28 versus 15), fog (15 versus 5), and sleet/hail (14 versus 6) weather conditions. There was an equal number of before and after injury crashes during snow/blizzard conditions (126). The Chi-square test indicated a difference (statistically significant) in the number of before and after injury crashes for only the snow/blizzard condition ($\chi^2(5) = 12.577$, $p<0.05$). The test indicated that the number after injury crashes in the snow/blizzard condition did not decrease as expected (i.e., the expected number, obtained by using the marginal row and column totals to derive a proportion for calculating the expected number of after snow/blizzard crashes, was higher than expected). None of the other weather conditions were statistically reliable.

Table 18. Injury Crashes by Weather Condition

Weather Condition	Before	After	Change	%Change
Clear	162	104	-58	-35.8%
Snow/Blizzard	126	126	0	0.0%
Raining	25	24	-1	-4.0%
Strong Wind	28	15	-13	-46.4%
Fog	15	5	-10	-66.7%
Sleet/Hail	14	6	-8	-57.1%

Table 19 shows the number of fatality crashes by weather condition and time period. Comparing before and after fatality crashes found that there were fewer total fatality crashes after ITS deployment. Although total fatality crashes decreased in the after period, none of the changes were statistically different from the expected number of crashes ($\chi^2(5) = 7.78$, $p=0.169$).

Table 19. Fatal Crashes by Weather Condition

Weather Condition	Before	After
Clear	9	1
Snow/Blizzard	5	6
Raining	1	1
Strong Wind	2	1
Fog	2	0
Sleet/Hail	0	1

Summary: The number of crashes by weather condition found that the increase in after crashes for snow/blizzard weather conditions and the decrease in after crashes for clear, strong wind, sleet/hail, and fog weather conditions were statistically reliable. Also, the number of injury crashes for snow/blizzard conditions was found to be higher than expected in the after period. This finding complements the previous road condition analysis which found the not dry road condition had higher than expected crashes.

3.1.3.12 Crashes by Weather and Road Conditions

In addition to investigating the weather and road conditions separately, an analysis was conducted to examine: (1) the combinations of weather and road conditions that had the greatest number of crashes and (2) whether any of the weather and road conditions yielded a noteworthy difference between the before and after periods. Figure 28 shows the number of before and after crashes by weather and road conditions present during crashes. The top six most common crash conditions are highlighted. The before and after change in crashes are as follows:

1. Snow/Blizzard weather with Snow/Ice/Frost conditions (824 crashes, increased from 380 before to 444 after);
2. Clear weather with Dry roads (559 crashes, decreased from 323 before to 236 after);
3. Clear with Snow/Ice/Frost conditions (286 crashes, decreased from 151 before to 135 after);
4. Strong Wind with Snow/Ice/Frost conditions (129 crashes, decreased from 88 before to 41 after);
5. Raining with Wet roads (93 crashes, increased from 40 before to 53 after);
6. Sleet/Hail with Snow/Ice/Frost conditions (40 crashes, decreased from 35 before to 5 after).

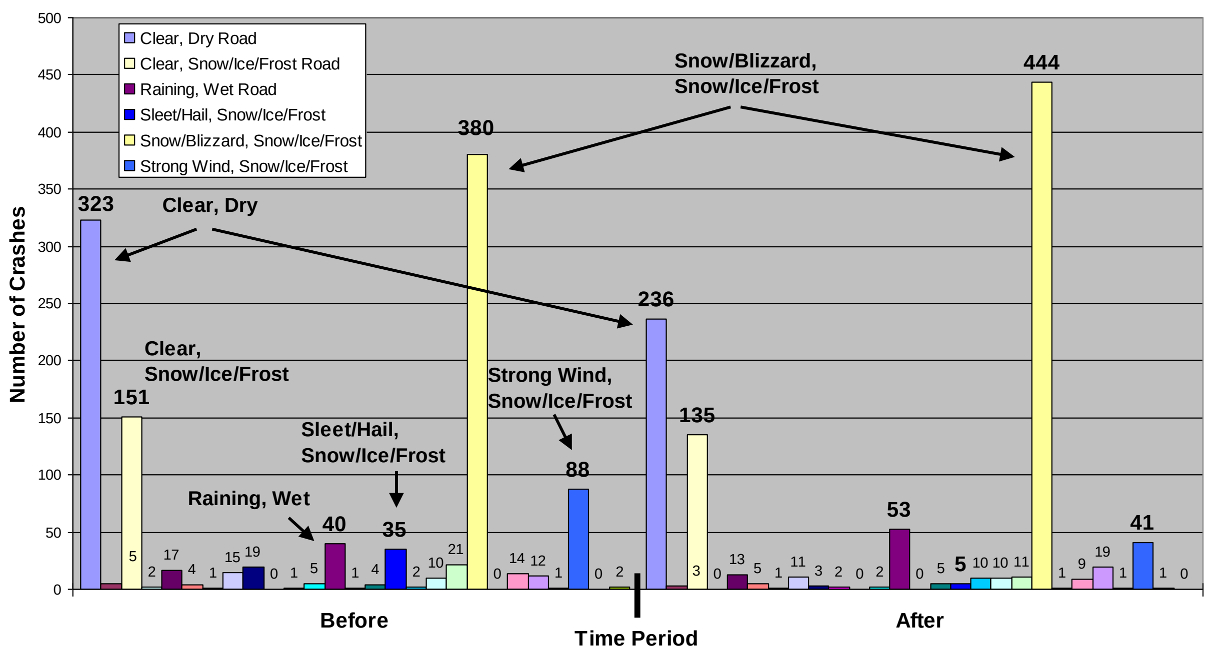


Figure 28. Before and After Crashes by Weather and Road Condition

Table 20 shows the complete list of weather and road combinations, the number of before and after crashes, the change in the number of crashes between the before and after time periods, and the percent of change. Two weather/road conditions were found to have (statistically significant) before and after differences larger than expected, they include:

1. Sleet/hail with snow/ice/frost roads had 35 crashes before and 5 crashes after, showing a decreased of 85.7 percent ($\chi^2(3) = 24.183$, $p<0.001$).
2. Strong winds with snow/ice/frost roads had 88 crashes before and 41 crashes after, showing a decrease of 53.4 percent ($\chi^2(4) = 12.275$, $p<0.015$).

Table 20. Before and After Crashes by Weather and Road Condition

Weather Condition	Road Condition	Before	After	Total	Change	Percent Change
Clear	Dry	323	236	559	-87	-26.9%
	Slush	5	3	8	-2	-40.0%
	Snow/Ice/ Frost	151	135	286	-16	-10.6%
	Wet	17	13	30	-4	-23.5%
Fog	Dry	4	5	9	1	25.0%
	Slush	1	1	2	0	0.0%
	Snow/Ice/ Frost	15	11	26	-4	-26.7%
	Wet	19	3	22	-16	-84.2%
Raining	Dry	0	2	2	2	-
	Slush	1	0	1	-1	-100.0%
	Snow/Ice/ Frost	5	2	7	-3	-60.0%
	Wet	40	53	93	13	32.5%
Sleet/Hail	Dry	1	0	1	-1	-100.0%
	Slush	4	5	9	1	25.0%
	Snow/Ice/ Frost	35	5	40	-30	-85.7%
	Wet	2	10	12	8	400.0%
Snow/ Blizzard	Dry	10	10	20	0	0.0%
	Slush	21	11	32	-10	-47.6%
	Snow/Ice/ Frost	380	444	824	64	16.8%
	Wet	14	9	23	-5	-35.7%
Strong Wind	Dry	12	19	31	7	58.3%
	Slush	1	1	2	0	0.0%
	Snow/Ice/ Frost	88	41	129	-47	-53.4%
	Wet	2	0	2	-2	-100.0%

Comparison of Before and After Injury/Fatal Crashes by Weather and Road Condition

The investigation of before and after injury crashes by weather and road conditions was conducted to examine the combinations of weather and road conditions that had the greatest number of injury crashes and how the number of injury crashes may have changed after ITS deployment.

Table 21 shows the complete list of weather and road combinations, the number of before and after injury crashes, the change in number of crashes between before and after time periods, and the percent of change. Two weather/road condition combinations were found to have (statistically significant) before and after differences larger than expected ($\chi^2(2) = 6.01, p<0.05$). Under foggy conditions:

1. Roads with snow/ice/frost had 2 crashes before and 3 crashes after, showing an increase of 50 percent.
2. Wet roads had 12 crashes before and 1 crashes after, showing a decrease of 91.7 percent.

Table 21. Before and After Injury Crashes by Weather and Road Condition

Weather Condition	Road Condition	Time Period		Total	Change	Percent Change
		Before	After			
Clear	Dry	110	67	177	-43	-39.1%
	Slush	2	1	3	-1	-50.0%
	Snow/Ice/Frost	40	31	71	-9	-22.5%
	Wet	9	5	14	-4	-44.4%
Fog	Dry	1	1	2	0	0.0%
	Slush	0	0	0	0	0.0%
	Snow/Ice/Frost	2	3	5	1	50.0%
	Wet	12	1	13	-11	-91.7%
Raining	Dry	0	2	2	2	100.0%
	Slush	0	0	0	0	0.0%
	Snow/Ice/Frost	3	0	3	-3	-100.0%
	Wet	22	22	44	0	0.0%
Sleet/Hail	Dry	1	0	1	-1	-100.0%
	Slush	1	2	3	1	100.0%
	Snow/Ice/Frost	11	3	14	-8	-72.7%
	Wet	1	1	2	0	0.0%
Snow/ Blizzard	Dry	2	1	3	-1	-50.0%
	Slush	5	0	5	-5	-100.0%
	Snow/Ice/Frost	114	122	236	8	7.0%
	Wet	5	3	8	-2	-40.0%
Strong Wind	Dry	4	6	10	2	50.0%
	Slush	1	0	1	-1	-100.0%
	Snow/Ice/Frost	22	9	31	-13	-59.1%
	Wet	1	0	1	-1	-100.0%

Table 22 shows the number of before and after fatal crashes by weather and road combination. A comparison of before and after fatal crashes by weather and road combinations did not find any significant differences due to the small number of fatal crashes.

Table 22. Before and After Fatal Crashes by Weather and Road Condition

Weather Condition	Road Condition	Time Period		Total	Change	Percent Change
		Before	After			
Clear	Dry	8	1	9	-7	-87.5%
	Wet	1	0	1	-1	-100.0%
Fog	Snow/Ice/Frost	1	0	1	-1	-100.0%
	Wet	1	0	1	-1	-100.0%
Raining	Wet	1	1	2	0	0.0%
Sleet/Hail	Snow/Ice/Frost	0	1	1	1	100.0%
Snow/ Blizzard	Dry	1	0	1	-1	-100.0%
	Snow/Ice/Frost	4	6	10	2	50.0%
Strong Wind	Dry	1	1	2	0	0.0%
	Snow/Ice/Frost	1	0	1	-1	-100.0%
	Total	**19**	**10**			

3.1.3.13 Other Factors: Lighting, Driver Characteristics

An analysis of factors such as lighting condition and driver characteristics was also conducted to investigate differences in the before and after distribution of crashes. As with previous analyses of this nature, the purpose was to identify any factors that may have had differences greater than an estimate of expected frequencies.

The lighting condition at the time of the crash was also recorded in the crash records. Figure 29 shows the distribution of the 2,180 crashes by before and after period and light condition. For the 1,155 crashes in the before period about 63 percent were in daylight and 32 percent were in dark, unlighted conditions. For the 1,025 after period crashes, daylight crashes decreased to about 58 percent of crashes and dark, unlighted crashes increased to 32 percent of crashes. Direct comparison of before and after daylight crashes found the overall number decreased 18.4 percent from 733 to 598 crashes. Although this difference was approaching statistical significance ($\chi^2(4) = 7.618$, $p=0.107$) the number of crashes were within the range of expected values based on the proportion of crashes across all lighting categories.

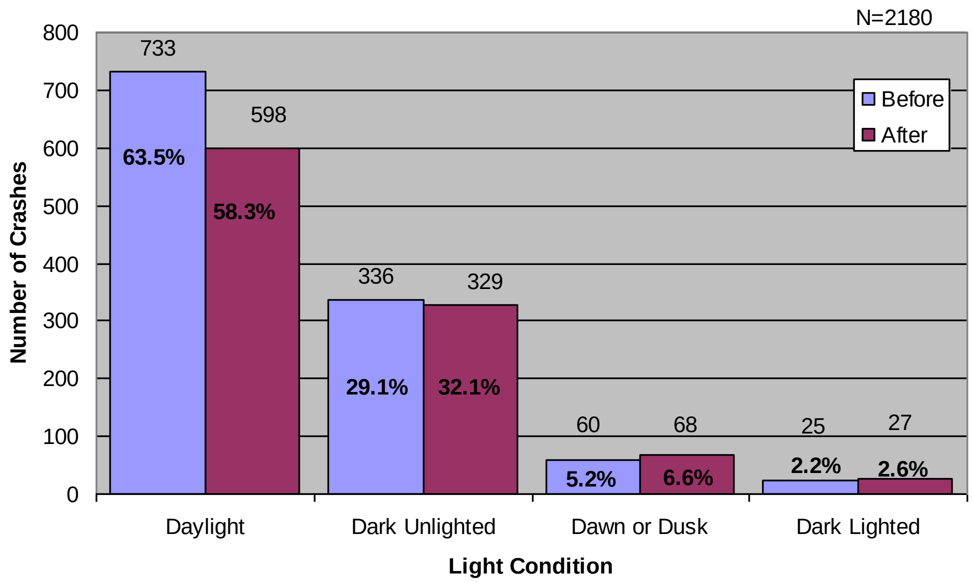


Figure 29. Before and After Crashes by Light Condition.

Table 23 shows the number of before and after injury crashes by lighting condition and the change in the number of crashes between before and after time periods. The largest difference was in daylight conditions, where injury crashes decreased from 244 (before) to 163 (after) representing a decrease of 33 percent. However, none of the differences in after injury crashes were outside the range of expected values based on a proportional decrease across all after lighting categories ($\chi^2(3) = 4.246$, p=0.236).

Table 23. Before and After Injury Crashes by Light Condition

	Before	After	Change	% Change
Daylight	244	163	-81	-33.2%
Dark Unlighted	96	88	-8	-8.3%
Dawn or Dusk	23	21	-2	-8.7%
Dark Lighted	7	8	1	14.3%

Table 24 shows the number of before and after fatal crashes by lighting condition and the change in the number of crashes between the before and after time periods. The largest difference was in daylight conditions, where fatality crashes decreased from 14 (before) to 2 (after), representing a statistically reliable ($\chi^2(2) = 11.443$, p<0.01) 86 percent decrease. The other lighting conditions were within the range of expected values.

Table 24. Before and After Fatal Crashes by Light Condition

	Before	After	Change	% Change
Daylight	14	2	-12	-85.7%
Dark Unlighted	5	5	0	0
Dawn or Dusk	0	3	3	300%

Summary: The decrease in the number of daylight fatal crashes was found to have a difference larger than expected. Although the comparison of the overall number of crashes and number of injury crashes showed decreases for daylight crashes in the after period, the proportions were not greater than expected. None of the other lighting conditions were found to have before and after changes that were statistically significant.

3.1.3.14 Driver Characteristics

Crash records were examined to investigate four driver characteristics: age, gender, primary cause of crash, and causal driver's vehicle type. The causal driver as identified in the crash records (i.e., the driver likely to have initiated the crash) was the focus of the analyses. The purpose of these analyses was to investigate how the reduction in after crashes was reflected in the various driver characteristics and to identify any that may have benefited the most from the ITS deployment.

Driver Age. The ages of the causal drivers were investigated to determine if there were any before and after changes in crashes as a function of age. The age of causal drivers ranged from 15 to 90 years old. The distribution of driver ages, shown in Figure 30, shows that 19- to 23-year-olds had the highest incidence of crashes. The number of crashes tended to decrease for drivers aged 50 and older.

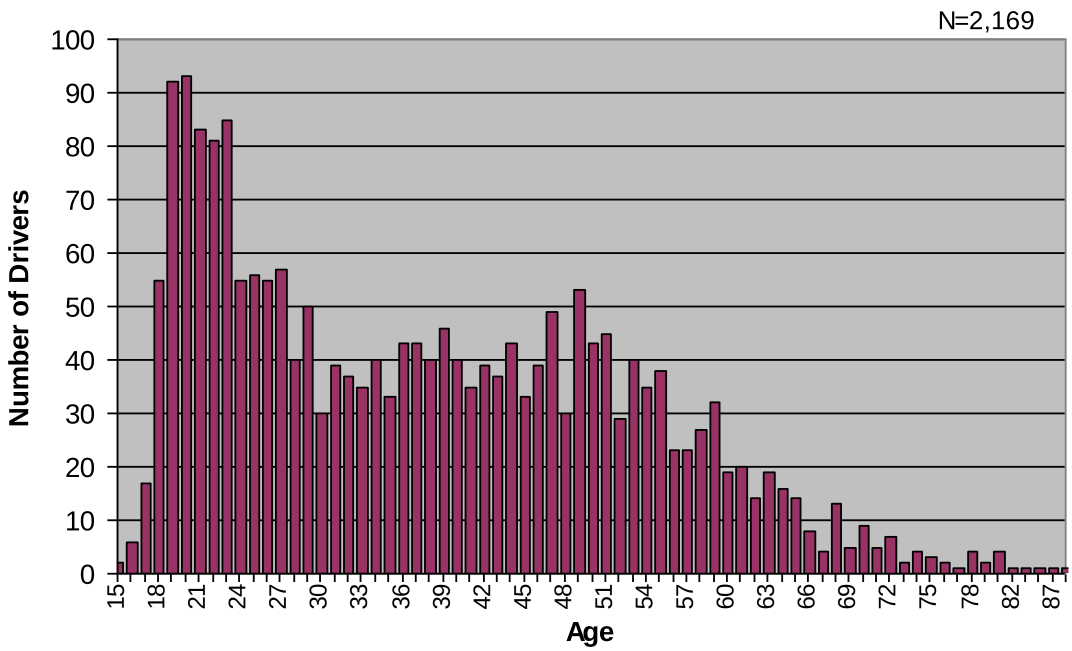


Figure 30. Age of Drivers Involved in Crashes

To investigate before and after crash differences by the driver's age, ages were combined into six age groups (15-24, 25-34, 35-44, 45-54, 55-64, and 65 and older). The number of drivers by age group for before and after time period is shown in Figure 31. The number of after crashes decreased the greatest for the two youngest age groups. The 15 to 24 year old group decreased by about 25 percent and the 25 to 34 year old group decreased by about 12 percent. However, the decrease in after period crashes for the 15 to 24 year old group was within the range expected based on the proportion for the after period. Consequently, none of the age groups were found to have before and after changes that were statistically larger than expected ($\chi^2(5)$ = 6.133, p=0.293). This result suggests that all age groups were equally represented (i.e., equally benefited) in the reduction in after crashes.

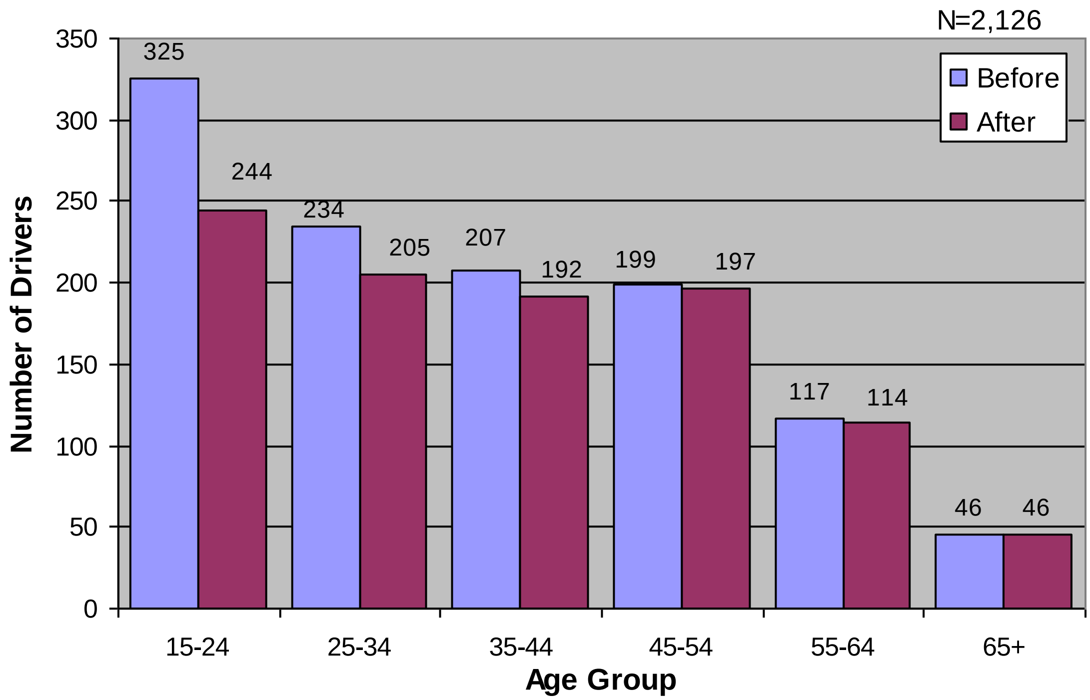


Figure 31. Drivers Involved in Crashes by Age Group for Before and After Periods

Driver Gender. There were 2,169 causal drivers that had gender information recorded, with 1,150 in the before period and 1,019 in the after period. Overall, more males (about 74 percent) were involved in crashes than females (about 26 percent). The percentage of males and females did not change dramatically when comparing before and after percentages (see Figure 32). The gender ratio differences between the before and after evaluation periods were not statistically different ($\chi^2(1) = 0.322$, $p=0.570$). Again, this result indicates that both genders equally benefited (in relation to their proportions) in the after crash reduction.

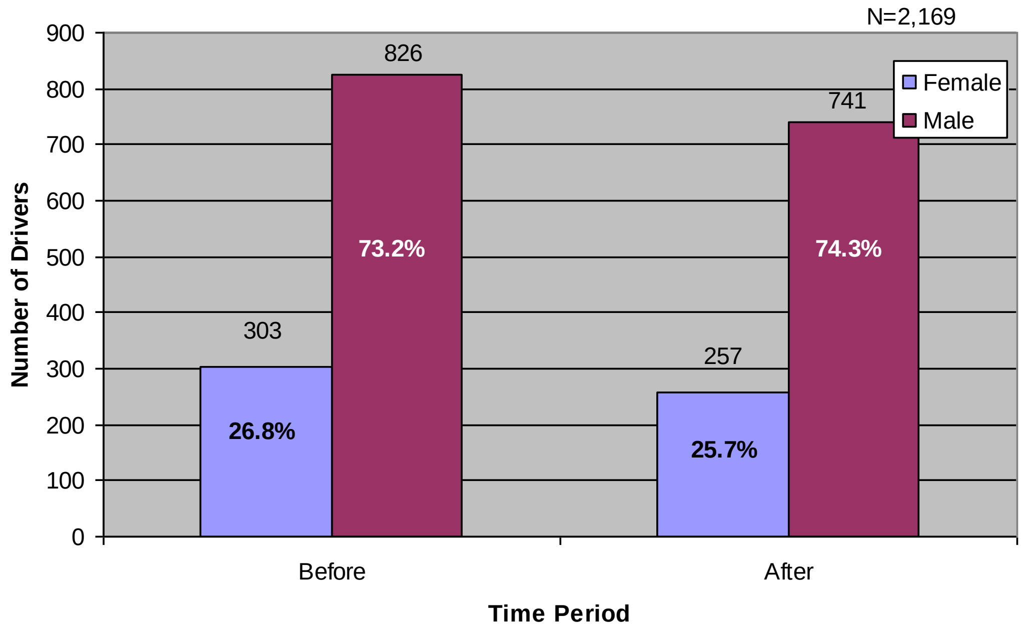


Figure 32. Gender of Drivers Involved in Crashes

Primary Cause of Crash. The primary cause of the crash was explored to examine if any differences in the before and after periods were apparent. Figure 33 shows the number of crashes by the cause of crash for the top five cause of crashes. Driving too fast for the conditions was the most frequently recorded primary cause. In the before period, 593 crashes (or 52 percent of crashes) were due to excessive speed. In the after period, the number decreased to 485 (or 48 percent). The second most frequent cause of crashes was "No Improper Driving" with 203 (about 18 percent) before and 192 (about 19 percent) during the after period. The "No Improper Driving" designation includes accidents that were caused by events such as hitting an animal/object/vehicle, loss of control, overturn or rollover, etc.

To investigate differences between types of primary causes, the causes were categorized into four categories: Drove Too Fast; All Other Improper Driving; Trying to Avoid a Hazard; and No Improper Driving. Figure 34 shows the percentage of crashes by primary cause category for the before and after time periods. The test for larger-than-expected differences in before and after proportions found the proportion of after crashes in the Drove Too Fast and All Other Improper Driving categories to be larger than expected ($\chi^2(3) = 24.126, p<0.01$). However, closer examination of the data found that crashes often have multiple causes (e.g., Drove Too Fast could also be recorded under failed to keep proper lane and ran off road, which are included under All Other Improper Driving) which makes identifying a single primary cause sometimes difficult and misleading. Consequently, an analysis was performed to examine if there was a difference in the number of improper and not improper primary causes. To investigate whether a difference exists, the primary causes were categorized into two categories: Improper Driving and No Improper Driving. The test for larger than expected differences found no statistically reliable difference between the categories in the before and after periods ($\chi^2(1) = 0.47$, p=0.829). Therefore, although there appears to be a decrease in the number of crashes categorized under Drove Too Fast, this finding should be considered somewhat questionable without additional supporting evidence.

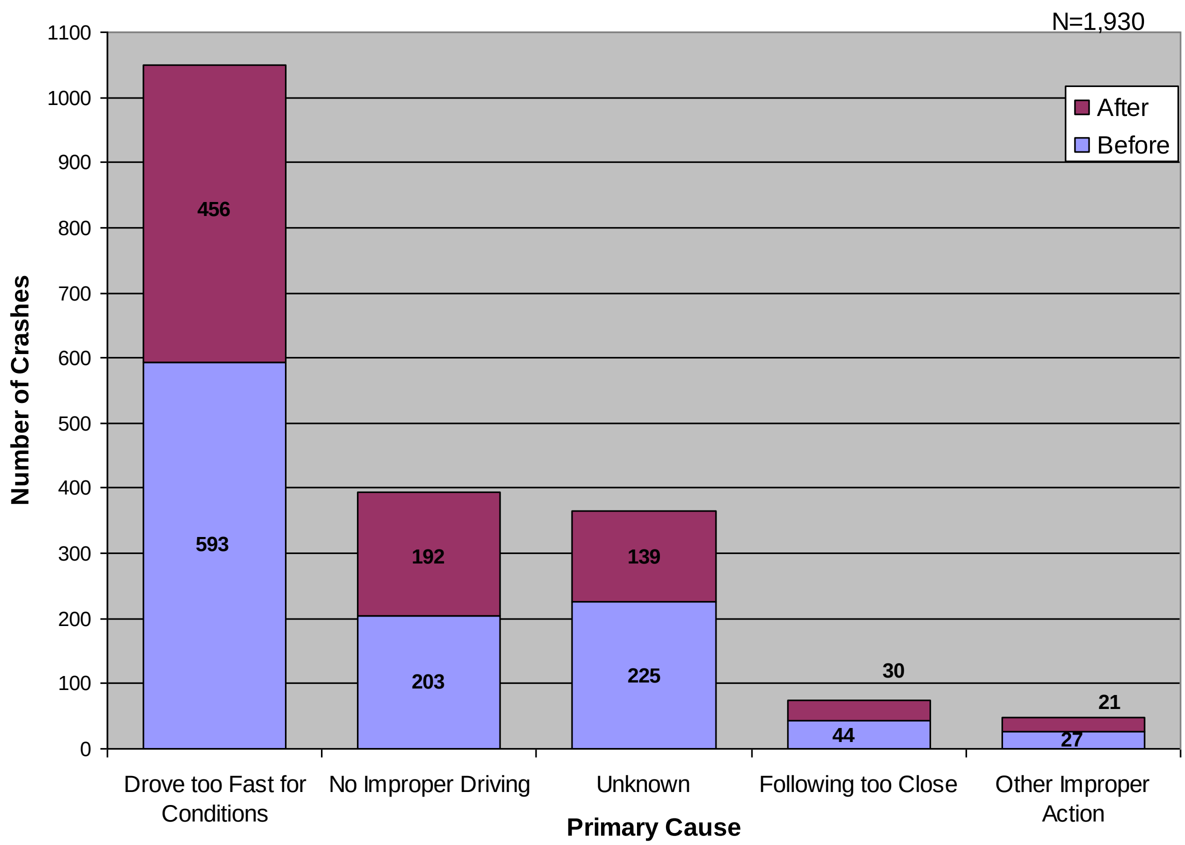


Figure 33. Primary Cause of Crashes

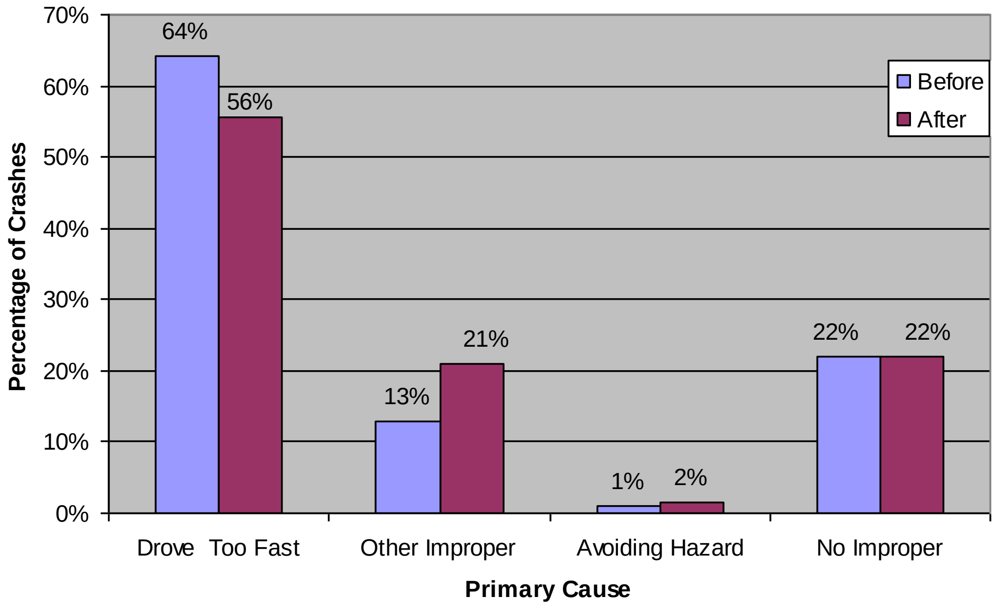


Figure 34. Before and After Cause of Crash by Category

Causal Driver's Vehicle Type. The type of vehicle the causal driver was using at the time of the crash was explored to examine if any before and after differences were apparent. Table 25 shows the vehicle types used by the causal drivers and the number of times each type was involved in crashes during the before and after period. Passenger cars (with 992) were the most common vehicle involved in crashes followed by heavy trucks (550), and pickup trucks (520).

Table 25. Vehicle Types by Before and After Time Period

Type	Before	After	Total
Passenger	575	417	992
Heavy Truck	258	292	550
Pickup	281	239	520
Medium Truck	16	13	29
Other	10	4	14
Motorcycle	6	4	10
Motorhome	3	4	7
Total	**1149**	**973**	**2122**

A comparison of before and after differences revealed that the number of passenger cars, pickups, medium trucks, other, and motorcycles decreased in the after period, while heavy trucks and motorhomes increased. Statistical testing indicated that the decrease in Passenger Cars and the increase in Heavy Trucks were greater than expected ($\chi^2(6) = 19.622$, $p<0.01$). This is reflected in Figure 35, which shows the before and after change in percentages for each of the vehicle types. For passenger cars, the percentage was 50 percent during the before period but dropped to about 43 percent in the after period. For Heavy Trucks, the percentage was about 23 percent before and increased to 30 percent after. Consequently, these results indicate that the mix of vehicle types involved in crashes shifted slightly in the after period, with passenger cars slightly less likely to be involved in a crash and heavy trucks slightly more likely.

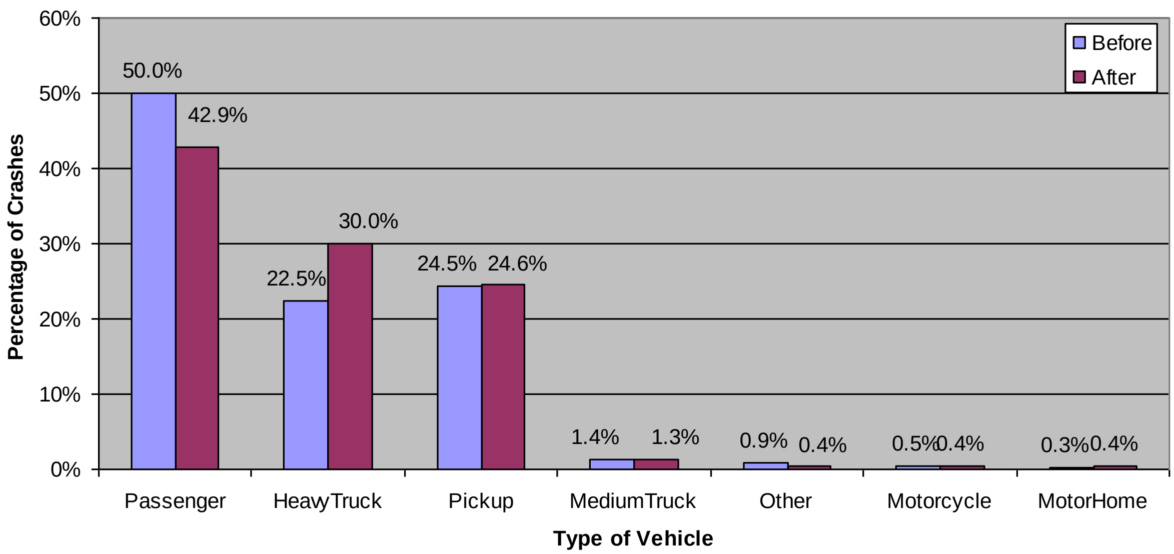


Figure 35. Before and After Percentages of Vehicle Types

Summary: The investigation of driver characteristics to identify any specific set of characteristics that may have benefited some drivers more than others from the ITS deployment found no specific age group or gender that had a before and after difference greater than expected statistically. The number of crashes with a cause listed as Drove Too Fast during the after period may have decreased more than expected, but because crashes often have multiple causes the finding is considered questionable. In addition, no overall difference between Improper Driving and No Improper Driving as primary causes were found between the before and after periods. A comparison of vehicle types indicated that the mix of vehicle types involved in crashes shifted slightly in the after period, with passenger cars slightly less likely to be involved and heavy trucks slightly more likely.

3.1.4 Safety Impacts Summary

3.1.4.1 Impact on Reducing Traffic Speeds

In general, it appears that the project was effective in reducing traffic speeds in response to deteriorated roadway conditions. Speeds tended to change as a function of both DMS message and road/weather conditions. It appears that the overall variability of the before and after hourly average speeds were very similar, both having an average standard deviation of about 7 mph. Unfortunately, because this was an observational study with a variety of influencing factors that were not experimentally controlled or manipulated, what factors are effective in reducing speeds can be hypothesized but cannot at this point be supported by quantitative "proof." The type of advisories that appeared to be most effective in decreasing speeds were: "Poor/Reduced Visibility;" "Advise X MPH;" "Reduce Speed;" and "Slick Road, Blowing Snow." Road and weather conditions that had the greatest effect included reduced visibility due to fog, snowfall, or blowing snow followed by icy/snowy/slick roads. When these road/weather conditions were paired with a specific speed advisory message, before and after time period comparisons and upstream/downstream comparisons of speeds found that average speeds often decreased from 3 to 10 mph (typically about 5 mph during the first hour).

Consistent messages (and conditions) across several DMS segments tended to increase driver compliance with the advisory being displayed on the DMS. Finally, it was also observed that drivers tended to adjust their vehicle speeds to about 10 miles per hour over the advised speed.

3.1.4.2 Impact on Ability to Obtain Weather, Road, and Traffic Conditions

In general, WYDOT and WHP stakeholders were in agreement that the implementation of ITS technology on the Summit Corridor greatly increased their ability to obtain weather, road, and traffic information and respond to changes in conditions.

The CCTV cameras were clearly the favorite technology for checking and verifying information, monitoring remote portions of I-80, and identifying changing weather, road, and traffic conditions. Although not part of the original I-80 Dynamic Message Sign project, the TMC in Cheyenne has also improved the ability of WYDOT and WHP to obtain travel information, coordinate, and perform their respective missions.

Suggestions for improvements included additional sensors and DMS in and around the corridor to expand operator awareness of conditions in surrounding areas and also to forewarn travelers and DOTs in the surrounding States of prolonged road closures. Stakeholders also mentioned their desire for a better system for communicating during major storm events.

3.1.4.3 Impact on Overall Rate of Crashes, Fatalities, and Injuries

In general, it appears that the project was effective in reducing overall crashes, injury crashes, and fatal crashes. The total number of crashes by year was found to have a trend of decreasing crashes and the overall number of crashes decreased from 1,155 in the before period to 1,025 in the after time period. The decrease in after period crashes was statistically robust.

These findings are supported by crash rate analyses which found that the crashes per vehicle miles traveled were also reduced for overall, injury, and fatal crashes during the after period. Overall, crashes per million vehicle miles traveled decreased from 1.63 (before) to 1.44 (after).

The first harmful event analysis found fewer accidents involving overturned vehicles and more non-collision accidents (i.e., jackknife, fire, run off road, etc.) during the after period. Although accidents involving collisions (with other motor vehicles, fixed objects, or animals) also decreased during the after period, the difference was not statistically reliable.

Regarding injury crashes, fewer crashes involving injuries occurred during the 2006-2009 after deployment years (281) compared to the 2002-2005 before years (370). Comparison of before period and after period injury crash rates supported these results as the after period injury crash rate decreased from 0.52 to 0.39 injury crashes per MVM. For fatal crashes, fewer crashes resulted in fatalities (19 crashes involved fatalities before deployment while 10 involved fatalities after deployment). Comparison of before and after periods showed the after period had a lower fatality crash rate (0.03 to 0.01 fatal crashes) per MVM.

In general, more crashes occurred during the winter months (October through April) than the spring, summer, and fall months. A comparison of the number of before and after crashes by month found April and November had large decreases in after crashes while September and December had large increases. Comparison of winter driving season crashes found a trend for fewer after period winter season crashes. However, the total number of before crashes and the total number of after crashes were nearly equivalent. As such, although there were fewer winter season injury and fatal crashes during the after period, the reductions were not large enough to be statistically reliable at the $p<0.05$ level.

The analysis of before and after crashes by time of day did find a reduction in the number of after period crashes during AM (5:00 AM to 10:00 AM), Noon (10:00 AM to 3:00 PM), and Evening (8:00 PM to 12:00 AM) times; however, the differences were not large enough to be statistically reliable at the $p<0.05$ level.

The crashes by road condition analysis found a reduction in the number of after crashes. However, only when road conditions were collapsed into two categories, “dry” and “not dry,” were the before and after differences statistically reliable. Although the total number of injury and fatality crashes decreased during the after period, statistical analyses did not indicate any unique road categories that were larger than expected.

The crashes by weather condition analysis found the majority of crashes occurred during two types of weather conditions: snow/blizzard and clear weather. The snow/blizzard weather condition was found to have more crashes than expected and the clear, strong wind, sleet/hail, and fog weather condition had fewer crashes than expected ($\chi^2(5) = 34.099$, $p<0.005$). This finding complements the previous road condition analysis, which found the not dry roads had more crashes than expected. The number of injury crashes for snow/blizzard conditions was found to be more than expected in the after period. No larger than expected differences were found in before and after fatal crashes.

The crashes by weather and road conditions analysis found two combinations that had fewer after crashes than expected: sleet/hail with snow/ice/frost on the roads and strong winds with snow/ice/frost on the roads. For injury crashes, two combinations that had larger than expected changes in the number of after crashes: foggy weather with Snow/Ice/Frost road had more after crashes than expected and foggy weather with Wet road had fewer after crashes than expected. The comparison of before and after fatal crashes by weather and road combinations did not reveal any significant differences due to the small number of fatal crashes.

The crashes by lighting condition analysis found differences approaching statistical significance ($\chi^2(4) = 7.618$, $p=0.107$). However, the number of crashes was within the range of expected values. For injury crashes, there were no larger than expected differences in after crashes. For fatal crashes, a larger than expected reduction in daylight fatal crashes was found during the after period.

The analysis of driver characteristics found no specific age group or gender that had a before and after difference greater than expected. No overall difference between improper driving and no improper driving primary causes were found between the before and after periods. The comparison of vehicle types indicated that the mix of vehicle types involved in crashes shifted slightly in the after period, with passenger cars slightly less likely to be involved and heavy trucks slightly more likely.

3.2 Mobility Impacts

The Mobility study investigated the following hypotheses:

1. The project will increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner.

2. The project will result in a reduction in the overall number and duration of road closures.

The following sections describe the analyses that were conducted to investigate the impact on public/private entities' ability to respond to changes in weather, road, and traffic conditions, and the number and duration of road closures.

3.2.1 Impact on Stakeholder Ability to Respond to Changes in Weather, Road, and Traffic Conditions

This section discusses the perceived impact the ITS information and devices have had on stakeholders' ability to respond to changes in weather, road, and traffic conditions. The operations and maintenance staff interviews and traveler surveys were used to investigate this topic. Since the interviews with operations and maintenance staff explored the ability to both obtain information and respond to changing conditions, those perceptions were described in Section 3.1.2. Consequently, the section below presents only traveler perceptions.

3.2.1.1 Traveler Perceptions

Results presented in this section rely on survey responses collected from two groups of travelers; a panel of local drivers who participated in the survey process throughout the entire evaluation period and were contacted when an incident occurred (either a travel advisory or a road closure), and travelers who were asked to complete a survey on I-80 while they were traveling (either at a Rest Stop, a Travel Plaza, or by mailing back a survey). A number of items on the surveys requested which type of information the travelers relied upon to get information on changes to weather, road, and traffic conditions.

As shown in Figure 36, the panel survey participants reported using the Wyoming DOT Web site as the most frequently used source prior to their trips, followed by broadcast radio and the 511 service.

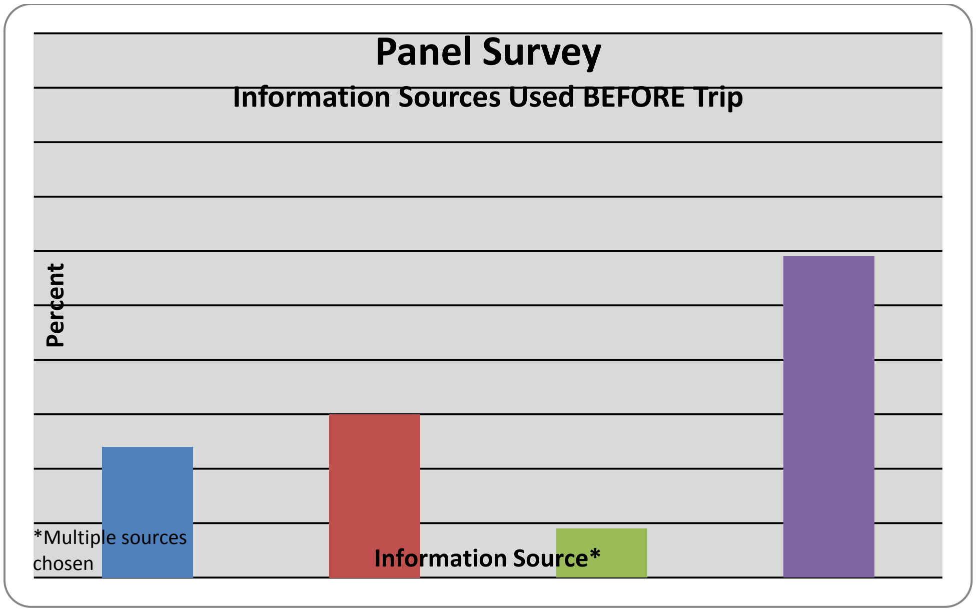


Figure 36. Panel Survey – Information Sources Used Before Trip

In fact, based on this information, 78 percent of the respondents reported they were aware of the incident before their trip started. And, based on this information, as shown in Figure 37, the effect on their trip planning was evident. While they could choose more than one behavior, 30 percent reported they cancelled the trip, 25 percent left earlier, and 1 in 10 decided to postpone the trip. These respondents also reported that the information helped them decide what action to take.

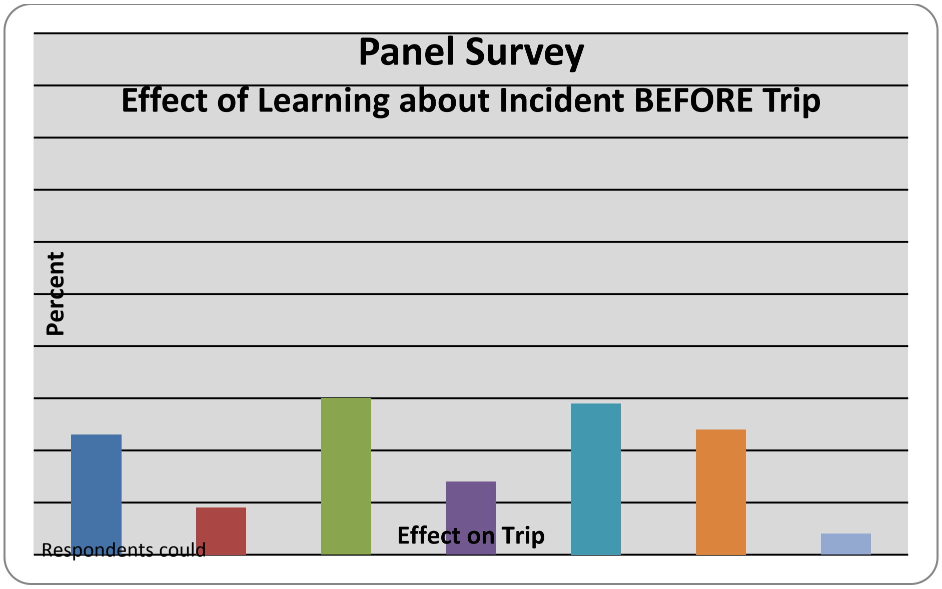


Figure 37. Panel Survey – Effect of Learning About Incident *Before* Initiating the Trip

When queried about sources used *during* their trip (if it was taken), the panelists (as shown in Figure 38) chose similar sources, though it is apparent that their choices are somewhat limited, since they are traveling. As shown, the predominant source is the driver him/herself, "I encountered the weather/incident while driving." However, respondents also showed high rates of using the flashing yellow caution signs and the dynamic message signs, with almost 40 percent reporting using these sources while driving. In contrast to the high proportion who had used the 511 service or even broadcast radio, there does appear to have been a heavy reliance on these two sign types.

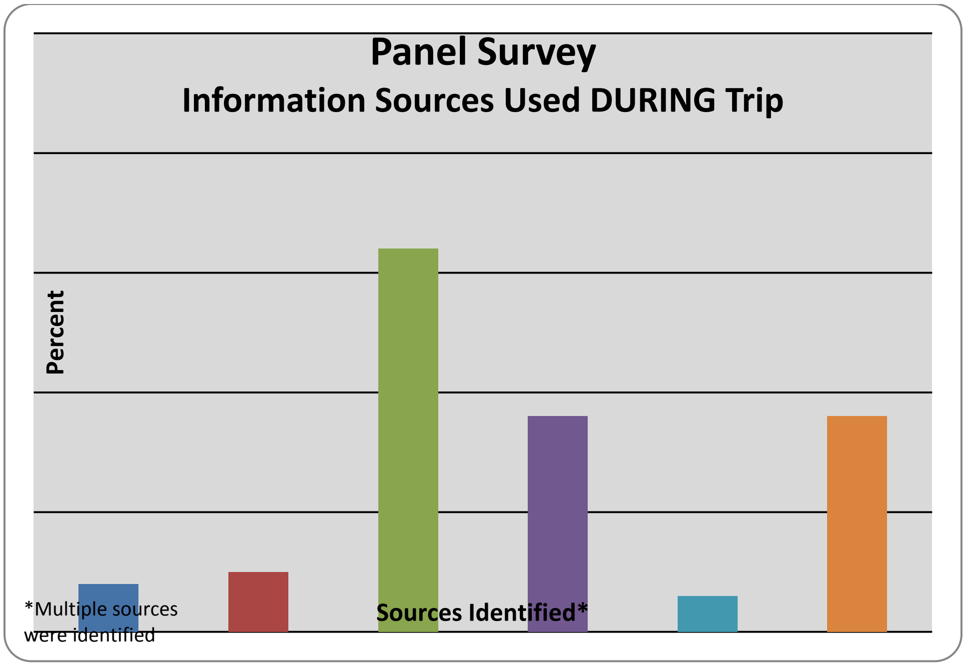


Figure 38. Panel Survey – Information Sources Used *During* the Trip

Drivers responses to the information they received during the trip were similar to their reactions if they received the information before their trip. As shown in Figure 39, very few drivers reported the information had no effect on them. For those who did respond, most reported that they took the advised action and that the information helped them decide what action to take.

Figure 40 summarizes the ratings of the information attributes from the panel for the information sources used during their trips. As shown in this figure, respondents rely on the information they get "while on the road" and, when comparing different attributes, their perceptions were that the information made them better prepared, told them what action to take, and was accurate. While the ratings for other attributes are somewhat lower, approximately two-thirds reported the information they used (which was primarily the caution signs and the DMS) was easy to understand, was credible, timely, and made the trip safer. Somewhat puzzling was the lower ratings for "usefulness" – it would appear that the other attributes would constitute components of "usefulness" but these respondents seemed to not interpret this dimension in the same way.

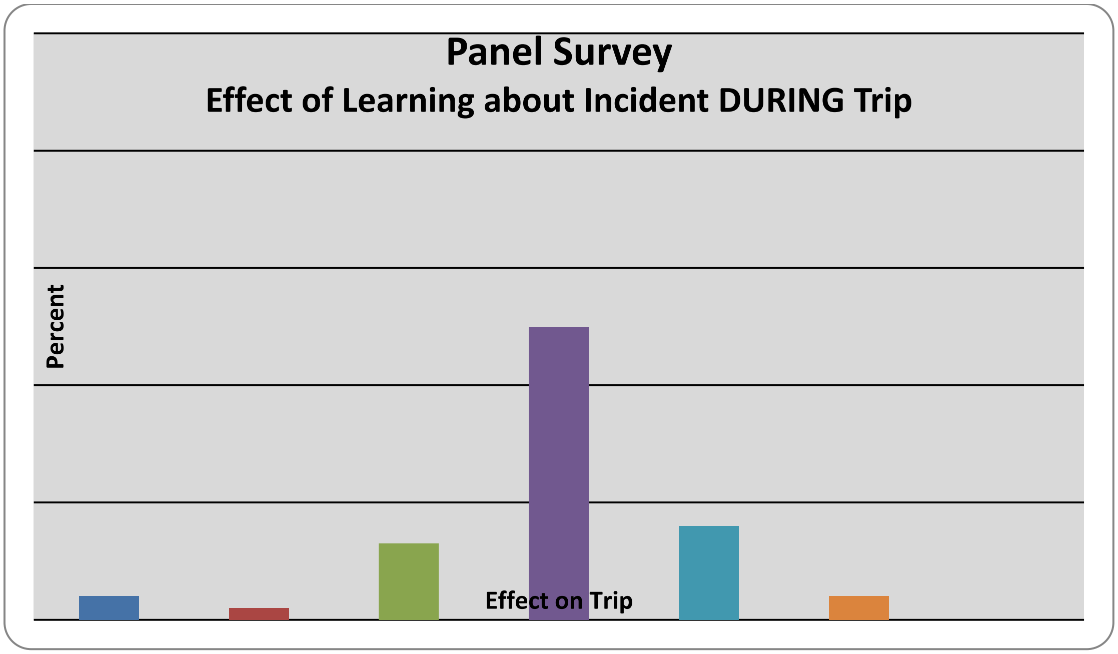


Figure 39. Panel Survey – Response to Learning About Incident While on the Trip

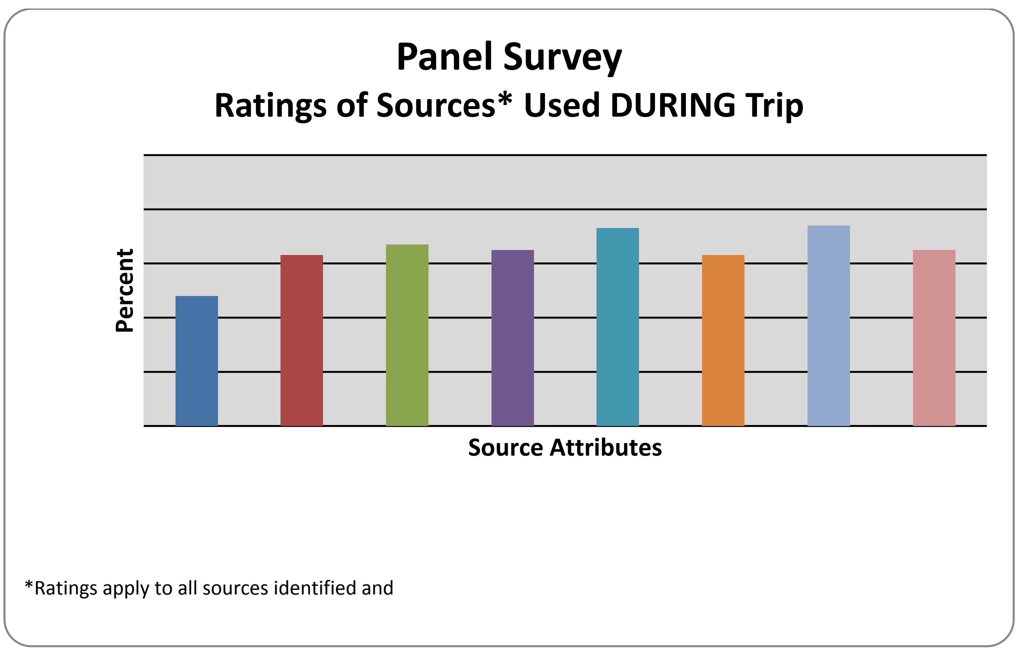


Figure 40. Panel Survey – Response to Learning About Incident While on the Trip

Responses from the drivers who were surveyed along I-80 (the intercept surveys) were asked similar (though not identical) questions regarding the information they used when they traveled; due to the timing of the survey, the information used by the travelers could have been obtained either before or during their trips. As shown in Figure 41, their sources were slightly more varied than the panelists; however, like the panelists, once “on the road” they did rely on the caution signs and the DMS. Almost half said they used the DMS and almost 40 percent used the caution signs.

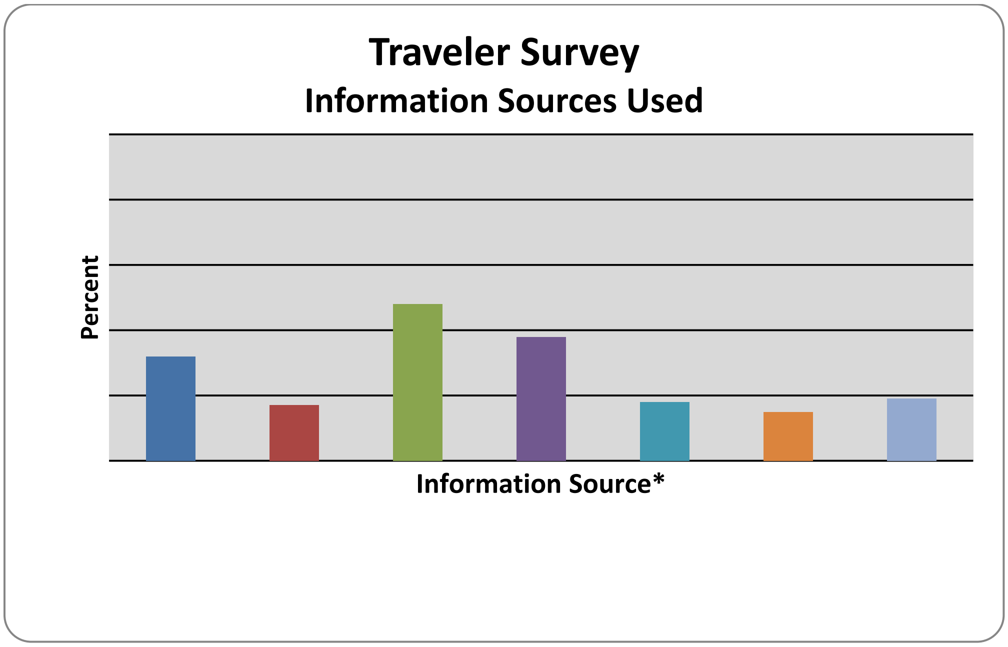


Figure 41. Intercept Survey Respondents – Information Sources Used

Similar to the panelist, these drivers also used the 511 service and broadcast radio, though at a much lower proportion. In addition, use of the web for these respondents was much lower, perhaps because they were traveling – these results may, then, represent the sources they use primarily while they are traveling, in which case their experiences are similar to the panelists’. In addition, for both sets of respondents (panelists and the intercept sample) a few respondents did also mention use of the 511 notification service that was offered in Fall of 2009 and transmitted incident and road closure information to the driver’s cell phone. For the few who did mention this service they responded they were very positive about receiving that information and found it very helpful.

The respondents who were part of the intercept survey sample were asked specifically about the DMS and the effect these signs had on their driving. Figure 42 summarizes their ratings of the DMS attributes.

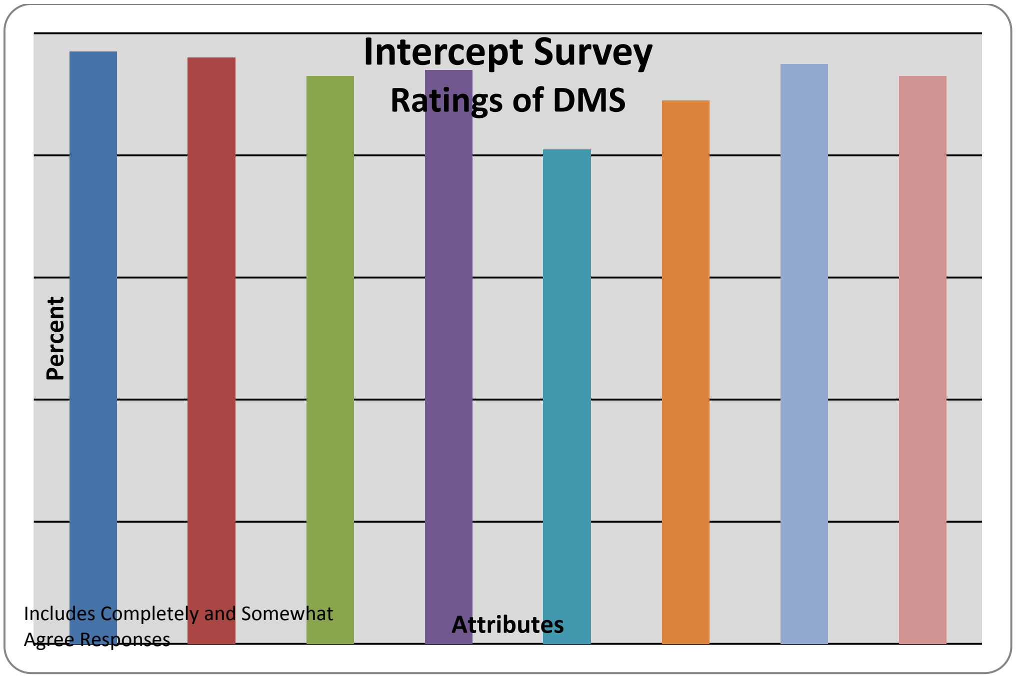


Figure 42. Intercept Survey Respondents – Information Sources Used

As this figure illustrates, these respondents rated essentially all the attributes of the DMS very highly. In fact, most of the ratings are in the 94-96 percent range and include feedback on the signs' usefulness, accuracy, understandability, visibility (even in poor weather conditions), and whether they are appropriately spaced. The information given also appeared to make the drivers better prepared and encouraged them to take the appropriate actions. While still relatively high, with 80 percent of respondents saying the signs were detailed enough, it would appear that drivers would like even more detailed information about conditions to help them prepare for their trips and anticipate any problems they may encounter.

The effect of having the DMS information is shown in Figure 43. The intercept sample reported having the information on the signs did effect their behavior – almost all reported that they drove more carefully and slowly; conversely, less than 10 percent said it had no effect on their behavior. Similar to the findings from the panel survey, after receiving information about the incident from the DMS, these drivers also reported they considered cancelling or postponing their trips.

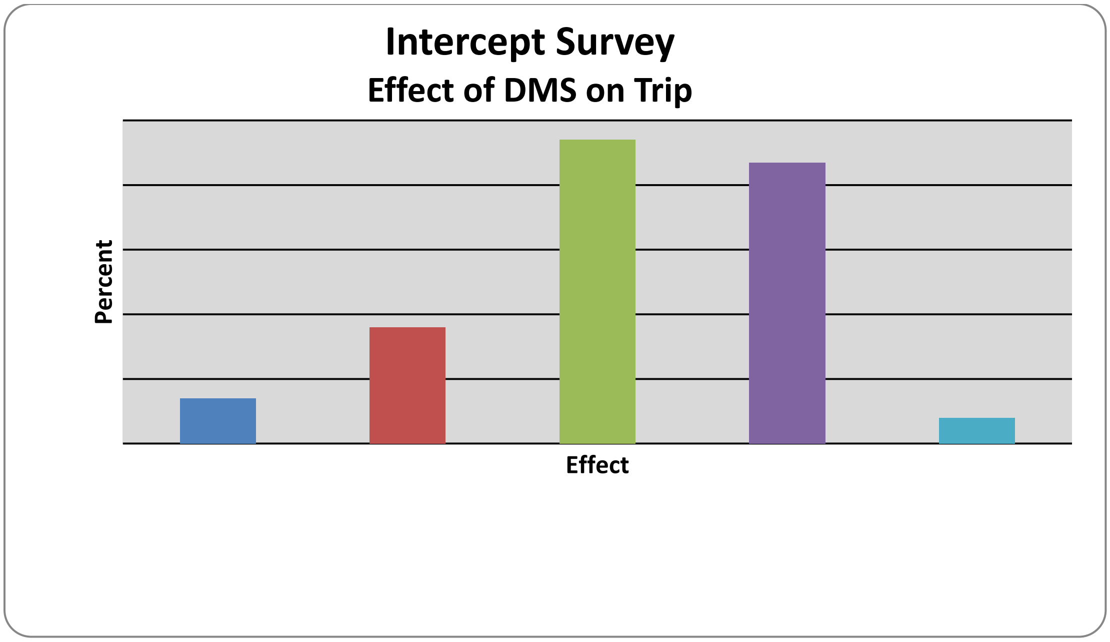


Figure 43. Intercept Survey Respondents – Effect of Receiving Information

3.2.2 Impact on Reducing the Number and Duration of Road Closures

The following describes the analyses that were conducted to investigate road closures to determine if the ITS deployment may have contributed to a change in the number, cause, or duration of road closures.

3.2.2.1 Number of Road Closures

The dispatchers' log data were used to obtain the number (and duration) of I-80 Summit Corridor road closures as recorded by the WYDOT dispatcher for the period from January 1, 2002, to December 31, 2009. The before period (2002-2005) had a total of 48 road closures. The after period (2006-2009) had 113 closures for an increase of 135 percent. It should be noted that the system may have led to this increase in the frequency of road closures, since it is presumed that operators had better visibility of dangerous weather conditions.

As shown in Figure 44, 2007 had the highest number of road closures with 49 occurring that year. The year 2008 saw 27 closures, 2009 had 24, and 2003 had 23 closures. Also, the number of road closures by direction (eastbound/westbound) was roughly equal for most years except for 2009, which had a greater number of eastbound closures. Overall, the number of eastbound road closures increased slightly more in the after period (see Table 26) compared to the westbound closures. However, this is largely a result of the inequality between eastbound/westbound closures in 2009.

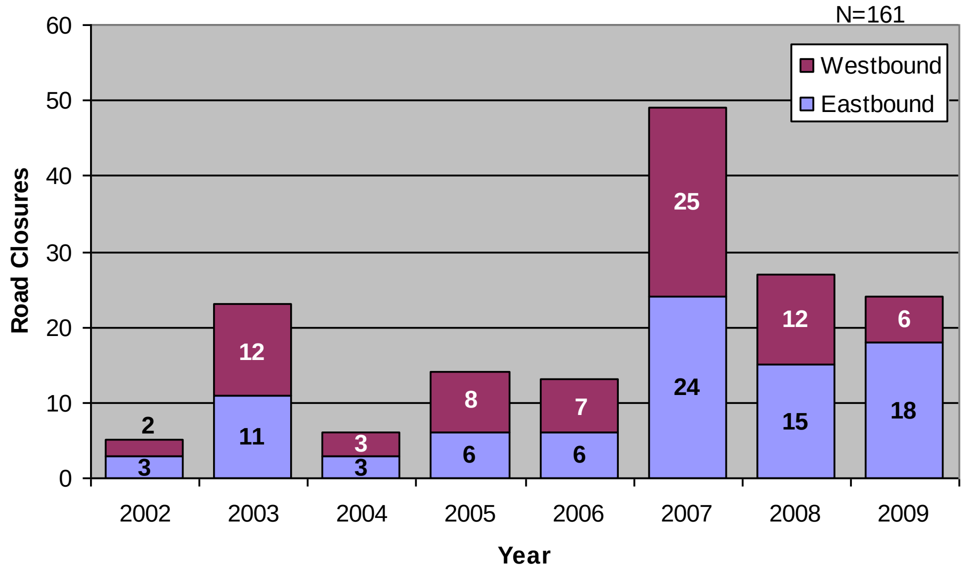


Figure 44. Road Closures by Year and Direction.

Table 26. Before and After Closures by Direction

Direction	Before (2002-5)	After (2006-9)	Total	Change	%Change
Eastbound	23	63	86	+40	173.9%
Westbound	25	50	75	+25	100.0%
Total	**48**	**113**	**161**	**+66**	**135.4%**

As shown in Figure 45, the majority of the closures (about 86 percent) occurred during the winter months (October through April). This is consistent with Wyoming's road closure policy, allowing Highway Patrol, WYDOT, police, and sheriffs all to have authority to close roads whenever they consider it necessary for public health or safety. During the winter, hazardous driving conditions, such as, ice, snow, and poor visibility, are much more likely to result in a closure. The next analysis will investigate the number of road closures by winter driving season to determine the similarities or differences with the closures by year.

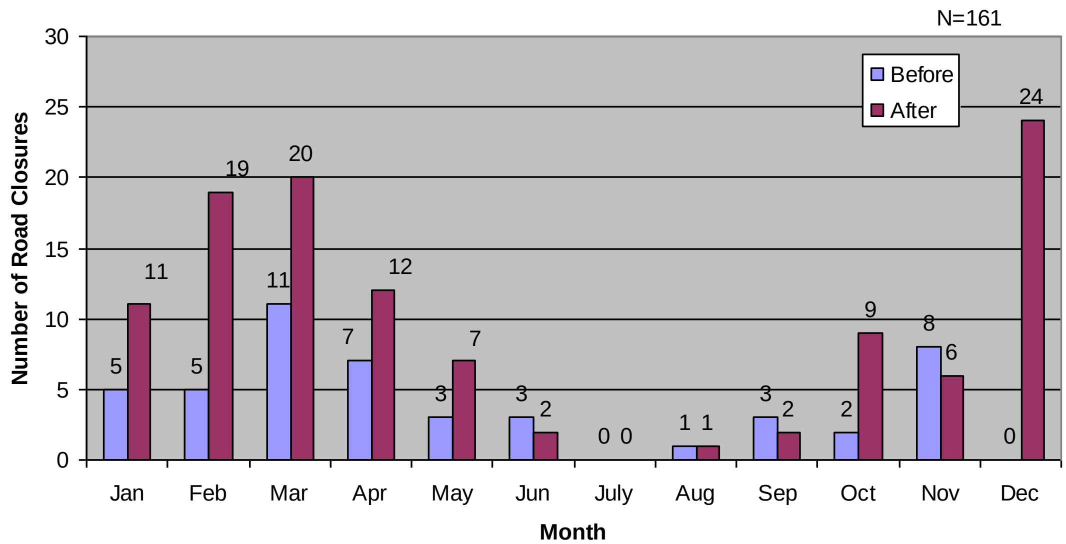


Figure 45. Number of Before and After Road Closures by Month

Figure 46 shows the number of road closures for eastbound and westbound lanes when closures are combined into winter driving seasons (October through April). When viewed by winter driving season several similarities emerge. First, the two winter seasons that include 2007 closures show the greatest number of closures. Second, the number of closures for each direction (i.e., westbound versus eastbound) is about equal for most years (with the exception of the 2008-09 and 2009-10 seasons). Third, there are many more closures in the after period (2006-07 to 2009-10) than in the before period (2002-03 to 2005-06). The next analysis will investigate the cause of road closures to identify the before and after period similarities and differences.

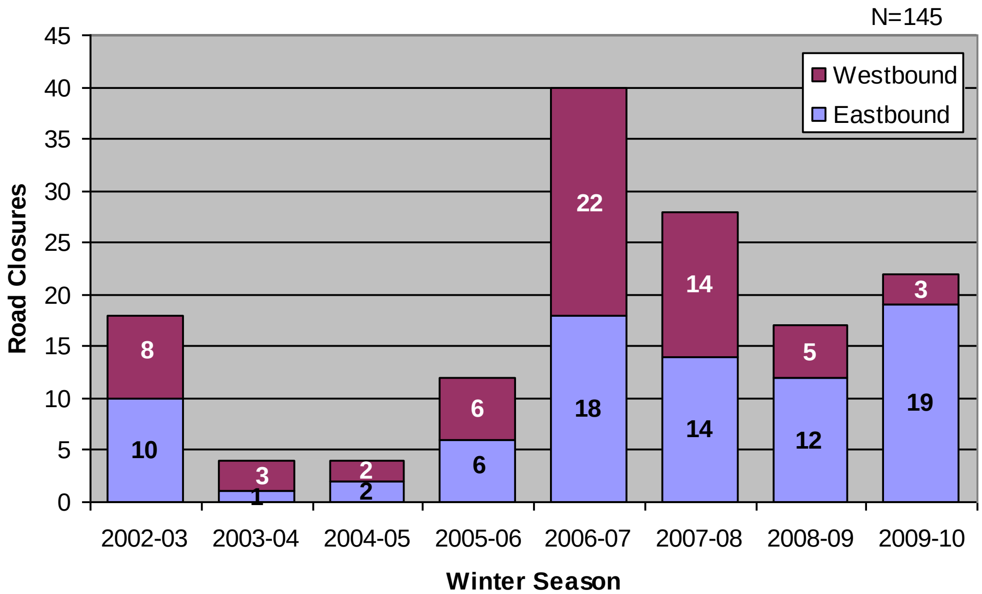


Figure 46. Road Closures by Winter Driving Season and Direction

Investigating the causes of road closures and comparing before and after periods found that adverse weather conditions were the most frequent cause for road closures, especially during the after period. Figure 47 shows the causes of road closures by time period. Weather-related closures increased from 21 to 49, reflecting a 133 percent increase. The second most common reason was adverse weather accompanied with a traffic accident, which increased from 15 to 42 for a 180 percent after period increase. The third most common cause was traffic accidents, which also increased from 10 to 22 for a 120 percent increase. These data seem to show that WYDOT has either improved their ability to detect conditions requiring road closures, relaxed their criteria and became more lenient in closing roads, or had more adverse weather condition days during the after period. The next analysis investigates the road and weather conditions reported at the time of closure to identify the specific conditions leading to the closures.

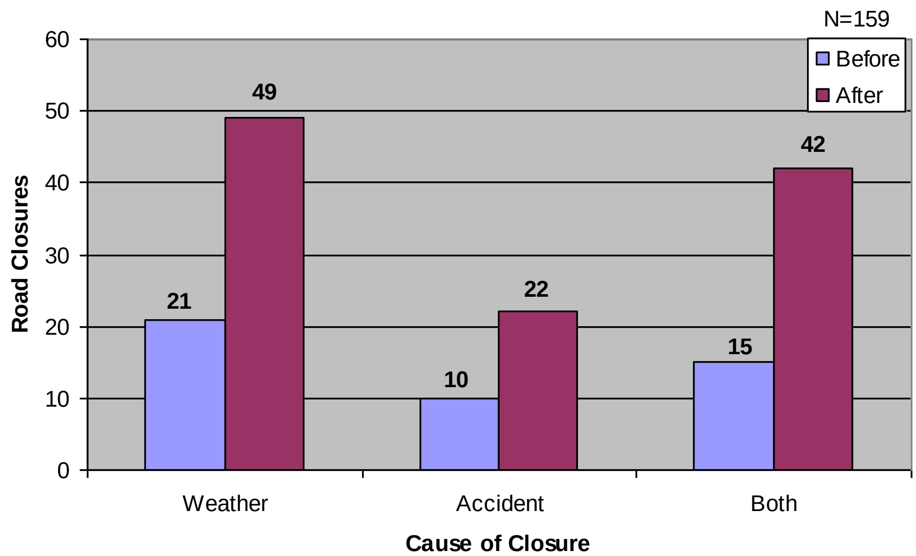


Figure 47. Number of Before and after Road Closures by Cause

Investigating the road and weather conditions at the time of the closure and the before and after differences found that there were more instances of adverse road (slick road, slick spots, drifting snow) and weather conditions (snowing, strong winds, blowing snow, limited visibility) during the after period. The road and weather conditions reported at the time of the road closures is shown in Figure 48. The after period shows a substantially greater number of adverse weather and road conditions that contributed to closures. Adverse road conditions for slick roads increased from 14 to 50 instances, slick spots increased from 11 to 36, and drifting snow increased from 2 to 20. Among adverse weather conditions, snow increased from 16 to 62 instances, strong winds increased from 11 to 59, blowing snow increased from 14 to 61, and limited visibility increased from 17 to 65.

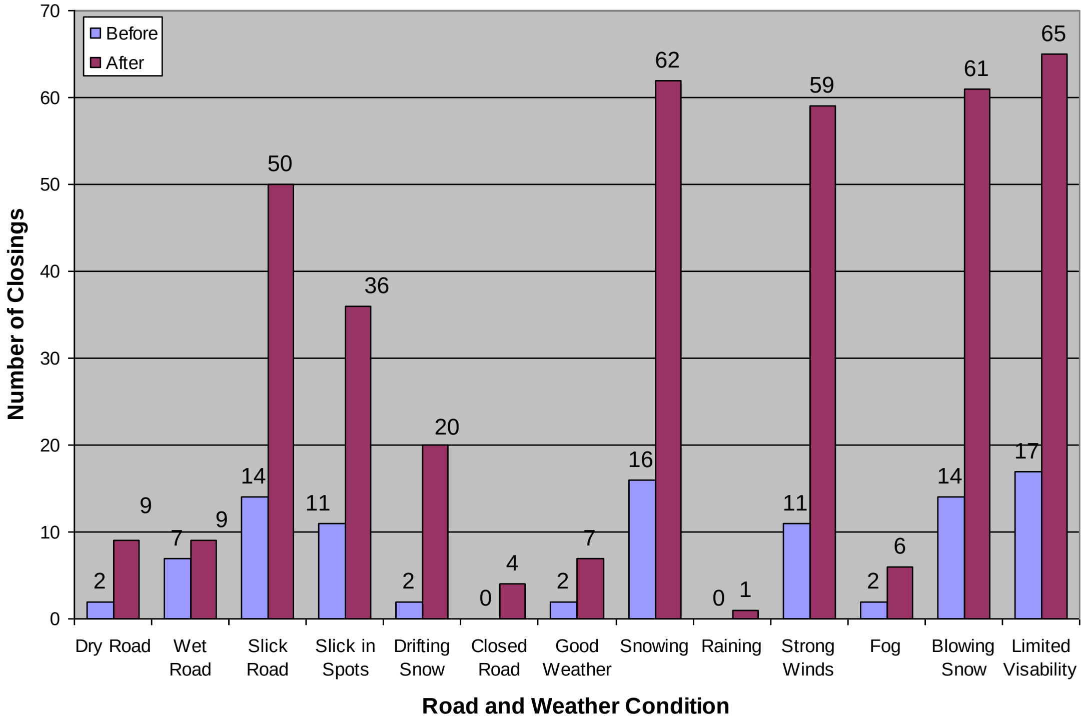
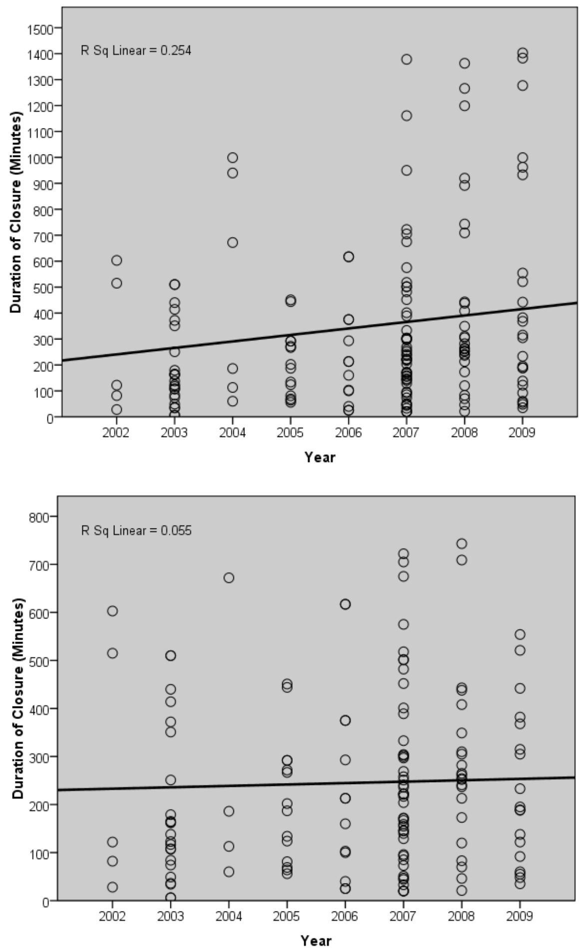


Figure 48. Road and Weather Conditions Reported at Time of Closure

Summary: The before and after comparison of the number of road closures found that the after period had substantially more closures in the winter months primarily due to adverse road and weather conditions. Given Wyoming's road closure policy of closing roads whenever necessary for public health or safety, it is likely that the increase in after period (2006-2009) closures resulted from technology improvements enabling WYDOT operators to identify more days with adverse conditions.

3.2.2.2 Duration of Road Closures

Analysis of the duration of road closures found that the closures ranged from 6 minutes (road closed due to blasting) to over 23 hours (due to slick roads, snow, strong winds, and drifting snow). Figure 49 (a) and (b) shows the road closure durations by year. The linear regression lines indicate that closure durations tended to increase for the after period. However, this is strongly influenced by the 14 extremely protracted closures in 2007, 2008, and 2009 (see Figure 49 (a)). Excluding extreme closures lessened the correlation between year and duration (see Figure 49 (b)).



(a) (b)

Figure 49. Closure Durations by Year With (a) and Without (b) Extremes

Figure 50 shows the mean road closure duration by year with the extreme durations excluded. In comparing the mean durations by year, the durations were not found to be statistically different ($F(7)=0.531$, $p=.810$). Similarly, a comparison of the closure durations for before and after time periods found mean closure durations of 3.5 hours before and 4.25 hours after. An analysis of the variance found the before and after durations were not statistically different ($F(1)=1.971$, $p=0.163$).

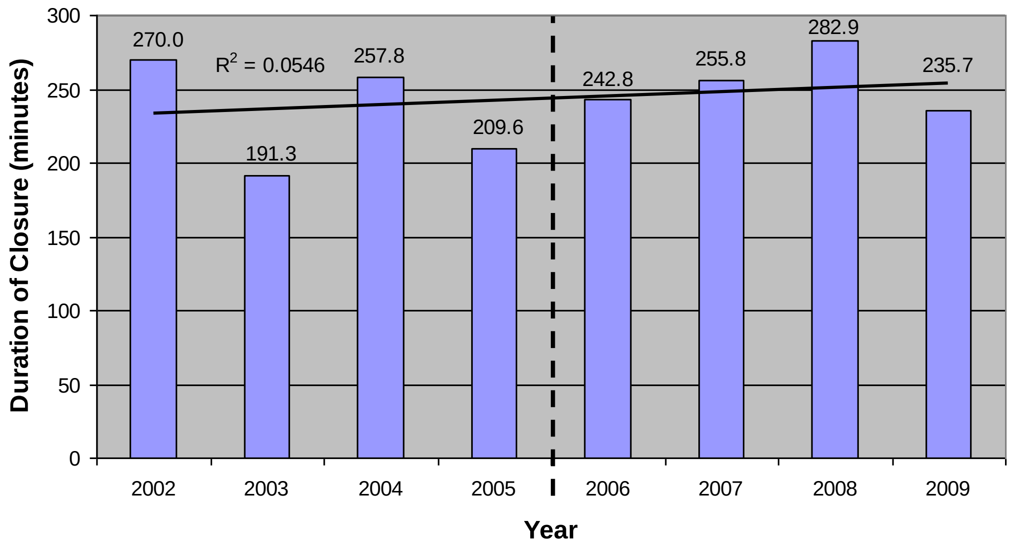


Figure 50. Average Road Closure Duration by Year

3.2.3 Mobility Impacts Summary

3.2.3.1 Impact on Skakeholders' Ability to Respond to Changes in Weather, Road, and Traffic Conditions

The project appears to be effective in improving the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner. The qualitative analyses of interviews/discussions with WYDOT and WHP staff described in section 3.1.2 found that they were in agreement that the implementation of ITS technology on the Summit Corridor had greatly increased their ability to obtain weather, road, and traffic information and respond to changes in conditions.

Travelers' perceptions, whether they were panelists or intercepted travelers contacted on I-80, support the notion that drivers want and will use information available to them to help in their decision making regarding safe travel. Both sets of respondents reported using the DMS, 511, and the Wyoming DOT Web site to gather information, especially to anticipate road closures or travel advisories. The use of the DMS appeared to have an effect on their behavior, as most reported that the information encouraged them to drive more carefully and slowly in response to the road conditions. Many also used the information to decide to postpone or cancel their trips. Ratings for the attributes that travelers would want for the information they receive centered on timeliness, credibility, accuracy and ease of understanding. These ratings were seen by all travelers as reflecting the information they received, based on their responses to the surveys.

3.2.3.2 Impact on Reducing the Number and Duration of Road Closures

The project did not result in a reduction in the overall number and duration of road closures. Compared to the before period, the after period was found to have more road closures and a similar closure duration (after eliminating the extremes). However, these findings appear to be a positive result of the deployment of ITS technologies. When considering that WYDOT has improved their ability to detect and respond to deteriorated travel conditions through the addition of ITS technologies, it seems reasonable that more road closings may result from better identification of hazardous conditions. Although the duration of post-deployment closings did not change, the additional post-deployment closings did coincide with fewer crashes and fewer injury/fatality crashes.

3.3 Customer Satisfaction Impacts

The customer satisfaction study investigated the following hypotheses:

1. The automated road closure system will be perceived as useful in closing and/or re-opening roadways.
2. The traveling public will be able to easily understand the messages and advisories enabled by the deployment of the project and will act upon this information to effect safer travel.
3. The project will be perceived as useful in assisting local travelers to make go/no go travel decisions.

The following sections describe the analyses that were conducted to investigate the automated road closure system's usefulness for closing and re-opening roads, travelers' ability to understand advisory messages and act on the information, and the usefulness of information for local travelers making go/no go travel decisions.

3.3.1 Usefulness for Closing and Re-opening Roadways

Road closure and opening gates are used on I-80 to prevent travelers from driving on hazardous roads or through dangerous areas. Manually closing or opening the gates requires a WYDOT maintenance staff member to travel to the gate location and manually activate the gate. With the large number of commercial vehicles utilizing I-80, the prevalence of just-in-time delivery of goods, and the pressure on commercial vehicle drivers to keep on schedule, WYDOT has relied on the assistance of the Wyoming Highway Patrol to close I-80 and ensure that drivers do not go around the closure gates.

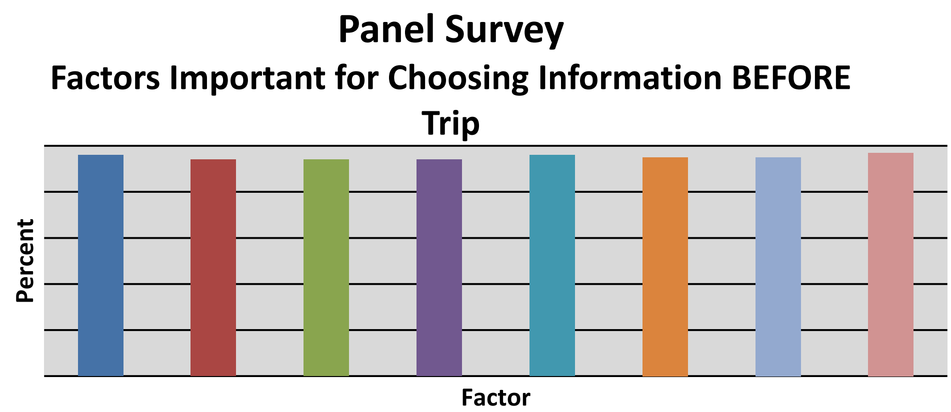
An automated road closure system is a collection of technologies that enable a remotely located operator to monitor for hazardous conditions, communicate with the closure gate system to lower/raise the gate arm or physical barrier, and disseminate road closure information to travelers via DMS, flashing signs, etc. Automating the road closure process and disseminating the road status to travelers would allow WYDOT to close the road more quickly when adverse conditions arise by not requiring WYDOT and WHP to travel to the gate. In addition, providing this information to travelers may help alleviate traffic congestion and the back-ups that develop at the gate during closures.

However, implementing a remotely operated closure system on I-80 between Cheyenne and Laramie has not occurred. WYDOT implemented an automated gate closure and warning light system on the West Side of the Teton Pass on WYO Route 22 between Victor, Idaho and Jackson, Wyoming that was deployed during winter 2000-2001 and 2001-2002. However, due to the heavy volume of vehicles using I-80 and safety concerns due to various entry points along the Summit corridor (entry/exit ramps, roadside parking areas, etc.), an automated road closure system has not been deployed. Consequently, an investigation of its usefulness was not performed.

3.3.2 Understandability of Advisory Messages

As discussed in Section 3.2.1.1, respondents were very much in agreement that the advisory messages were understandable to both sets of travelers surveyed. Approximately 60 percent of panelists reported using the DMS as did one-half of the intercept survey sample. In addition to being understandable, panelists reported that the information sources, including the HAR and caution signs, were accurate, credible, and timely. Having the information available reportedly made the drivers better prepared, made the trip safer, and helped them take the actions that were advised.

In addition, their perceptions seemed to have met their expectations for the factors that were important when choosing information sources. As shown in Figure 51, virtually all respondents reported that each factor they were queried on was important for information used before and during their trips.



*Includes Extremely Important
and Very Important

Figure 51. Panel Survey – Ratings of Factors for Before Trip Information

Between 94 and 98 percent of panelists reported that accuracy, convenience, usefulness, timeliness, availability, accessibility, and especially credibility were important characteristics of the information they obtained before starting their trips.

Interestingly, as shown in Figure 52, these same factors, while still important, rank slightly lower while the panelists are traveling ("during their trips"), between 82% and 90%. A slightly higher proportion of respondents reported that the factors of accuracy, accessibility, and credibility were more important than the other factors.

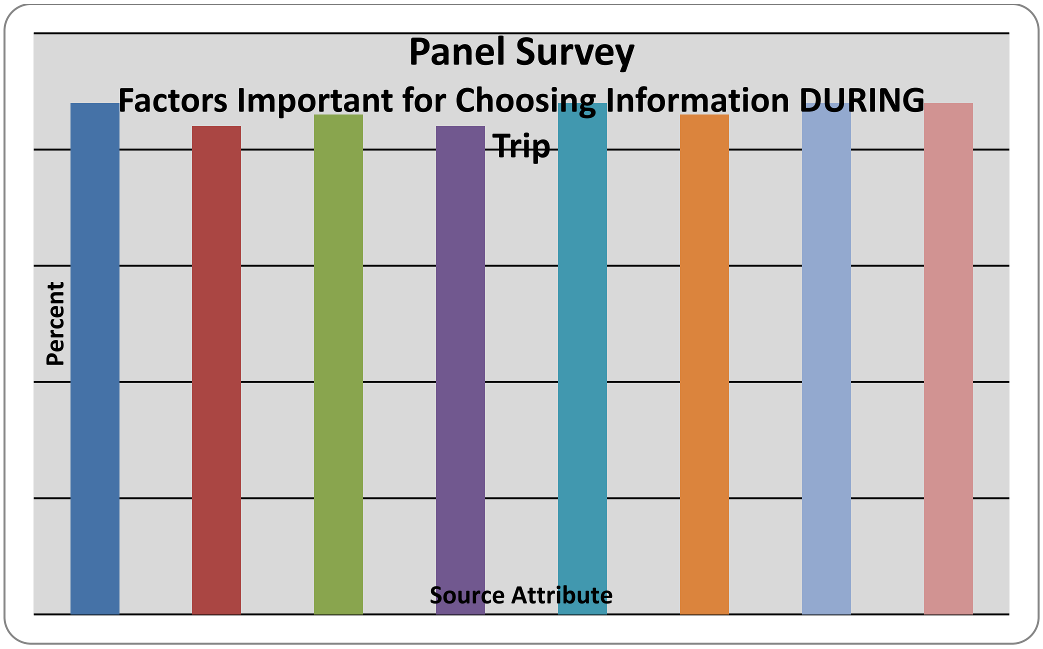


Figure 52. Panel Survey – Ratings of Factors for During Trip Information

The difference between the ratings is somewhat surprising, though it might be understood from drivers' reactions to the information while on their trips. Because more drivers tend to postpone or delay trips before they begin, they may perceive the information has to be as accurate and timely as possible so they can make truly informed choices. While on the trip, they have already, in essence, decided to travel; therefore, they may be looking for information that will help them be prepared for upcoming traffic conditions and make the trip safer (both of which were rated highly by this group).

When considering the responses of the intercept survey sample, their perceptions were somewhat similar to the panelists in terms of accuracy, timeliness, and credibility. As shown in Figures 53 through 55, relative rankings of the information sources identified were high for accuracy for DMS, the caution signs, and broadcast radio. When considering these sources used during a trip, they all received high proportions of a "1 Ranking." In addition, the HAR also received a high proportion of the same rank. The source with the highest proportion of any source that received a "1 Ranking" was the WYDOT Web site. Presumably, this source was used primarily, if not exclusively, before their trips began.

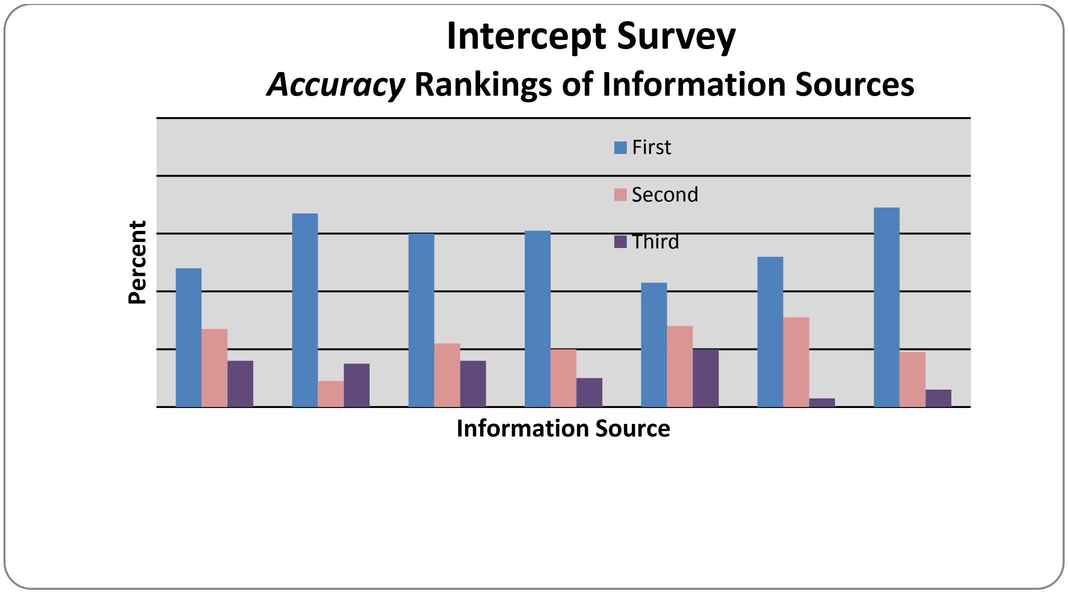


Figure 53. Intercept Survey Respondents – Accuracy Ratings of Information Sources

In terms of credibility, a similar pattern of ranks was obtained from this sample, though interestingly, use of the 511 service received a higher proportion of "1 Rankings" than the sources, including broadcast radio, DMS and the flashing caution signs – all of which showed decreases in the proportions of the highest ranking.

This discrepancy may be explained by examining respondents' perceptions of the timeliness of the information. Figure 55 depicts ratings across all information sources and shows, again, that the source with the highest proportion of "1 Rankings" was the WYDOT Web site. DMS and broadcast radio received the second and third highest proportion of top ratings for this factor. When considering their perceptions, these drivers seem to have interpreted timeliness in terms of the warnings in proximity to the incident/road conditions.

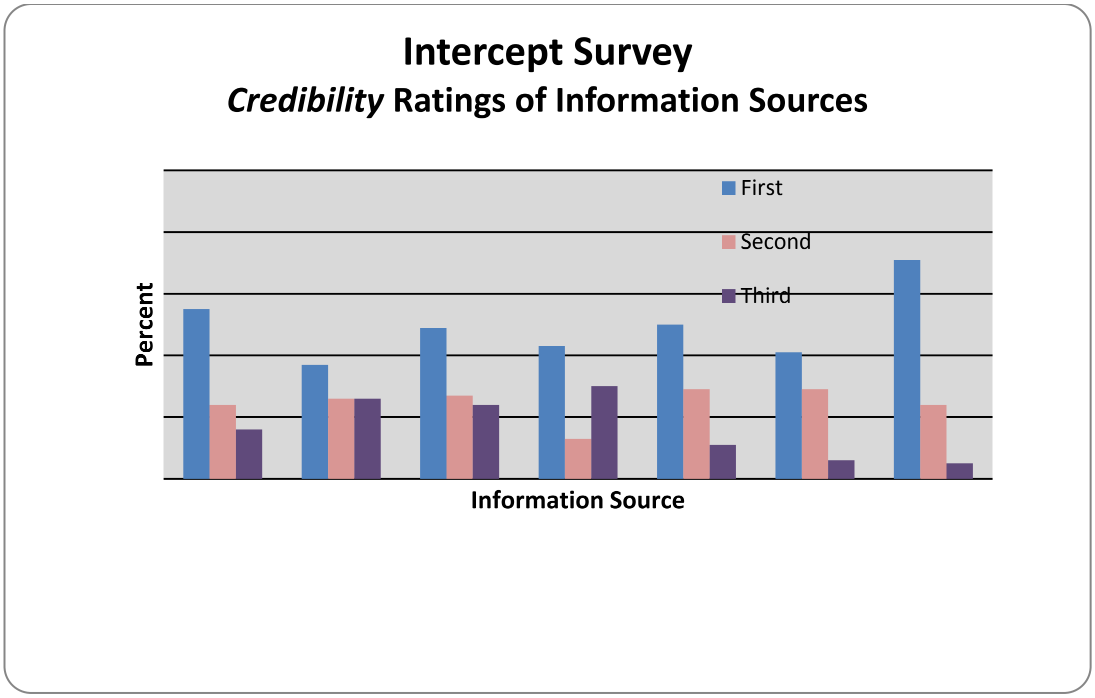


Figure 54. Intercept Survey Respondents – Credibility Ratings of Information Sources

Taken together, these findings suggest that drivers give “high marks” to using the WYDOT Web site, but that the information obtained from the site may be used more for trip planning. High rankings were also obtained for the 511 service, the DMS, and the caution signs – information sources that would be used while on a trip on I-80. These high rankings were similar for accuracy, credibility, and timeliness.

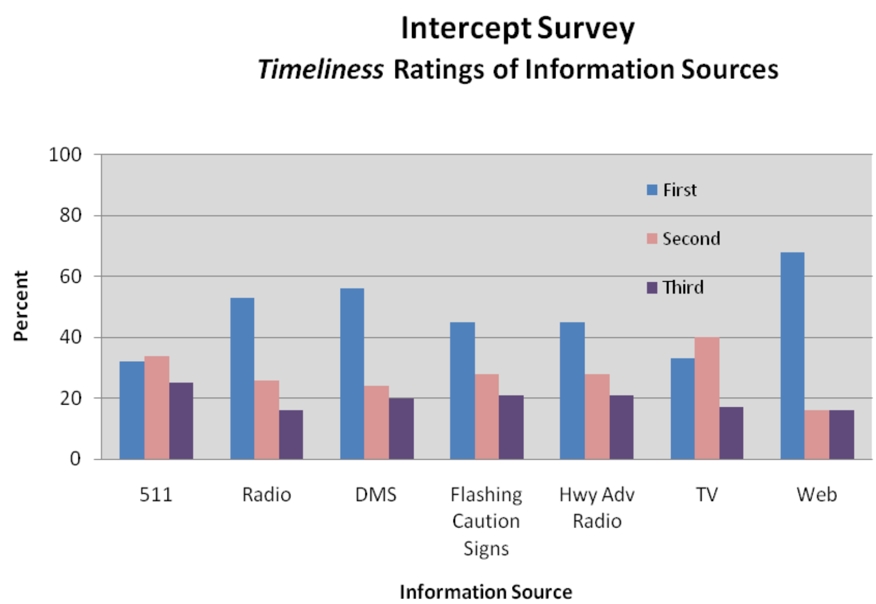


Figure 55. Intercept Survey Respondents – Timeliness Ratings of Information Sources

3.3.3 Drivers Act upon the Information for Safer Travel

As discussed in Section 3.2.1.1, the sources of information drivers were using for their travel did have an impact on their travel behavior. Both local panelists and travelers surveyed on I-80 reported that the information they had available to them (including the DMS, the caution signs, HAR, and broadcast radio) were important to help them make decisions regarding their trips, to drive based on the action advised, and to feel their trips were safer.

3.3.4 Useful for Assisting Local Traveler Making Go/No-Go Travel Decisions

Panelists' responses to the information sources, as discussed in Section 3.2.1.1, showed a reliance on the information sources to help determine if they should proceed with their planned trips. Less than 10 percent of these respondents reported they "ignored" the information they received, regardless of the source (or across all sources). Approximately one-third postponed their trips and approximately one in five reported they had cancelled a trip based on the information.

3.3.5 Customer Satisfaction Summary

3.3.5.1 Project's Usefulness in Decisions to Close and Re-Open Roadways

An investigation of the usefulness of the project for closing and re-opening the gates was not performed. Due to the heavy volume of vehicles using the I-80 Summit Corridor and due to safety concerns because of the various entry points along the corridor (entry/exit ramps, roadside parking areas, etc.), an automated road closure system was not deployed during the evaluation.

3.3.5.2 Impact on Understandability of Advisory Messages and Acting on the Information for Safer Travel

The surveys conducted showed that high proportions of travelers rated the usefulness, understandability, timeliness, and credibility of the sources very highly. The proportion who reported using the DMS was also high with more than three-fourths of respondents saying they had read the signs. The usefulness of these information sources was borne out by the high proportion of travelers who reported that the information encouraged them to take the action that was advised, helped them decide on trip actions, and made the trip safer.

3.3.5.3 Impact on Assisting Local Travelers Making Travel Decisions

Panelists showed a reliance on the information sources to help determine if they should proceed with their planned trips. Less than 10 percent of these respondents reported they "ignored" the information they received, regardless of the source (or across all sources). Approximately one-third postponed their trips and approximately one in five reported they had cancelled a trip based on the information.

CHAPTER 4. LESSONS LEARNED

A variety of lessons regarding planning and operating the I-80 DMS Project and traveler information in general were gleaned from the I-80 DMS Project. In addition to the system impact evaluation and interviews and discussions with WYDOT and WHP, a focus group session was conducted with a mix of daily commuters and commercial truck drivers to obtain insights and feedback regarding the helpfulness of ITS and traveler information along the I-80 Summit Corridor. The lessons that follow were derived from the evaluation results, focus group discussions, and interviews/discussions with WYDOT and WHP stakeholders that have taken place over the past 5 years.

4.1 Planning and Operations

The following are some of the lessons related to planning and operating the ITS technology.

4.1.1 Use of Cameras

WYDOT and WHP stakeholders believe the cameras were a very useful tool for quickly checking road/weather conditions. When used in conjunction with other sources of information (e.g., weather/speed/ice sensors, snowplow operator reports, traveler reports, weather forecast information), TMC operators were better able to identify adverse conditions and avoid having to send a driver out to inspect conditions. This, in turn, made it easier for operators to dispatch snowplows and respond to rapidly changing conditions.

4.1.2 Integration of Technologies

Integrating the sensor technologies has helped the operators identify and confirm changing road/weather conditions. Sometimes the sensors (without the cameras) can be unreliable, misleading, or sound false alarms. The cameras allow operators to check to see if snow is building up or to confirm that ice has developed on the road, and then to develop an appropriate plan of action.

Colocating WYDOT and WHP at the TMC has benefited both agencies and increased their ability to share camera and sensor information. Sharing this information and technology is especially beneficial when dealing with accidents during storm conditions.

4.1.3 Use of DMS Advisories

The use of DMS advisories can be effective in warning travelers of conditions and reducing traffic speeds. DMS advisories were also found to be effective in controlling traffic speeds during periods of improving conditions. However, the effectiveness appears to be highly dependent on multiple factors, including type of weather (snow, strong winds, fog), road condition (dry, icy, blowing snow), traffic condition (accident), whether conditions are improving or getting worse, type of vehicle (passenger vehicle versus large trucks), driver's perception of message accuracy, message type, and message consistency on successive signs.

4.1.4 Implementing an Automated Road Closure System

Agencies considering deploying a fully automated, remotely operated road closure system need to consider safety factors. Safety concerns have slowed the implementation of a fully automated closure system for the I-80 Summit Corridor. The corridor, which is about 40 miles long, has several entry/exit ramps, roadside parking areas, and a small town within the corridor. Consequently, any new automated system must allow the road to be closed in a timely, secure manner, provide the ability to give advance warning of the closure, and provide the ability to monitor traffic near the gates, whether the system of gates and lights are functioning correctly, etc. In addition, the heavy volume of trucks and past history of truck drivers going around closure gates has resulted in WHP manning every gate to enforce closures. A new system would also have to overcome concerns of driver compliance and safety as well as the reliability of the technology.

4.1.5 Continuous Improvement

Agencies should plan to look for and improve deficiencies continuously. WYDOT is constantly identifying areas needing improvement. For example, when it became apparent that the process used to obtain travel condition information needed improvement to support all the areas covered by the DMS, 511, and the WYDOT Web site, WYDOT developed a program to bolster the number of trained observers. In the past, plow drivers working on the corridor used specific guidelines and training on how to read and report on weather and road conditions. Plow drivers reported the conditions to the WYDOT operators who, in turn, updated the messages/information on the HAR, DMS, 511, and Web sites accordingly. However, when it became apparent that busy plow drivers could not continuously monitor the entire length of the corridor, WYDOT developed the Enhanced Citizen Assisted Reporting (ECAR) program to augment their travel condition information. The ECAR program is growing, and as a result, the quality of travel information and WYDOT's ability to obtain travel conditions has improved.

4.2 Traveler Information

The following lessons related to traveler information were also noteworthy.

4.2.1 Accuracy, Timeliness, Precision

The focus group members believed that WYDOT could better motivate desired changes in traveler behavior by improving traveler confidence in the accuracy, timeliness, precision, and overall quality of information on DMS, 511, and the Web site. The commuters and truckers stated that they actively seek out traveler information, but would like to have more confidence in its credibility. They felt that regular updates (such as on the hour or more frequently than that) and communicating the update cycle to the public would prompt them to check for updates.

All focus group participants were aware of the WYDOT Web site, and most used it regularly and considered it to be very helpful. They liked the web cams and sensor information because they perceived it to be more accurate than other sources of information (DMS, HAR, 511) as they have noticed that other sources are often out of date or inconsistent with their experiences on the road.

All members of the focus group were aware of and valued the DMS. However, participants said that they did not always trust the signs' accuracy, that they did not feel the information in many cases is specific enough to be helpful/useful, and that they felt that the DMS signs were not always placed in the most helpful locations. However, the group stated that they felt the messages were improving and that accurate, updated information would influence their behavior. Timeliness and accuracy is essential to gaining credibility and influencing travel behavior.

Finally, the focus group participants desired clear, unambiguous messages that included location information (such as mile marker or town) for all traveler information updates. For example, on DMS, participants unanimously preferred "Speed Limit" language to "Advise" language, coupled with mile marker information to delineate the affected area of the limit and a rationale ("black ice"). Participants felt that the "Speed limit" language was clear and unambiguous whereas, they stated, they were not sure how to respond to "advisories."

4.2.2 Sensor and Weather Information

Given that conditions can rapidly change along portions of the Summit Corridor, travelers reported that they would prefer that the system have both atmospheric and weather sensors that provide complete coverage of the corridor. They indicated a desire to link temperature and wind speeds to web cameras and DMS signs so that both information sources can report real-time icy conditions and wind gust/speed information.

For commercial vehicle operators, the study found that the most important information is wind gust/speeds. Commercial vehicle operators reported that this information is the most important variable influencing their travel behavior. There is a threshold (typically 50 MPH) over which they are not permitted to drive or allow other operators to drive. One respondent commented that "if roads are slick with winds that's really dangerous; without wind you can guide it along, but with wind you can be blown right off." As an alternative to wind sensors, the truckers suggested placing wind socks along the roadside to judge wind direction and strength.

4.2.3 Scaled Content

Information content should be scaled to the type of travel information dissemination source. WYDOT flashing signs, DMS, and text messages which are very limited in the amount of information they can supply should provide very concise information (e.g., Road Closures, No Unnecessary Travel, Reduced Visibility, etc.). E-mail and HAR can provide longer, more verbose information. The 511 travel information service with its interactive nature can be used to provide both concise and detailed information depending on caller choices.

For example, WYDOT's 511 travel information service has the ability to provide the following:

- Road surface conditions (dry, wet, slick, etc.);
- Travel advisories currently in effect;
- Temporary and seasonal closures;
- Current weather conditions; and
- Short-term weather forecasts (which include predicted changes in temperatures, wind speed and direction, and visibility for the upcoming six hours)

Callers can choose the route in which they are interested and hear a condition report either for the entire route or for only a portion of the route. Callers can also choose to hear the report corresponding to their direction of travel.

Finally, kiosks and web sites, which are very interactive and rely on user inputs and choices, can supply the most detailed information.

As such, agencies would be well served to consider developing a travel information distribution plan that describes the types of dissemination sources to be used for providing travel information, when travelers would be expected to receive/use the information (pre-trip or en-route), the information content (by dissemination source), and methods for educating the public on the resulting implementation.

4.2.4 Raise Public Awareness

Consider having a public information campaign to raise public awareness and educate the public about the traveler information services available, how to interpret travel information, how to use it to influence travel decisions, and how to report travel conditions through initiatives such as ECAR program. Also, adopting a rating system to provide a more uniform, systematic way to report road and weather conditions to the public—like that used in ECAR (or a simplified version)—would improve the public's confidence in WYDOT's traveler information. Additional suggestions for raising public awareness include: publicizing online sources of WYDOT articles and news, placing information kiosks in shopping malls, and adding a section to the local newspaper (like the weather) so that over time the public becomes conversant in traveler information terminology.

4.2.5 Expand the Enhanced Citizen Assisted Reporting Program

To increase the number of trained observers who can provide reliable and accurate travel condition reports, WYDOT is expanding the ECAR program to include trained commuter drivers as well as truck drivers. Increasing the number and quality of travel condition reports improves WYDOT's ability to monitor and identify hazardous travel conditions, which in turn improves the accuracy and timeliness of travel advisory messages. As a result, travelers will gain confidence in the advisory messages, seek out the information, and be more likely to modify their behavior.

During past winters, reports from volunteers have proven to be timely and accurate and have been a valuable supplement to WYDOT's traditional method of relying solely on reports from WYDOT snowplow drivers and other maintenance crews. An ideal ECAR volunteer is a person who regularly drives a particular roadway and can provide first hand observations of the travel conditions for the benefit of others traveling the same roadway. Volunteers are provided with an illustrated handbook which includes written and visual definitions of the different types of pavement and weather conditions used by WYDOT. In addition, volunteers are instructed on how and when to report issues such as road kill or other debris on the roadway as well as how to report incorrect information on DMS.

CHAPTER 5. CONCLUSIONS

The evaluation of the ITS deployment along southern Wyoming's I-80 Summit corridor has resulted in a better understanding of the safety, mobility, and customer satisfaction impacts that can result from the implementation, management, and utilization of this combination of ITS technologies. The study of safety impacts found that the I-80 DMS project did have a positive impact on traveler safety in terms of reducing traffic speeds during hazardous travel conditions; enhancing the ability of WYDOT and WHP to obtain weather, road, and traffic condition information; and reducing the overall number of crashes, injury crashes, and fatal crashes. The study of mobility impacts found that the ITS deployment was viewed favorably by operations, maintenance, dispatcher staff, and the traveling public because it increased their ability to identify and respond to changes in travel conditions. Being able to identifying hazardous conditions more accurately led to more actions in response, which is supported by the increase in the number of road closures since the ITS deployment. The study of customer satisfaction impacts found that travelers rated the understandability of the DMS messages and advisories very highly. They viewed the advisories as useful for making travel decisions and, as a result, felt that they had safer trips.

Conclusions for the key and secondary evaluation hypotheses are described below and reveal whether the evaluation found results that supported/contradicted the hypotheses, or whether the result were inconclusive.

Key Hypothesis: The project will effectively reduce traffic speeds and variability in response to deteriorated roadway conditions (e.g., during incidents, inclement weather, etc.). *This hypothesis was supported with the results obtained from the quantitative data analysis.* The analysis of traffic speeds during 16 periods of adverse travel conditions revealed that the DMS advisories were often effective in reducing overall traffic speeds. This effect was most pronounced in the eastbound direction which often showed average speeds decreasing from 5 to 10 mph depending on the advisory message and travel conditions. Also, it appears that a number of factors may influence the effectiveness of DMS advisories in reducing speeds including the travel conditions, the type of message displayed, and the consistency of the messages across multiple DMS locations. The overall variability of the before and after hourly average speeds were very similar, both having an average standard deviation of about 7 mph.

Key Hypothesis: The project will increase the ability of operations, maintenance, and law enforcement to obtain useful weather, road surface, or traffic condition information on I-80 between Cheyenne and Laramie. *This hypothesis was supported with the results obtained from the interviews with WYDOT and WHP staff.* WYDOT and WHP stakeholders were in agreement that the implementation of ITS technology on the Summit Corridor greatly increased their ability to obtain weather, road, and traffic information. The CCTV cameras were clearly the favorite technology for obtaining information and were useful for operators to quickly obtain first-hand visual information to check and verify unconfirmed reports and (RWIS/speed/ice) sensor information.

Secondary Hypothesis: The project will result in a reduction in the overall rate of crashes, fatalities, and injuries. *This hypothesis was supported with the results obtained from the quantitative analysis of crash records.* The total number of crashes decreased from 1,155 in the pre-deployment period (2002 to 2005) to 1,025 in the post-deployment period (2006-2009). The number of crashes per vehicle miles traveled was also reduced for overall, injury, and fatal crashes during the after period. Overall, crashes per million vehicle miles traveled decreased from 1.63 (before) to 1.44 (after).

Fewer crashes involving injuries occurred during the post-deployment period (281) compared to the pre-deployment period (370). Comparison of injury crash rates supported these results as the injury crash rate decreased from 0.52 to 0.39 injury crashes per MVM. For fatal crashes, fewer crashes resulted in fatalities with 19 occurring before deployment and 10 occurring after deployment. The after period had a lower fatality crash rate, decreasing from 0.03 to 0.01 fatal crashes per MVM.

Secondary Hypothesis: The project will increase the ability of both public and private entities in the transportation community to respond to changes in weather, road, and traffic conditions in an effective manner. *This hypothesis was supported with the results obtained from the interviews with WYDOT and WHP staff and the traveler surveys.* Iinterviews with WYDOT and WHP staff revealed that they felt that the implementation of ITS technology on the Summit Corridor had greatly increased their ability to identify and respond to changes in weather, road, and traffic conditions. The colocation of WYDOT and WHP at the TMC in Cheyenne also improved the ability of both agencies to obtain and weather, road, and traffic condition information; to speak directly to each other to share information; and to coordinate their efforts to perform their responsibilities during hazardous travel conditions.

Traveler perceptions from the surveys indicated that drivers want and use the available information to help in their decision making regarding safe travel. Survey respondents reported using the DMS, 511, and the Wyoming DOT Web site to gather information, especially to anticipate road closures and travel advisories. The DMS appeared to affect their behavior, as most reported that the information encouraged them to drive more carefully and slowly in response to the road conditions. Many also used the travel information to decide to postpone or cancel their trips.

Secondary Hypothesis: The project will result in a reduction in the overall number and duration of road closures. *This hypothesis was not supported with the results obtained from the quantitative data analysis.* In fact, it was found that after ITS deployment the number of road closures increased. However, given that WYDOT has (through the addition of ITS technologies) improved their ability to detect hazardous travel conditions, it seems reasonable that more road closings may result from better identification of hazardous conditions. Also, since road closings occur due to hazardous weather conditions, accidents, or both and are implemented to protect travelers from harm, these findings appear to be a positive result of ITS deployment. This is supported by the decrease in post-deployment-period crashes.

Key Hypothesis: The automated road closure system will be perceived as useful in closing and/or re-opening roadways. *This hypothesis is inconclusive as an automated closure system was not deployed in time for evaluation. Consequently, an investigation of the usefulness was not conducted.* The interviews with WYDOT ITS, maintenance, and operations staff found that several challenges related to safety slowed the implementation of a fully automated road closure system. The primary challenges included having several entry points onto I-80 within the eastside and westside road closure gate areas and the need to have WHP present at gates to enforce gate closures.

Key Hypothesis: The traveling public will be able to easily understand the messages and advisories enabled by the deployment of the project and will act upon this information to effect safer travel. *This hypothesis was supported with the results obtained from the quantitative data analysis of the local panel surveys and intercept surveys.* The surveys that were conducted showed that high proportions of travelers rated the usefulness, understandability, timeliness, and credibility of the sources very highly. The proportion who reported using the DMS was also high, with more than three-fourths of respondents saying they had read the signs. The usefulness of these information sources was borne out by the high proportion of travelers who reported the information encouraged them to take the action that was advised, helped them decide on trip actions, and made their trips safer.

Secondary Hypothesis: The project will be perceived as useful to assist local travelers in making go/no go travel decisions. *This hypothesis was supported with the results obtained from the quantitative data analysis of the local panel surveys.* Panelists showed a reliance on the information sources to help them determine if they should proceed with their planned trips. Less than 10 percent of these respondents reported they "ignored" the information they received, regardless of the source (or across all sources). Approximately one-third postponed their trips and approximately one in five reported they had cancelled a trip based on the information.

Figure 56 highlights the overall benefits found during this evaluation. Overall, the I-80 DMS Project has been found to result in several positive outcomes. The CCTV cameras have been very effective in improving WYDOT's ability to identify, verify, and respond to hazardous weather, road, and travel conditions. The DMS and other travel information dissemination sources appeared to be mostly effective in controlling traffic speeds; however, the effect on speeds appear to be dependent on a variety of factors (the type of weather, the road condition, how conditions are changing, the type of vehicle, drivers' perception of the accuracy of the information, the type of message, the consistency of the message, etc.). The before and after comparison of crashes found that overall traffic crashes, injury crashes, and fatal crashes were reduced. Intercept surveys and local traveler panel surveys found that travelers appear generally satisfied with the understandability, usefulness, and availability of traveler information.

Summary of Overall Benefits

The ITS technologies deployed for the I-80 Summit Corridor between Cheyenne and Laramie were effective in:

- Improving identification of hazardous weather, road, traffic conditions;
- Reducing traffic speeds during hazardous travel conditions;
- Reducing the overall number of traffic crashes, injury crashes, and fatal crashes;
- Communicating and coordinating response efforts between WYDOT and WHP; and
- Providing useful advisory information to the traveling public.

Figure 56. Summary of Overall Benefits

Figure 57 highlights the lessons learned during the evaluation of the I-80 MDS Project. The implementation of the technologies and operational experience has provided WYDOT with numerous lessons that will guide the agency through future enhancements. During the evaluation period, WYDOT has continued to improve their ability to increase traveler safety, mobility, and satisfaction by expanding ITS technology across Wyoming. Interstates 25, 80, 90 and numerous state roads now have Dynamic Message Signs, CCTV cameras, weather stations, and road sensors with travel condition information accessible from HAR, DMS, text message, 511, e-mail, and the WYDOT Web site.[9]

[9] See: Wyoming Department of Transportation, "Wyoming Travel Information Map," available at: Wyoming Travel Information Map (last accessed October 5, 2010).

Summary of Lessons Learned

- Cameras are very useful for quickly observing and verifying travel conditions.
- Integrating information and colocating agencies improves agency coordination.
- DMS are often effective in controlling traffic speeds, but multiple factors influence that effectiveness.
- Consider the safety factors related to deploying a remotely operated road closure system.
- Travelers are most responsive to accurate, timely, and precise information.
- Information contents should be scaled to the type of dissemination source.
- The public needs to be made aware of the meanings of travel conditions and advisories.
- Expanding the ECAR program will increase the number of reliable road/weather reports.

Figure 57. Summary of Lessons Learned

CHAPTER 6. REFERENCES

1. "About Wyoming, A Narrative About Wyoming," State of Wyoming Web site, last accessed October 19, 2010: Wyoming website

2. ITS Lessons Learned Web site resource last accessed October 19, 2010 at: Lessons Learned Overview

3. *Safety Improvement Study: Interstate-80 Mile 325-335*, prepared by Tabler & Associates for the Transportation Commission of Wyoming, July 31, 2002.

4. U.S. Department of the Interior, U.S. Geological Survey, 2007.

5. "Wyoming's Weather & Climate," Wyoming Travel & Tourism Web site, last accessed October 19, 2010: Wyoming Office of Tourism

6. ANSI D16.1-2007 *Manual on Classification of Motor Vehicle Traffic Accidents, American National Standard*, 2007.

APPENDIX A

This section presents a snapshot of the 16 adverse travel events that were used in the analysis of traffic speeds. Table A1 shows the dates, road/weather condition, and direction and description of the adverse travel events that were examined for this analysis. For each date, a figure depicts the location of speed sensors and DMS along I-80 between milepost 339 and 321. The road surface is depicted as the horizontal gray area separated by dashed lines. Speed sensors are shown roadside with the milepost location underlined (e.g., s330 indicates a speed sensor at milepost 330). Additional sensors (not shown in all figures) were also located at 336.5, 335.5, and 326.9. The black numbered boxes show the location of the DMS (e.g., box 331 means the DMS is located at milepost 331). Along the top of the figure are milepost designations to provide an indication of the figure scale. When traveling westbound, vehicles are headed towards the summit (and Laramie) and for the most part experience a gradual upgrade climb until near the summit pass.

Changes of average traffic speeds were examined using two types of before and after comparisons: spatial and temporal. For each event, a table provides a brief description of the DMS messages by time and location. Then, a figure is used to depict the average vehicle speeds by location and time interval.

Table A1. Adverse Travel Events

Event #	Date	Road/Weather Condition	Direction and Description
1 2	May 27, 2008	Fog	WB: Heavy Fog Limited Visibility EB: Heavy Fog Limited Visibility
3 4	Oct. 12, 2008	Snowfall, Icy Road	WB: Icy Road Snowfall EB: Icy Road Snowfall
5 6	Nov. 23, 2009	Strong Wind, Blowing Snow, Slick Road	WB: Slick Road Strong Wind Blowing Snow EB: Slick Road Blowing Snow
7 8	Dec. 1, 2009	Fog, Blowing Snow, Slick Road	WB: Dense Fog Reduced Visibility Slick Road Snow Blowing EB: Slick Road Snow Blowing
9	Mar. 23, 2010	Blowing Snow, Poor Visibility, Slick Road	EB: Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH
10	Mar. 24, 2010	Slick Road	WB: Slick Road Advise 45/55/60/65 MPH
11 12	Apr. 2, 2010	Blowing Snow, Poor Visibility, Slick Road	WB: Advise 40 MPH Slick Road Poor Visibility EB: No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH

Event #	Date	Road/Weather Condition	Direction and Description
13 14	Apr. 7, 2010	Snow, Slick Spots, Wet Road	WB: Wet Road Snow Reduce Speed EB: I-80 Closed & Slick Spots Snow Reduce Speed
15 16	Apr. 17, 2010	Fog	WB: Dense Fog Poor Visibility Reduce Speed EB: Dense Fog Poor Visibility Reduce Speed

Legend: WB = Westbound, EB = Eastbound

Westbound I-80:

May 27, 2008 Westbound I-80

Figure A1 shows the location of speed sensors and DMS for westbound I-80 between MP 334.5 and 343.7. For the purposes of this analysis speeds were examined at three locations around DMS at MP 336.1: speed sensor at MP 336.5 (0.4 miles upstream of the DMS); speed sensor at MP 336.1 (at the location of the DMS); and speed sensor at MP 335.5 (0.6 miles downstream of the DMS). Table A2 shows a listing of DMS messages and speeds by time period and location. In the table Period -1 is the one hour "Before" and includes all DMS messages from 21:25 to 22:20. The "After" time periods are in one hour intervals and are shown as Period +1 (first hour after) and Period +2 (second hour after).

During Period -1 the DMS at MP343.7 was blank and the DMS at MP336.1 displayed "Click-It Don't Risk It Please Buckle Up". During Period +1 (from 22:25 to 23:20) the DMS at MP 343.7 was still blank and the DMS at MP336.1 displayed "Heavy Fog Limited Visibility Advise Max Safe Speed 45 MPH". At 21:27 the DMS advisory was changed to "Heavy Fog Limited Visibility Speed Limit 45 MPH".

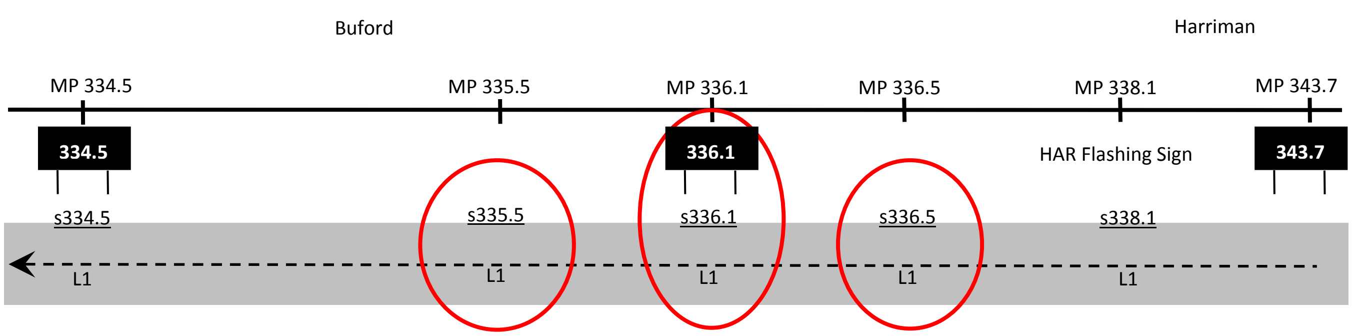


Figure A1. Speed Sensors and DMS for Westbound I-80 between MP 334 and 344

Table A2. Westbound I-80 DMS Messages by Time and Location for May 27, 2008

Period	Time	Sign @ MP 343.7	Sign @ MP 336.1
-1 (Before)	21:25 to 22:20	Blank Sign	16:45-Click-it Don't Risk It Please Buckle Up
+1 (After)	22:25 to 23:20	Blank Sign	22:21-Heavy Fog Limited Visibility Advise Max Safe Speed 45 MPH 22:27-Heavy Fog Limited Visibility Speed Limit 45 MPH
+2 (After)	23:25 to 0:20	Blank Sign	Heavy Fog Limited Visibility Speed Limit 45 MPH

Figure A2 shows the average vehicle speeds by location and time interval. The gold vertical bars indicate the location of the DMS. The DMS at milepost 343.7 displayed a blank sign and the DMS at milepost 336.1 displayed "Click-It Don't Risk It" in the Before period and "Speed Limit 45 MPH" during the first and second hours "After". In the Before period (Period -1) the average speed was about 57 miles per hour at milepost 336.5 and 59 miles per hour at milepost 335.5. In the After period, the first hour after (Period +1) had average speeds of about 53 miles per hour at milepost 336.5 and 56 miles per hour at milepost 335.5.

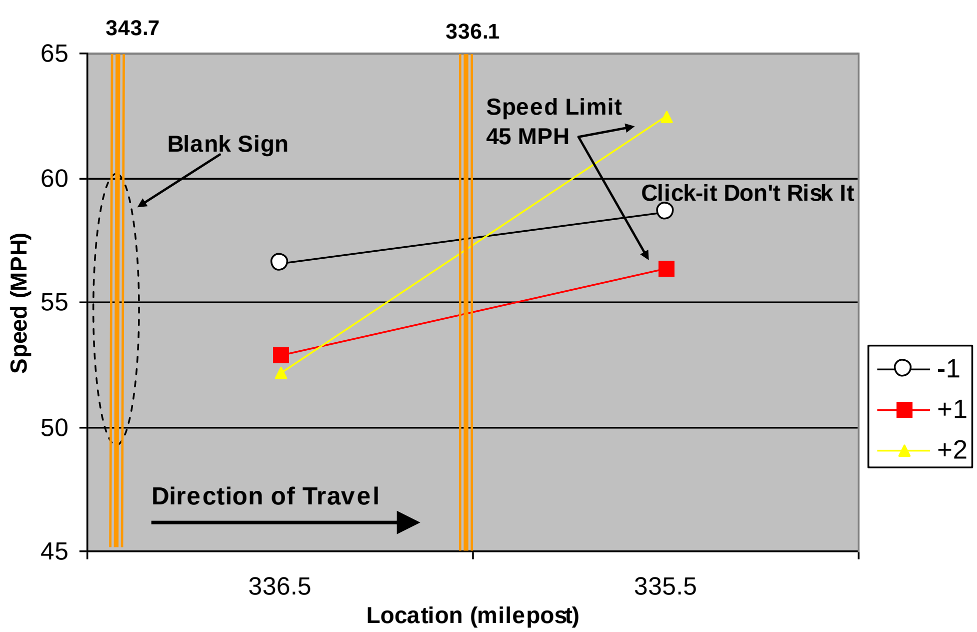


Figure A2. Average Vehicle Speeds by Hour and Location

For each of the remaining adverse travel events similar figures and tables are displayed to present specific information about the location of DMS and speed sensors, the DMS messages presented to travelers and the average speed by hour and location.

Oct. 12, 2008 Westbound I-80

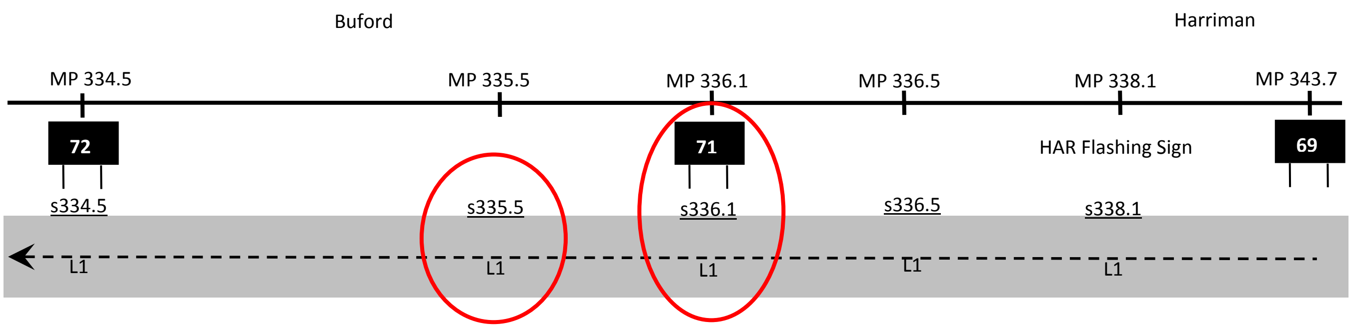


Figure A3. Speed Sensors and DMS for Westbound I-80 between MP 334 and 344

Table A3. Westbound I-80 DMS Messages by Time and Location for Oct. 12, 2008

Period	Time	Sign @ MP 343.7-7.6 miles upstream	Sign @ MP 336.1
-1 (Before)	18:15 to 19:10	18:15-Blank Sign 18:55-Icy Spots Snowfall Slow Down	18:15- Blank Sign 19:07-Icy in Spots Snowfall Slow Down
+1 (After)	19:15 to 20:10	Icy in Spots Snowfall Slow Down	19:15-Icy Road Snowfall Advise 45 MPH
+2 (After)	20:15 to 21:10	Icy in Spots Snowfall Slow Down	Icy Road Snowfall Advise 45 MPH
+3 (After)	21:15 to 22:10	Icy in Spots Snowfall Slow Down 21:57-Icy Spots Ahead Turn Off Cruise Control	Icy Road Snowfall Advise 45 MPH
+4 (After)	22:15 to 23:10	Icy Spots Ahead Turn Off Cruise Control	Icy Road Snowfall Advise 45 MPH

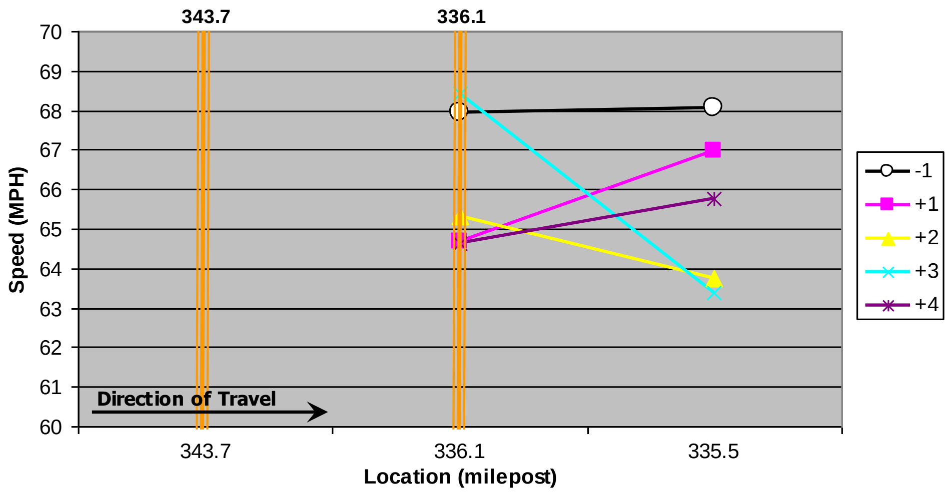


Figure A4. Average Vehicle Speeds by Hour and Location

Nov. 23-24, 2009 Westbound I-80

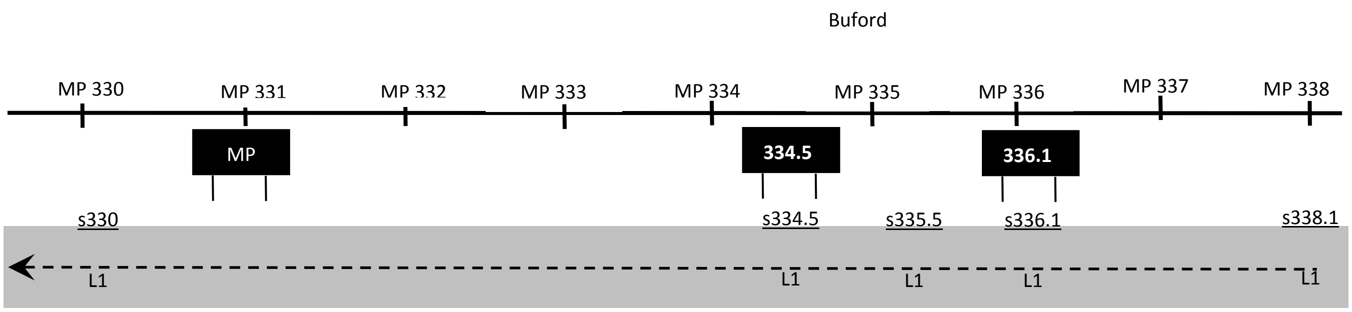


Figure A5. Speed Sensors and DMS for Westbound I-80 between MP 330 and 338

Table A4. Westbound I-80 DMS Messages by Time and Location for Nov. 23-24, 2009

Period	Time	Sign @ MP 343.7	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331
-1 (Before)	20:57 to 21:56	Blank Sign	21:10-Slick Road Strong Wind Blowing Snow	21:10-Slick Spots Strong Wind Blowing Snow	21:10-Slick Road Strong Wind Blowing Snow
+1 (After)	21:57 to 22:56	Blank Sign	21:57-Slick Road Strong Wind Blowing Snow Advise 45 MPH	21:58-Slick Road Advise 45 MPH Strong Wind Blowing Snow	21:58-Slick Road Advise 45 MPH Strong Wind Blowing Snow
+2 (After)	22:57 to 23:56	Blank Sign	Slick Road Strong Wind Blowing Snow Advise 45 MPH	Slick Road Advise 45 MPH Strong Wind Blowing Snow	Slick Road Advise 45 MPH Strong Wind Blowing Snow
+3 (After)	23:57 to 0:56	Blank Sign	00:20-Slick Road Strong Wind Blowing Snow Reduced Visibility Advise 45 MPH	Slick Road Advise 45 MPH Strong Wind Blowing Snow	Slick Road Advise 45 MPH Strong Wind Blowing Snow
+4 (After)	0:57 to 1:56	Blank Sign	Slick Road Strong Wind Blowing Snow Reduced Visibility Advise 45 MPH	Slick Road Advise 45 MPH Strong Wind Blowing Snow	Slick Road Advise 45 MPH Strong Wind Blowing Snow

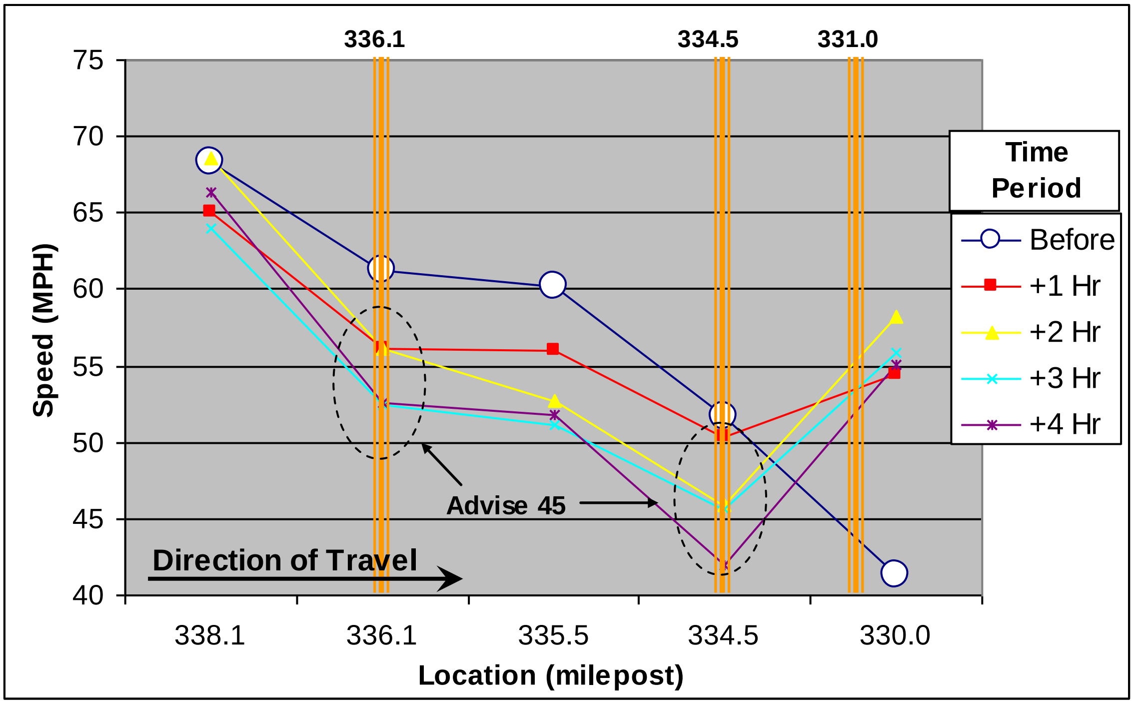


Figure A6. Average Vehicle Speeds by Hour and Location

Dec. 1, 2009 Westbound I-80

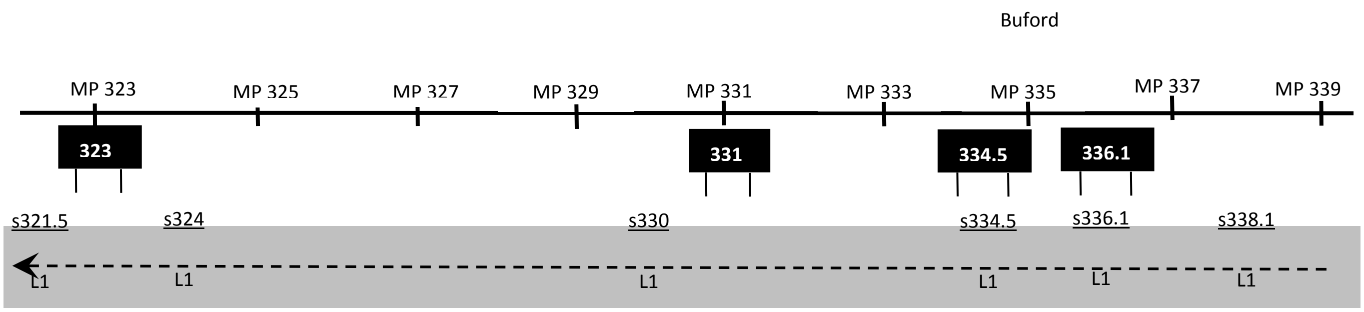


Figure A7. Speed Sensors and DMS for Westbound I-80 between MP 330 and 338

Table A5. Westbound I-80 DMS Messages by Time and Location for Dec. 1, 2009

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
-1 (Before)	17:31 to 18:30	Blank Sign	Blank Sign	Blank Sign	Blank Sign
+1 (After)	18:31 to 19:30	18:31-Dense Fog Reduced Visibility Reduce Speed 19:00-Dense Fog Reduced Visibility Snow Reduce Speed	18:30-Dense Fog Reduce Speed Reduced Visibility	18:30-Dense Fog Reduce Speed Reduced Visibility	18:30-Dense Fog Reduce Speed Reduced Visibility
+2 (After)	19:31 to 20:30	Dense Fog Reduced Visibility Snow Reduce Speed 19:35-Slick Road Snow Blowing Snow Reduce Speed	Dense Fog Reduce Speed Reduced Visibility	Dense Fog Reduce Speed Reduced Visibility 19:39-Slick Road Snow Blowing Snow	Dense Fog Reduce Speed Reduced Visibility 19:39-Slick Road Snow Blowing Snow
+3 (After)	20:31 to 21:30	Slick Road Snow Blowing Snow Reduce Speed	Dense Fog Reduce Speed Reduced Visibility	Slick Road Snow Blowing Snow	Slick Road Snow Blowing Snow 20:01-Slick Road Blowing Snow Reduced Visibility
+4 (After)	21:31 to 22:30	Slick Road Snow Blowing Snow Reduce Speed	Dense Fog Reduce Speed Reduced Visibility	Slick Road Snow Blowing Snow	Slick Road Blowing Snow Reduced Visibility

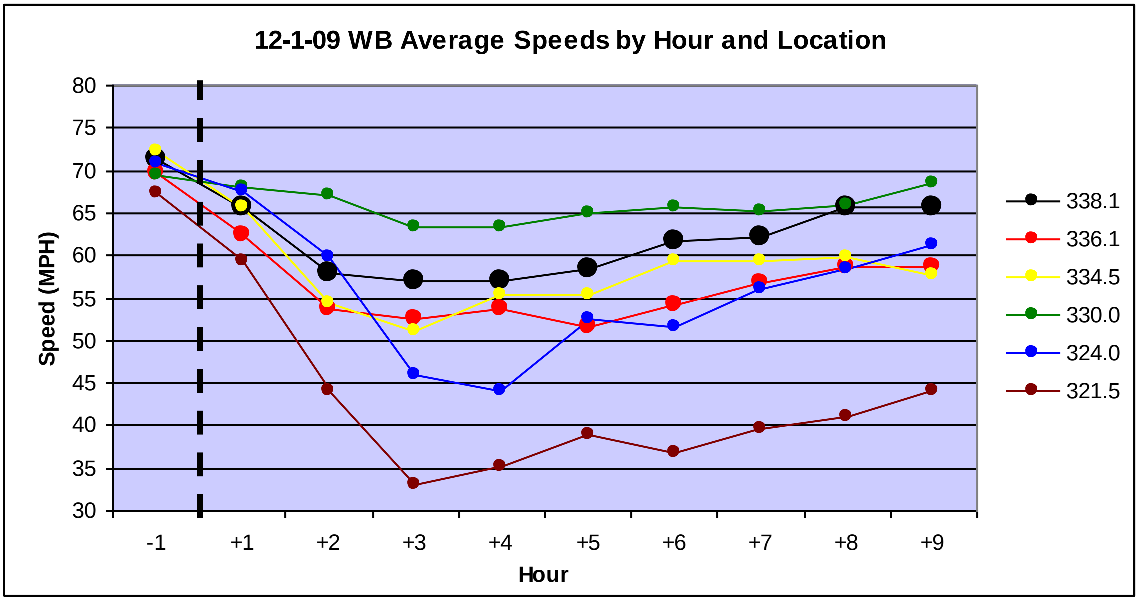


Figure A8. Average Vehicle Speeds for Westbound I-80 on Dec. 1-2, 2009

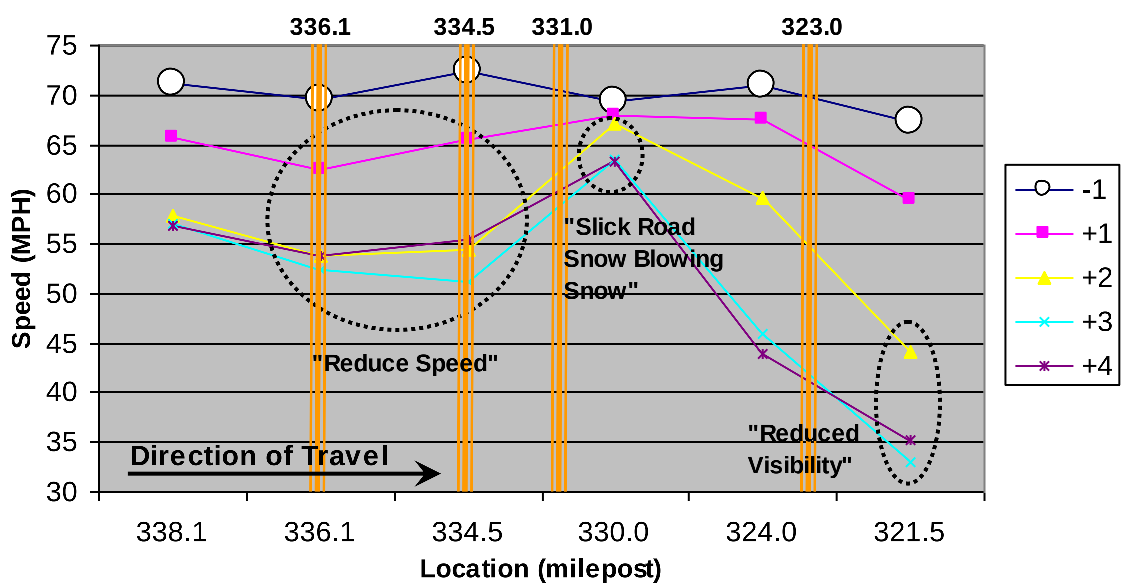


Figure A9. Average Vehicle Speeds by Hour and Location

March 23, 2010 Westbound I-80

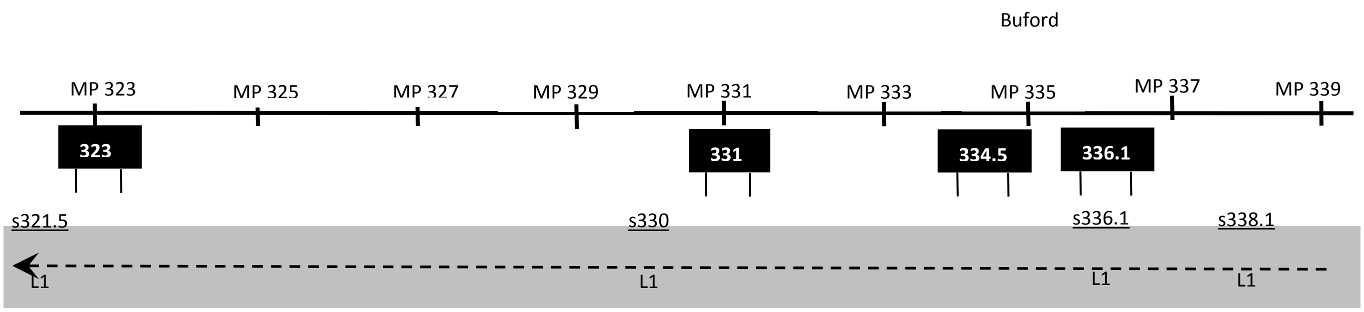


Figure A10. Speed Sensors and DMS for Westbound I-80 between MP 330 and 338

Table A6. Westbound I-80 DMS Messages by Time and Location for March 23, 2010

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
-1 (Before)	8:10 to 9:09	8:10 – Slick Road Snow I-80 Closed	8:10 – Slick Road Snow I-80 Closed 9:08 – Slick Road Snow	8:10 – Slick Road Snow I-80 Closed 9:08 – Blank Sign	8:10 – I-80 Closed 9:08 – Blank Sign
+1 (After)	9:10 to 10:42	9:10 – Slick Road Snow Advise 45 MPH 9:36 – Slick Road Advise 45 MPH	9:10 – Slick Road Snow Advise 45 MPH 9:36 – Slick Road Advise 45 MPH	9:11 – Advise 45 MPH	Blank Sign
+2 (After)	10:43 to 11:56	10:43 – Slick Road Advise 55 MPH 10:44 – Slick Road Advise 60 MPH	10:43 – Slick Road Advise 55 MPH 10:46 – Slick Road Advise 60 MPH	10:44 - Advise 55 MPH 10:46 - Advise 60 MPH	Blank Sign 11:23 – Wet Road Slick Spots Turn off Cruise Control
+3 (After)	11:57 to 12:58	11:57 – Slick Spots Advise 65 MPH 12:06 – Slick Spots Turn Off Cruise Control	11:57 – Slick Spots Advise 65 MPH 12:06 – Slick Spots Turn Off Cruise Control	11:58 – Slick Spots Advise 65 MPH 12:07 – Slick Spots Turn Off Cruise Control	Wet Road Slick Spots Turn off Cruise Control 12:46 – Blank Sign
+4 (After)	12:59 to 13:58	12:59 – Blank Sign	12:59 – Blank Sign	12:59 – Blank Sign	12:46 – Blank Sign

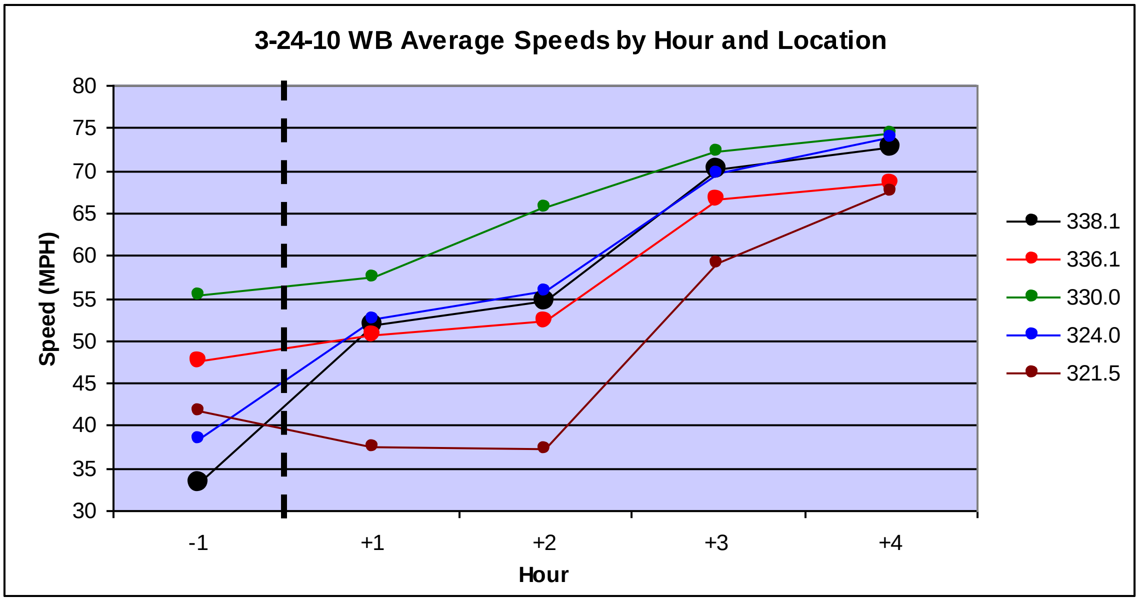


Figure A11. Average Vehicle Speeds for Westbound I-80 on March 23, 2010

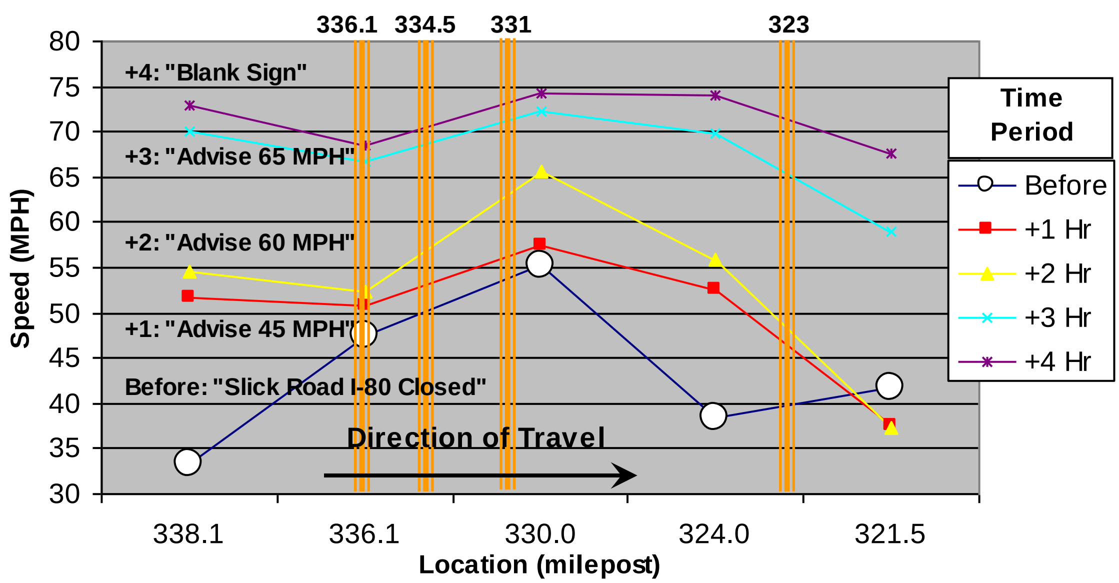


Figure A12. Average Vehicle Speeds by Hour and Location

April 2, 2010 Westbound I-80

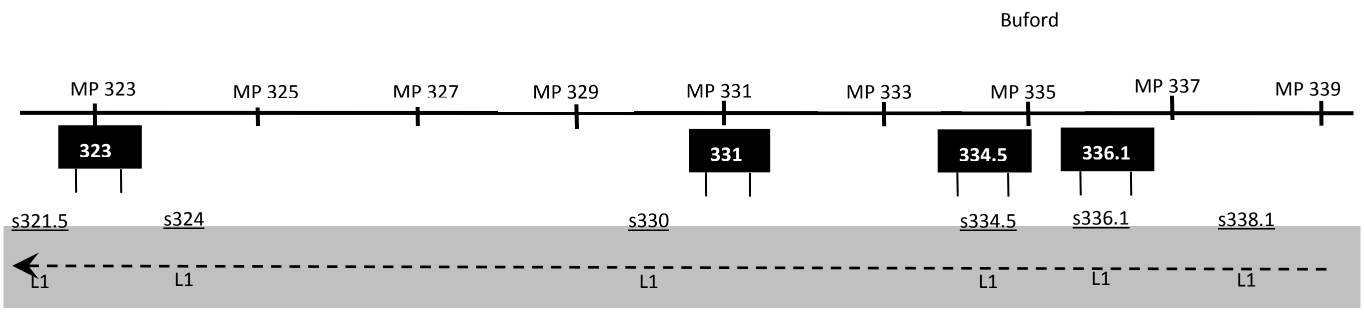


Figure A13. Speed Sensors and DMS for Westbound I-80 between MP 323 and 339

Table A7. Westbound I-80 DMS Messages by Time and Location for April 2, 2010

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
-1 (Before)	9:45 to 10:44	9:45 – Slick Road Advise 50 MPH Blowing Snow Reduced Visibility 9:49 – No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH 10:28 – No Unnecessary Travel Slick Road Wreck Ahead Use Left Lane Reduce Speed	9:45 – Slick Road Advise 45 MPH Blowing Snow Poor Visibility 9:51 – No Unnecessary Travel Slick Road Poor Visibility 10:42 – Advise 50 MPH Slick Road Poor Visibility	9:45 – Slick Road Advise 50 MPH Blowing Snow Poor Visibility 9:53 – No Unnecessary Travel Slick Road Poor Visibility 10:44 – Advise 50 MPH Slick Road Poor Visibility	9:45 – Slick Road Advise 45 MPH Strong Wind Blowing Snow 9:55 – No Unnecessary Travel Slick Road Blowing Snow
+1 (After)	10:45 to 11:44	No Unnecessary Travel Slick Road Wreck Ahead Use Left Lane Reduce Speed	10:45 – Advise 40 MPH Slick Road Poor Visibility	10:45 – Advise 40 MPH Slick Road Poor Visibility	No Unnecessary Travel Slick Road Blowing Snow 11:09 – No Unnecessary Travel Advise No Light Trailers
+2 (After)	11:45 to 12:44	No Unnecessary Travel Slick Road Wreck Ahead Use Left Lane Reduce Speed	Advise 40 MPH Slick Road Poor Visibility	Advise 40 MPH Slick Road Poor Visibility	No Unnecessary Travel Advise No Light Trailers
+3 (After)	12:45 to 13:44	12:45 – Slick Spots Strong Wind Blowing Snow Turn Off Cruise Control	Advise 40 MPH Slick Road Poor Visibility 12:47 – Slick Spots Blowing Snow Turn Off	Advise 40 MPH Slick Road Poor Visibility 12:49 – Slick Spots Blowing Snow Turn Off	No Unnecessary Travel Advise No Light Trailers 12:50 – Slick Spots Blowing Snow Turn Off

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
			Cruise Control	Cruise Control	Cruise Control
+4 (After)	13:45 to 14:44	Slick Spots Strong Wind Blowing Snow Turn Off Cruise Control	Slick Spots Blowing Snow Turn Off Cruise Control	Slick Spots Blowing Snow Turn Off Cruise Control	Slick Spots Blowing Snow Turn Off Cruise Control

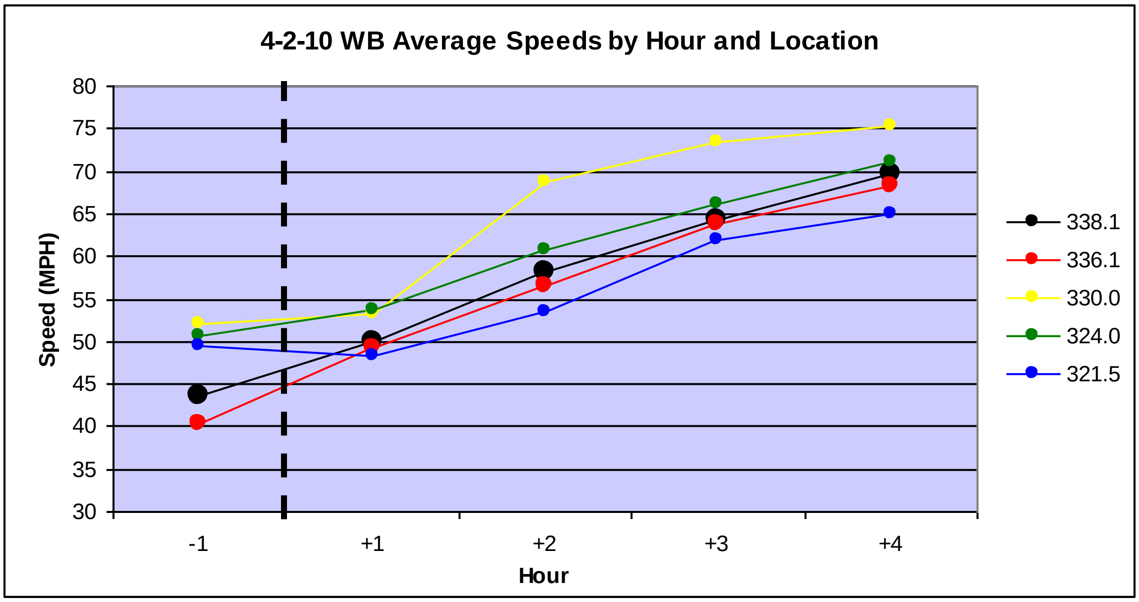


Figure A14. Average Vehicle Speeds for Westbound I-80 on April 2, 2010

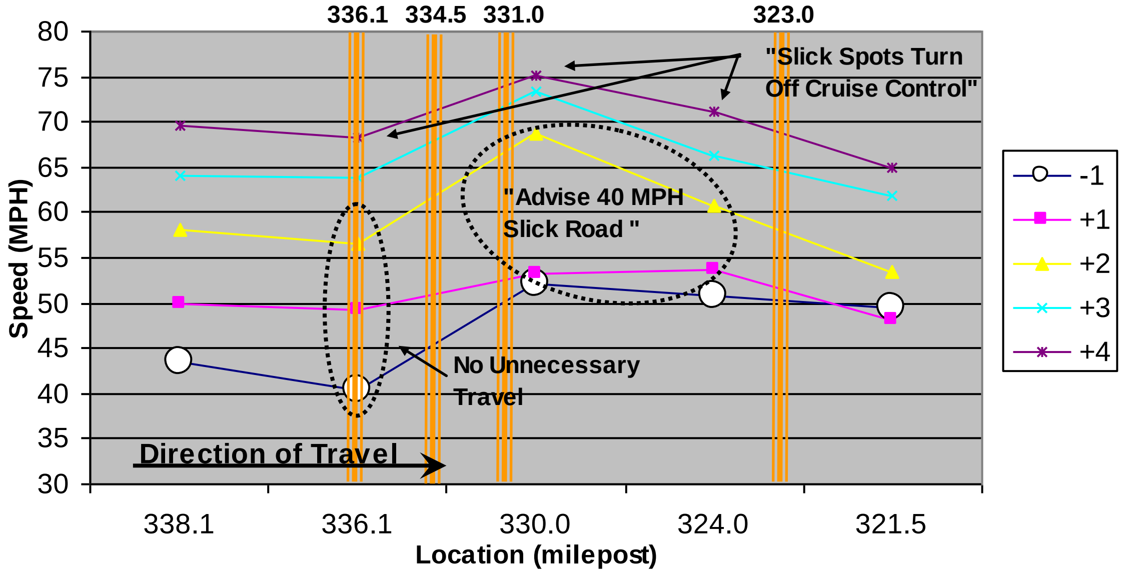


Figure A15. Average Vehicle Speeds by Hour and Location

April 7, 2010 Westbound I-80

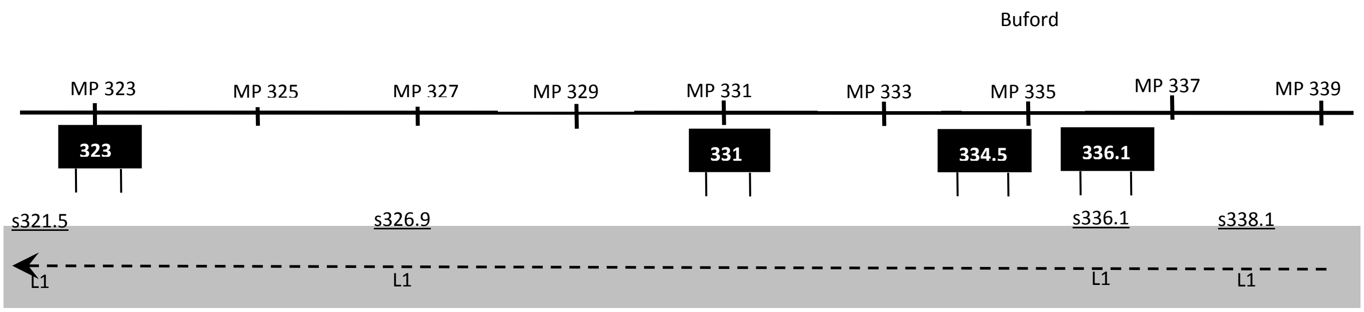


Figure A16. Speed Sensor and DMS Locations for WB I-80 between MP 339 and 321

Table A8. Westbound I-80 DMS Messages by Time and Location for April 7, 2010

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
-1 (Before)	15:44 to 16:43	15:44 – Blank Sign	15:44 – Blank Sign	15:44 – Blank Sign	15:44 – Blank Sign
+1 (After)	16:44 to 18:01	16:44 – Wet Road Snow Reduce Speed	16:45 – Wet Road Snow Reduce Speed	16:45 – Wet Road Snow Reduce Speed	16:45 – Wet Road Snow Reduce Speed 17:36 – Blank Sign
+2 (After)	18:02 to 18:43	18:02 – Blank Sign	18:02 – Blank Sign	18:02 – Blank Sign	Blank Sign
+3 (After)	18:44 to 20:11	18:44 – Slick Spots Blowing Snow Reduce Speed	Blank Sign	Blank Sign	Blank Sign
+4 (After)	20:12 to 21:11	20:12 – Slick Spots Blowing Snow Reduced Visibility Reduce Speed	20:12 – Slick Spots Blowing Snow Poor Visibility Reduce Speed	20:13 - Slick Spots Blowing Snow Poor Visibility Reduce Speed	Blank Sign

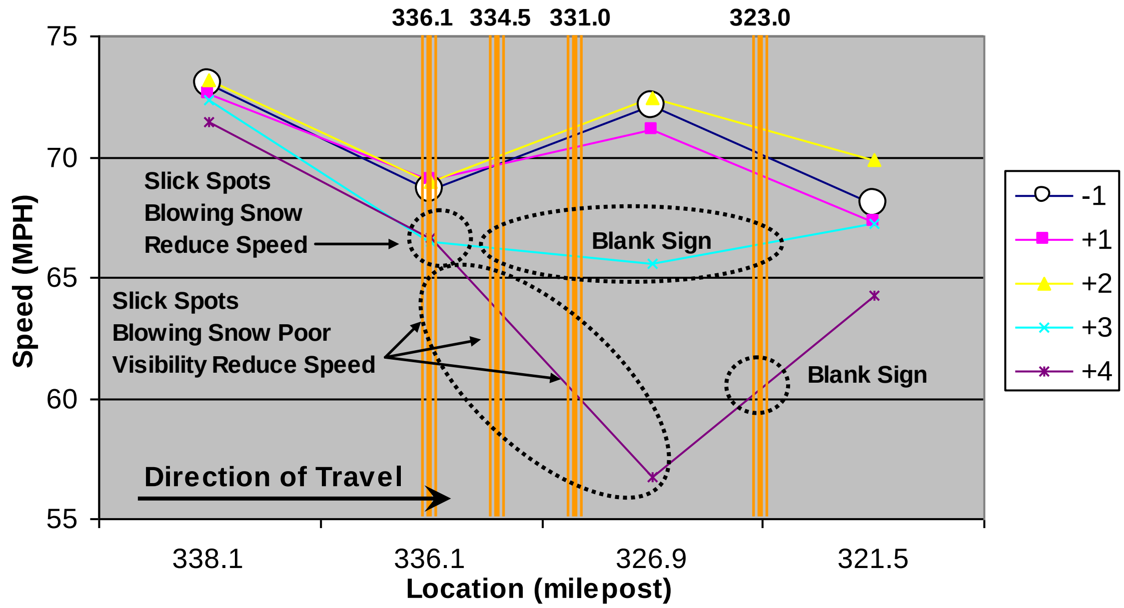


Figure A17. Average Speeds by Hour and Location for Westbound I-80 on April 7, 2010

April 17, 2010 Westbound I-80

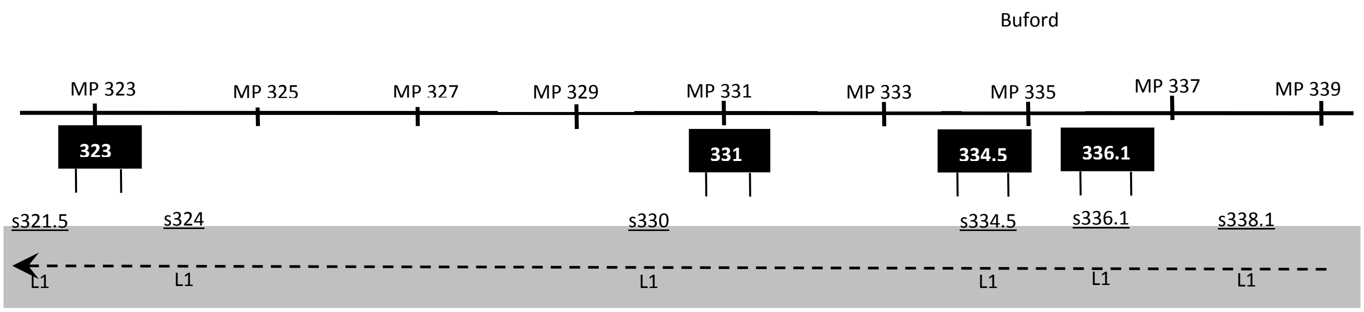


Figure A18. Speed Sensors and DMS for Westbound I-80 between MP 323 and 339

Table A9. Westbound I-80 DMS Messages by Time and Location for April 17, 2010

Period	Time	Sign @ MP 336.1	Sign @ MP 334.5	Sign @ MP331	Sign @ MP 323
-1 (Before)	1:22to 2:21	1:22 – Blank Sign	1:22 – Blank Sign	1:22 – Blank Sign	1:22 – Blank Sign
+1 (After)	2:22 to 3:21	2:22 – Dense Fog Reduced Visibility Reduce Speed	2:22 – Dense Fog Reduced Poor Reduced Speed 2:55 - Dense Fog Poor Visibility Reduce Speed	2:23 – Dense Fog Poor Visibility Reduced Speed 2:55 - Dense Fog Poor Visibility Reduce Speed	2:23 – Dense Fog Poor Visibility Reduced Speed 2:55 - Dense Fog Poor Visibility Reduce Speed
+2 (After)	3:22 to 4:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed
+3 (After)	4:22 to 5:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed
+4 (After)	5:22 to 6:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed

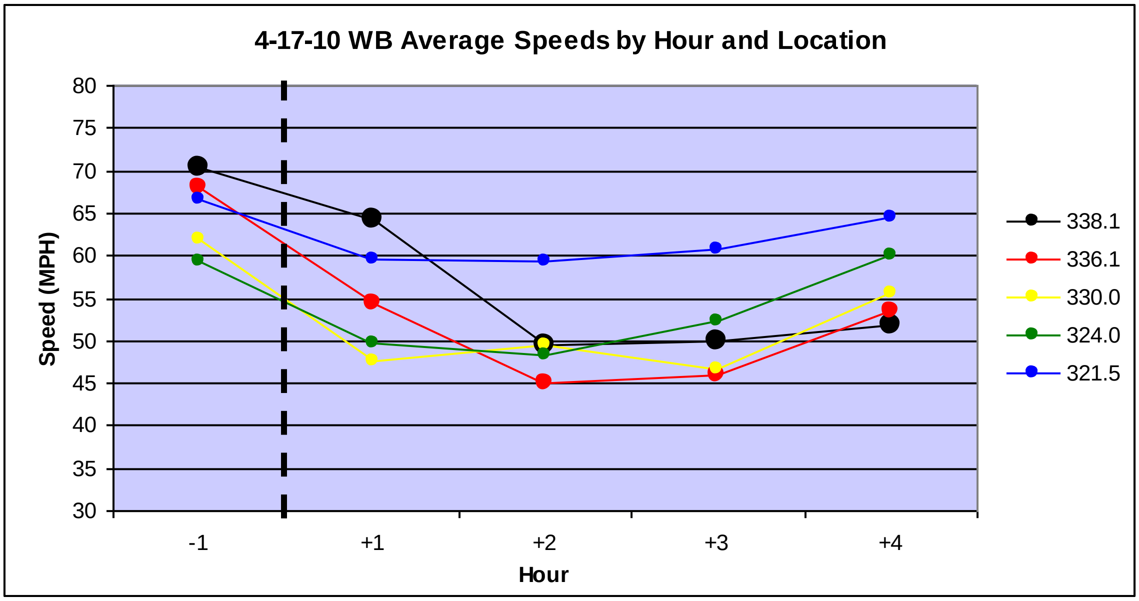


Figure A19. Average Vehicle Speeds for Westbound I-80 on April 17, 2010

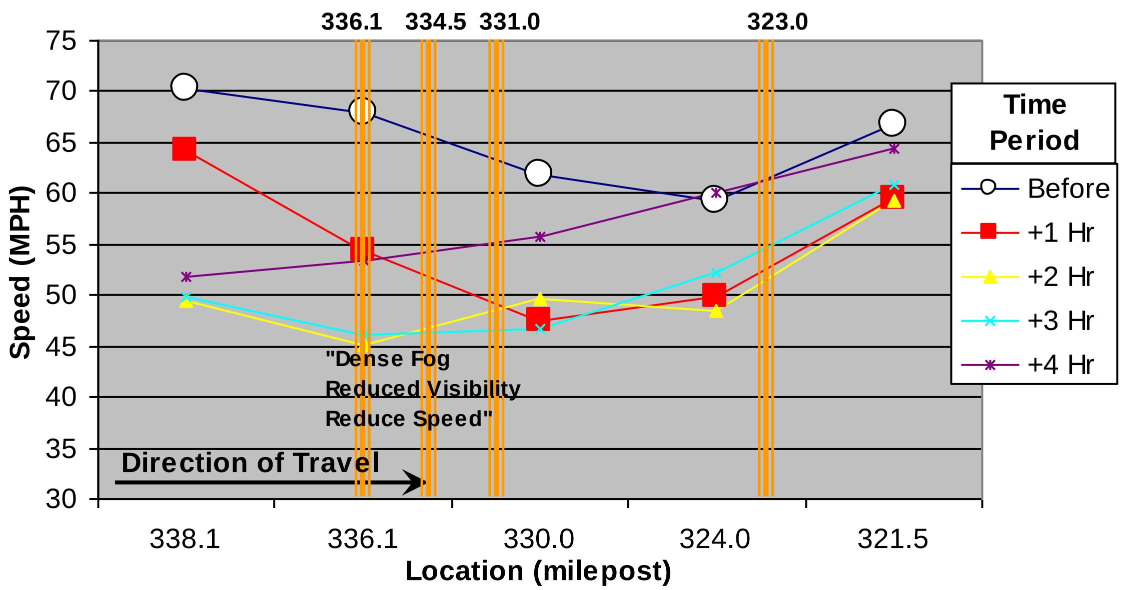


Figure A20. Average Vehicle Speeds by Hour and Location

Eastbound I-80

May 27, 2008 Eastbound I-80

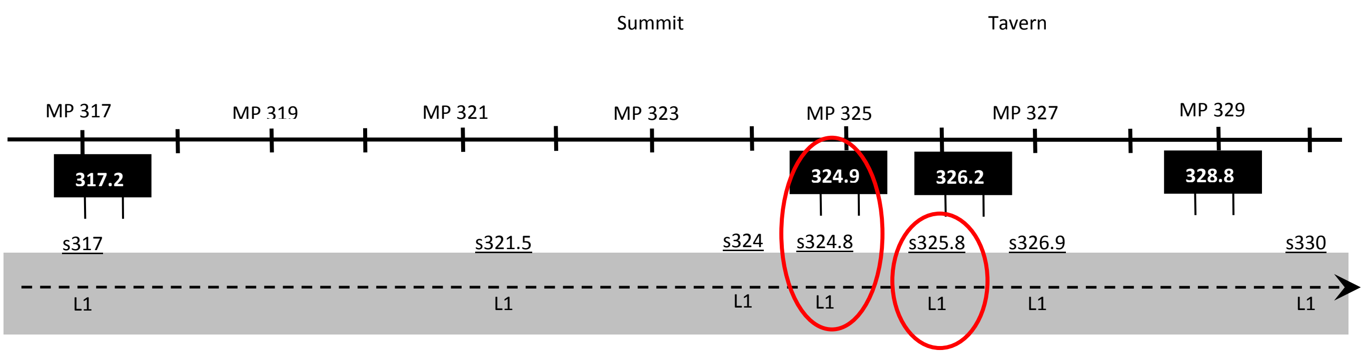


Figure A21. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A10. Eastbound I-80 DMS Messages by Time and Location for May 27, 2008

Period	Time	Sign @ MP 324.9
-1 (Before)	21:25 to 22:20	16:45-Click-it Don't Risk It Please Buckle Up 22:23-Heavy Fog Limited Visibility Advise Max Safe Speed 35 MPH
+1 (After)	22:25 to 23:20	22:27-Heavy Fog Limited Visibility Speed Limit 45 MPH
+2 (After)	23:25 to 0:20	Heavy Fog Limited Visibility Speed Limit 45 MPH

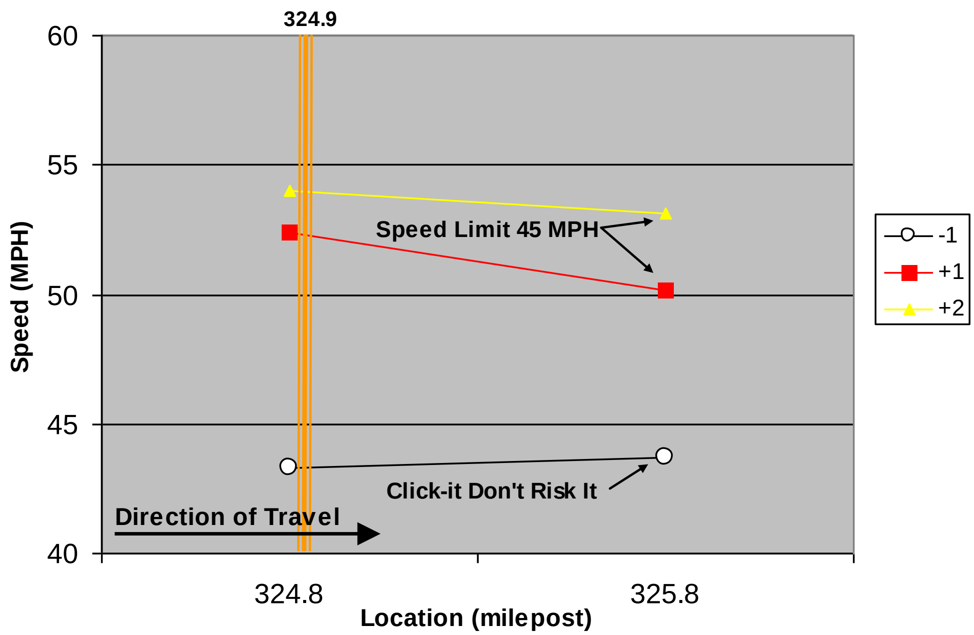


Figure A22. Average Vehicle Speeds by Location and Hour

Oct. 12, 2008 Eastbound I-80

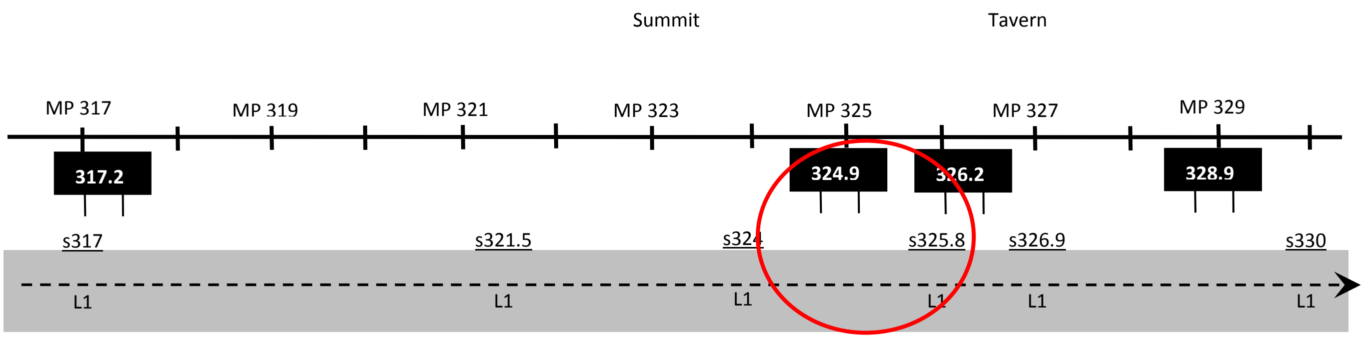


Figure A23. Speed Sensors and DMS for Eastbound I-80 between MP 334 and 344

Table A11. Eastbound I-80 DMS Messages by Time and Location for Oct. 12, 2008

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9
-1 (Before)	18:15 to 19:10	18:15-Blank Sign 18:56-Icy Spots Snowfall Slow Down	18:15- Blank Sign 19:07-Icy in Spots Snowfall Slow Down
+1 (After)	19:15 to 20:10	19:15-Icy Road Snowfall Advise 45 MPH 19:55-Road Closed Ahead 19:56-Road Closed Ahead Return to Laramie	19:15-Icy Road Snowfall Advise 45 MPH
+2 (After)	20:15 to 21:10	Road Closed Ahead Return to Laramie	Icy Road Snowfall Advise 45 MPH
+3 (After)	21:15 to 22:10	Road Closed Ahead Return to Laramie	Icy Road Snowfall Advise 45 MPH
+4 (After)	22:15 to 23:10	Road Closed Ahead Return to Laramie / 22:53-Icy Roads Advise 45 MPH Max	Icy Road Snowfall Advise 45 MPH

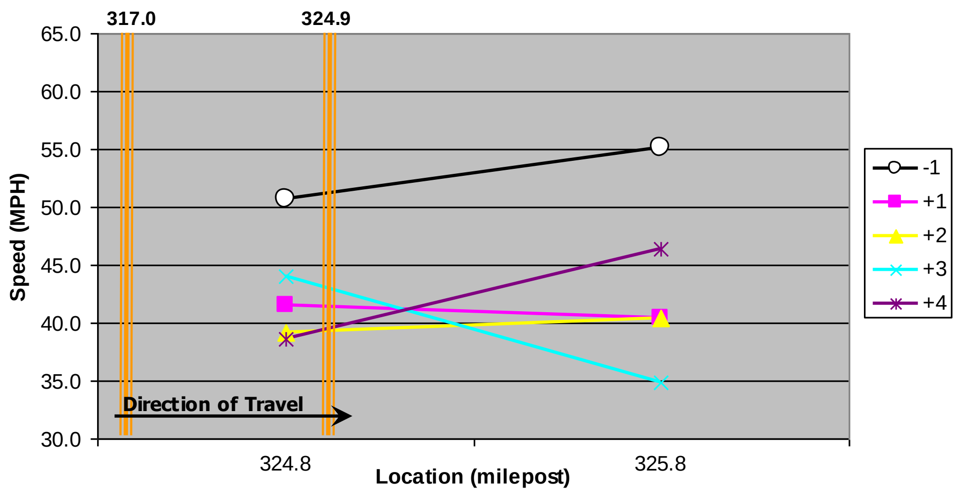


Figure A24. Average Vehicle Speeds by Location and Hour

Nov. 23-24, 2009 Eastbound I-80

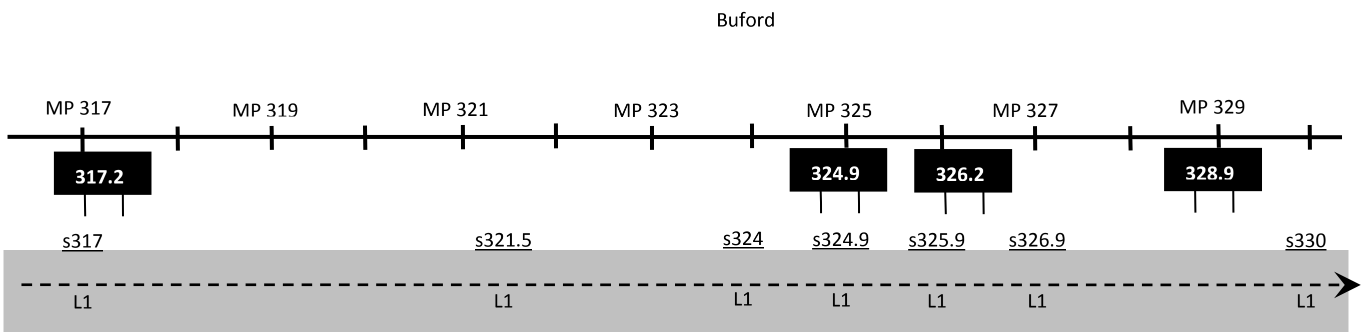


Figure A25. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A12. Eastbound I-80 DMS Messages by Time and Location for Nov. 23-24, 2009

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8	Sign @ MP341.6
-1 (Before)	21:27 to 22:26	20:32-I-80 Closed Temporarily Due to Wreck Return to Laramie	20:15-Wreck Ahead Reduce Speed Expect Delays	20:13-Wreck Ahead Reduce Speed Expect Delays	20:13-Wreck Ahead Reduce Speed Expect Delays	Blank Sign
+1 (After)	22:27 to 23:26	22:27-Slick Spots Advise 45 MPH 22:40-Slick Spots 22:54-Slick Spots Turn off Cruise Control	22:27-Slick Road Blowing Snow Advise 45 MPH 22:31-Slick Road Blowing Snow Advise 45 MPH	22:27-Slick Road Blowing Snow Advise 45 MPH	22:26- Slick Road Blowing Snow Advise 45 MPH	Blank Sign
+2 (After)	23:27 to 00:26	Slick Spots Turn off Cruise Control	Slick Road Blowing Snow Advise 45 MPH 23:52-Slick Road Blowing Snow Reduced Visibility Advise 45 MPH	Slick Road Blowing Snow Advise 45 MPH 23:54-Reduced Visibility Advise 45 MPH	Slick Road Blowing Snow Advise 45 MPH	Blank Sign
+3 (After)	00:27 to 01:26	Slick Spots Turn off Cruise Control	Slick Road Blowing Snow Reduced Visibility Advise 45 MPH	Reduced Visibility Advise 45 MPH	Slick Road Blowing Snow Advise 45 MPH	Blank Sign
+4 (After)	01:27 to 02:26	Slick Spots Turn off Cruise Control	Slick Road Blowing Snow Reduced Visibility Advise 45 MPH	Reduced Visibility Advise 45 MPH	Slick Road Blowing Snow Advise 45 MPH	Blank Sign

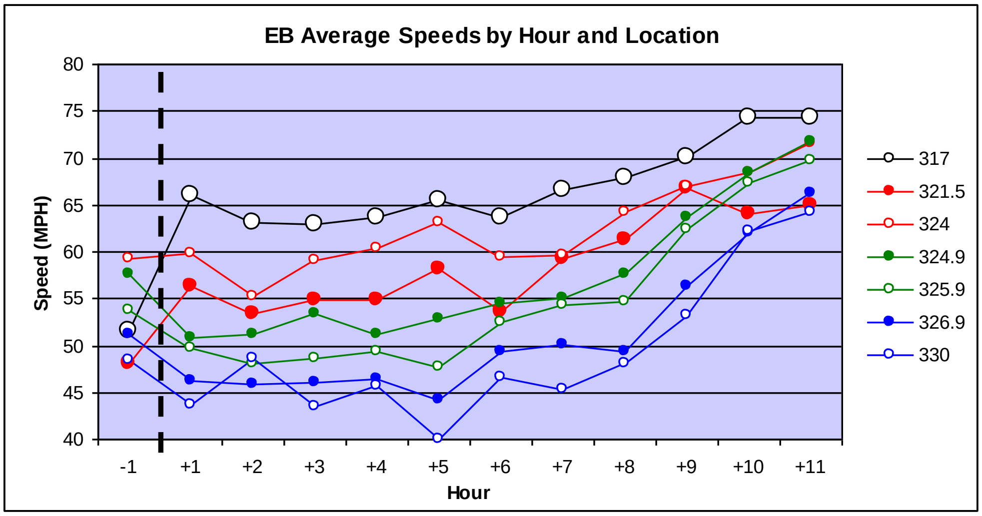


Figure A26. Average Vehicle Speeds by Hour and Location

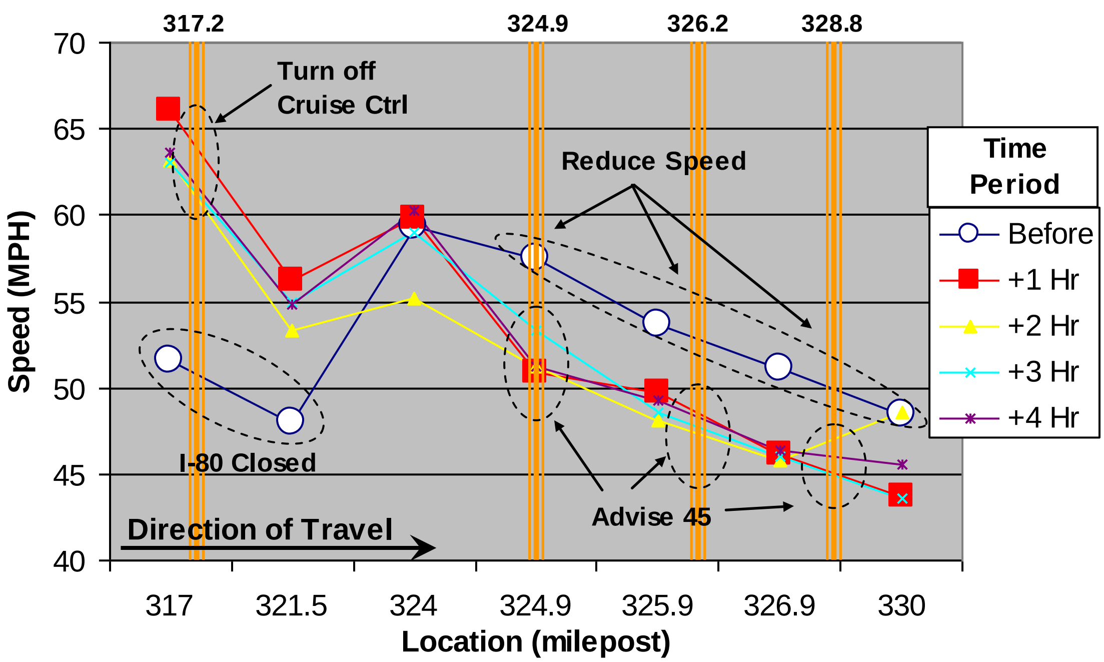


Figure A27. Average Vehicle Speeds by Location and Hour

Dec. 1-2, 2009 Eastbound I-80

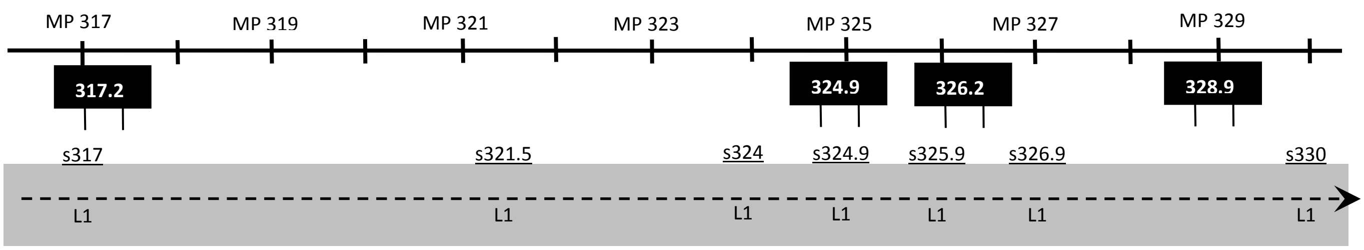


Figure A28. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A13. Eastbound I-80 DMS Messages by Time and Location for Dec. 1, 2009

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8
-1 (Before)	18:02 to 19:01	18:28-Blank Sign 18:29-Dense Fog Reduced Visibility	Blank Sign 18:30-Dense Fog Reduced Visibility Reduce Speed	Blank Sign 18:36-Dense Fog Reduce Speed Reduced Visibility	Blank Sign 18:35-Dense Fog Reduce Speed Reduced Visibility
+1 (After)	19:02 to 20:01	19:02-Dense Fog Reduced Visibility Snow Reduce Speed 19:36 Slick Road Snow Blowing Snow Reduce Speed 20:01-Slick Road Snow Blowing Snow Reduced Visibility Reduce Speed	19:02-Dense Fog Reduced Visibility Snow Reduce Speed 19:36-Slick Road Snow Blowing Snow Reduce Speed	Dense Fog Reduce Speed Reduced Visibility 19:41-Slick Road Snow	Dense Fog Reduce Speed Reduced Visibility 19:40-Slick Road Snow
+2 (After)	20:02 to 21:01	Slick Road Snow Blowing Snow Reduced Visibility Reduce Speed	Slick Road Snow Blowing Snow Reduce Speed	Slick Road Snow	Slick Road Snow
+3 (After)	21:02 to 22:01	Slick Road Snow Blowing Snow Reduced Visibility Reduce Speed	Slick Road Snow Blowing Snow Reduce Speed	Slick Road Snow	Slick Road Snow
+4 (After)	22:02 to 23:01	Slick Road Snow Blowing Snow Reduced Visibility Reduce Speed 23:01 Slick Road Snow Blowing Snow Reduce Speed	Slick Road Snow Blowing Snow Reduce Speed	Slick Road Snow	Slick Road Snow

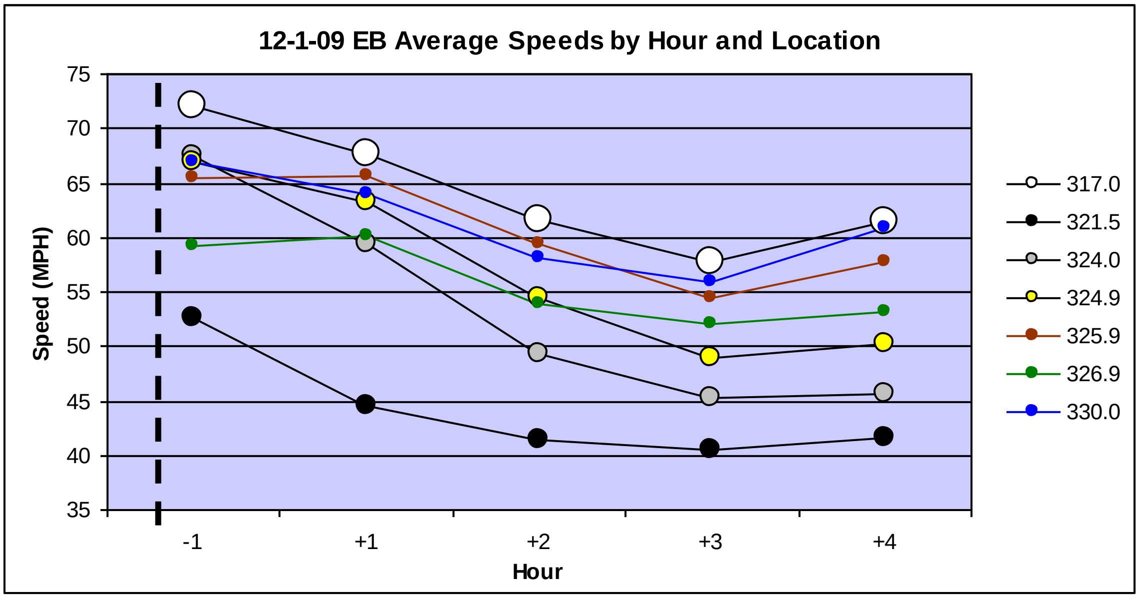


Figure A29. Average Vehicle Speeds by Hour and Location

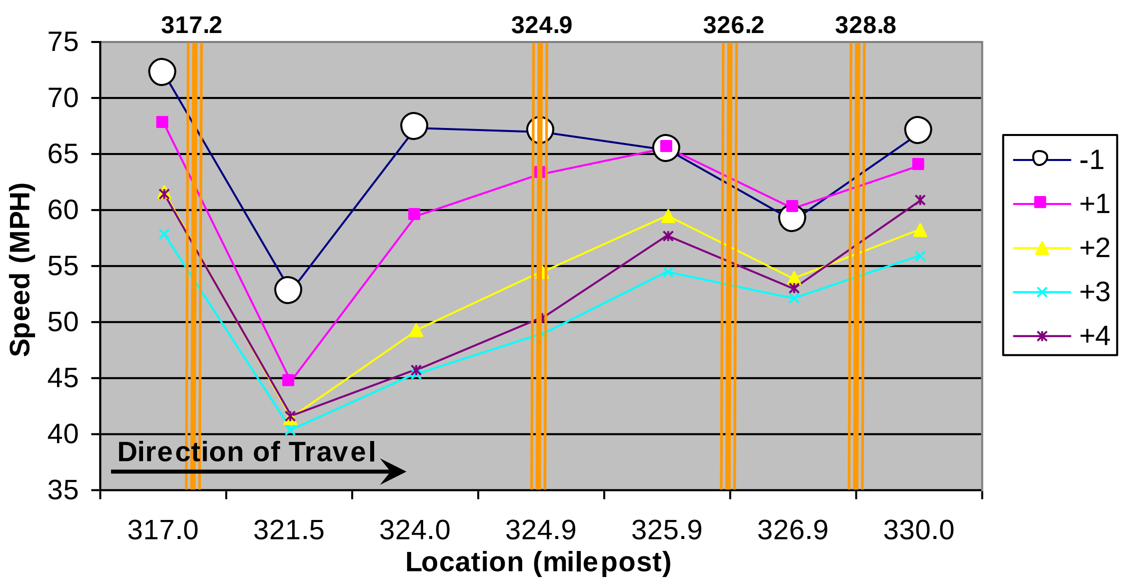


Figure A30. Average Vehicle Speeds by Location and Hour

March 23, 2010 Eastbound I-80

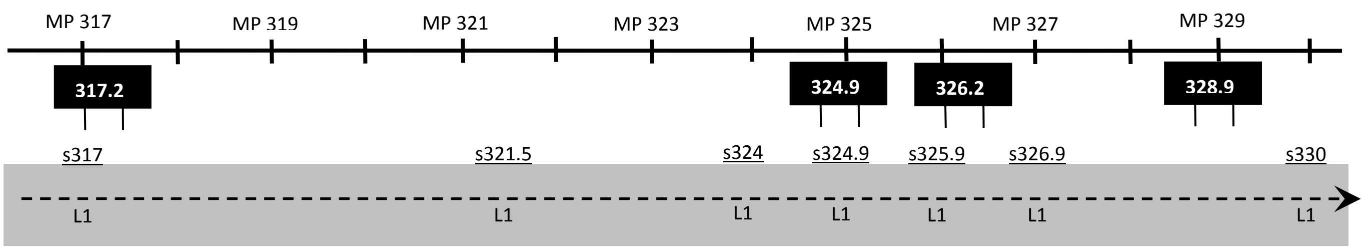


Figure A31. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A14. Eastbound I-80 DMS Messages by Time and Location for March 23, 2010

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8
-1 (Before)	13:35 to 14:34	13:35- Slick Road Snow Reduce Speed 14:06- Slick Road Snow Reduced Visibility Reduce Speed	13:35- Slick Spots Turn Off Cruise Control 14:13- Slick Road Snow Reduced Visibility Reduce Speed	13:35- Blank Sign 14:14- Slick Road Blowing Snow Reduce Speed	13:35- Blank Sign 14:14- Slick Road Blowing Snow Reduce Speed
+1 (After)	14:35 to 15:34	Slick Road Snow Reduced Visibility Reduce Speed	14:35- Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH	14:35- Slick Road Blowing Snow Advise Max Speed 55 MPH	14:37- Slick Road Blowing Snow Advise Max Speed 55 MPH
+2 (After)	15:35 to 16:34	Slick Road Snow Reduced Visibility Reduce Speed	Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH
+3 (After)	16:35 to 17:34	Slick Road Snow Reduced Visibility Reduce Speed	Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH
+4 (After)	17:35 to 18:34	Slick Road Snow Reduced Visibility Reduce Speed	Slick Road Blowing Snow Reduced Visibility Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH	Slick Road Blowing Snow Advise Max Speed 55 MPH

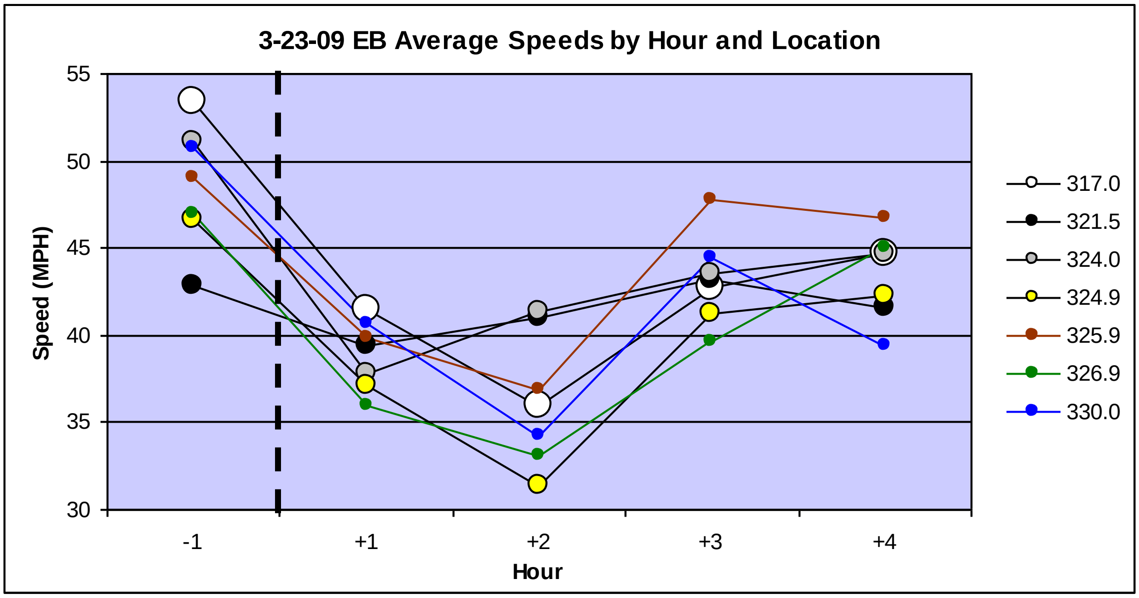


Figure A32. Average Vehicle Speeds by Hour and Location

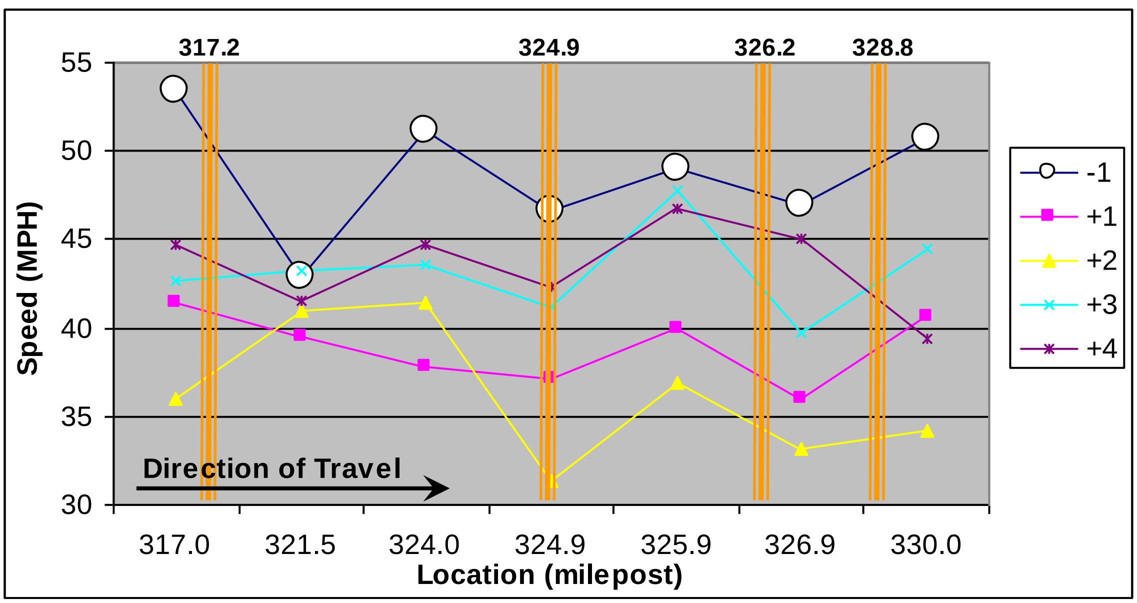


Figure A33. Average Vehicle Speeds by Location and Hour

April 2, 2010 Eastbound I-80

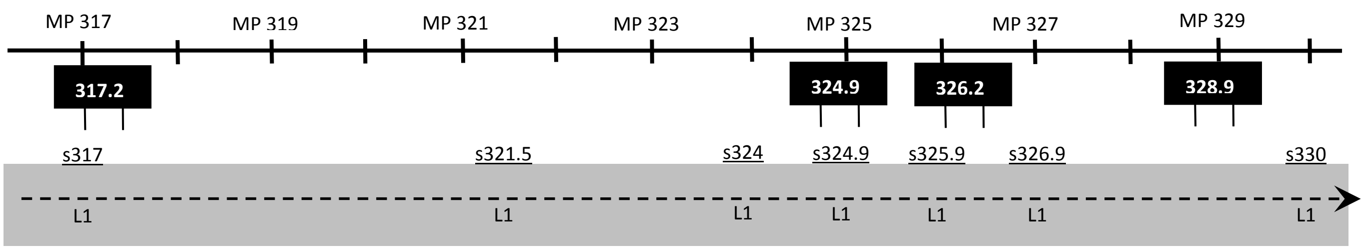


Figure A34. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A15. Eastbound I-80 DMS Messages by Time and Location for April 2, 2010

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8
-1 (Before)	9:45 to 10:44	9:45 – Advise No Light Trailers Slick Road WYO 210 Closed Between Laramie and Curt Gowdy 9:54 - No Light Trailers No Unnecessary Travel WYO 210 Closed Between Laramie and Curt Gowdy	9:45 – Slick Road Advise 50 MPH Blowing Snow Reduced Visibility 9:49 – No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH	9:45 – Slick Road Advise 50 MPH Blowing Snow Poor Visibility 9:52 – No Unnecessary Travel Slick Road Poor Visibility 10:44 – Advise 50 MPH Slick Road Poor Visibility	9:45 – Slick Road Advise 50 MPH Blowing Snow Poor Visibility 9:52 – No Unnecessary Travel Slick Road Poor Visibility 10:44 – Advise 50 MPH Slick Road Poor Visibility
+1 (After)	10:45 to 11:44	No Light Trailers No Unnecessary Travel WYO 210 Closed Between Laramie and Curt Gowdy	No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH	10:45 – Advise 40 MPH Slick Road Poor Visibility	10:45 – Advise 40 MPH Slick Road Poor Visibility
+2 (After)	11:45 to 12:44	No Light Trailers No Unnecessary Travel WYO 210 Closed Between Laramie and Curt Gowdy	No Unnecessary Travel Slick Road Blowing Snow Reduced Visibility Advise 50 MPH	Advise 40 MPH Slick Road Poor Visibility	Advise 40 MPH Slick Road Poor Visibility

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8
+3 (After)	12:45 to 13:44	12:50 – Slick Spots Blowing Snow Reduce Speed WYO 210 Closed Between Laramie and Curt Gowdy 13:38 – Slick Spots Blowing Snow Turn Off Cruise Control	12:49 – Slick Spots Blowing Snow Turn Off Cruise Control	Advise 40 MPH Slick Road Poor Visibility	Advise 40 MPH Slick Road Poor Visibility
+4 (After)	13:45 to 14:44	Slick Spots Blowing Snow Turn Off Cruise Control	Slick Spots Blowing Snow Turn Off Cruise Control 14:01 – Blank Sign	12:48 – Slick Spots Blowing Snow Turn Off Cruise Control	12:48 – Slick Spots Blowing Snow Turn Off Cruise Control

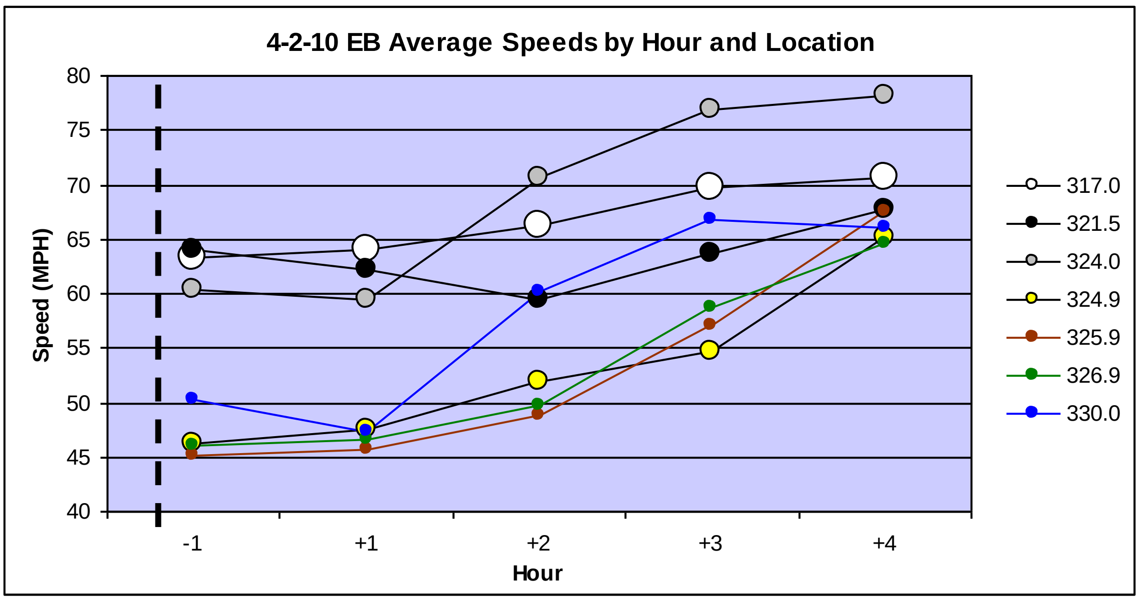


Figure A35. Average Vehicle Speeds by Hour and Location

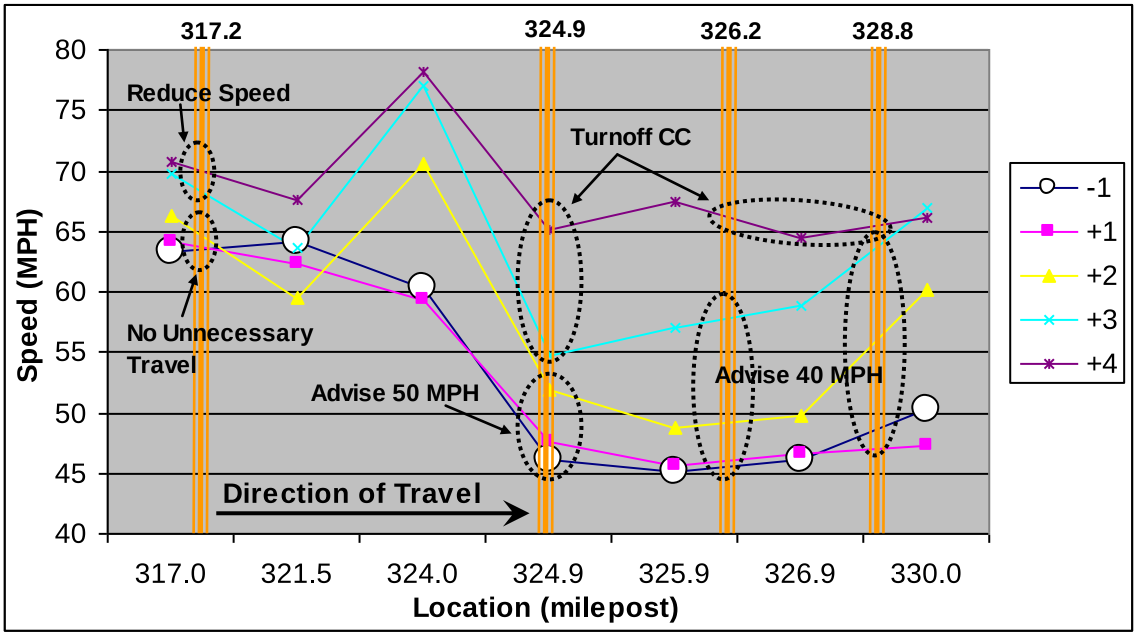


Figure A36. Average Vehicle Speeds by Location and Hour

April 7, 2010 Eastbound I-80

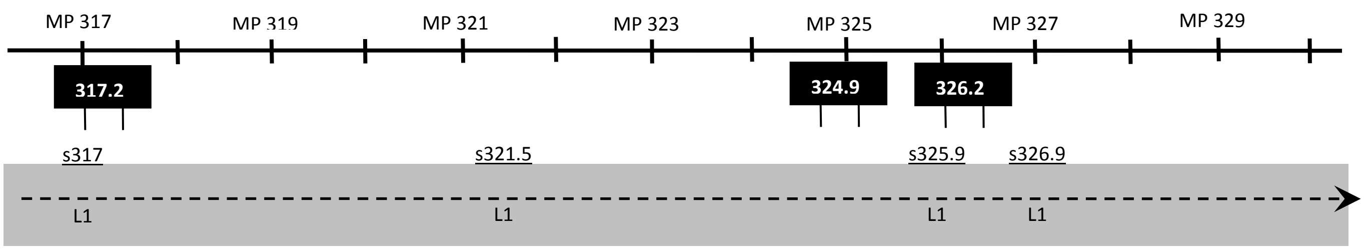


Figure A37. Speed Sensor and DMS Locations for EB I-80 between MP 317 and 329

Table A16. Eastbound I-80 DMS Messages by Time and Location for April 7, 2010

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2
-1 (Before)	17:44 to 18:43	17:44 – Blank Sign	Blank Sign	17:44 – Wet Road Snow Reduce Speed 18:02 – Blank Sign
+1 (After)	18:44 to 20:12	Blank Sign	Blank Sign	18:44 – Slick Spots Blowing Snow Reduce Speed
+2 (After)	20:13 to 21:21	20:14 – Slick Spots Blowing Snow Reduced Visibility Reduce Speed 20:20 – Reduced Visibility Blowing Snow Ahead Slick Spots Ahead Reduce Speed	Blank Sign	20:13 – Slick Spots Blowing Snow Poor Visibility Reduce Speed
+3 (After)	21:22 to 22:21	21:22 – Blank Sign 21:28 – I-80 Closed 10 Miles Ahead 21:32 - I-80 Closed 10 Miles Ahead Due To Wrecks 21:35 - I-80 Closed Due To Wrecks 21:37 - I-80 Closed Due To Multiple Wrecks	Blank Sign	Slick Spots Blowing Snow Poor Visibility Reduce Speed 21:31 – Multiple Wrecks Ahead 21:32 – Multiple Wrecks Ahead Use Caution 21:49 – Multiple Wrecks Ahead
+4 (After)	22:22 to 23:21	I-80 Closed Due To Multiple Wrecks	Blank Sign	Multiple Wrecks Ahead

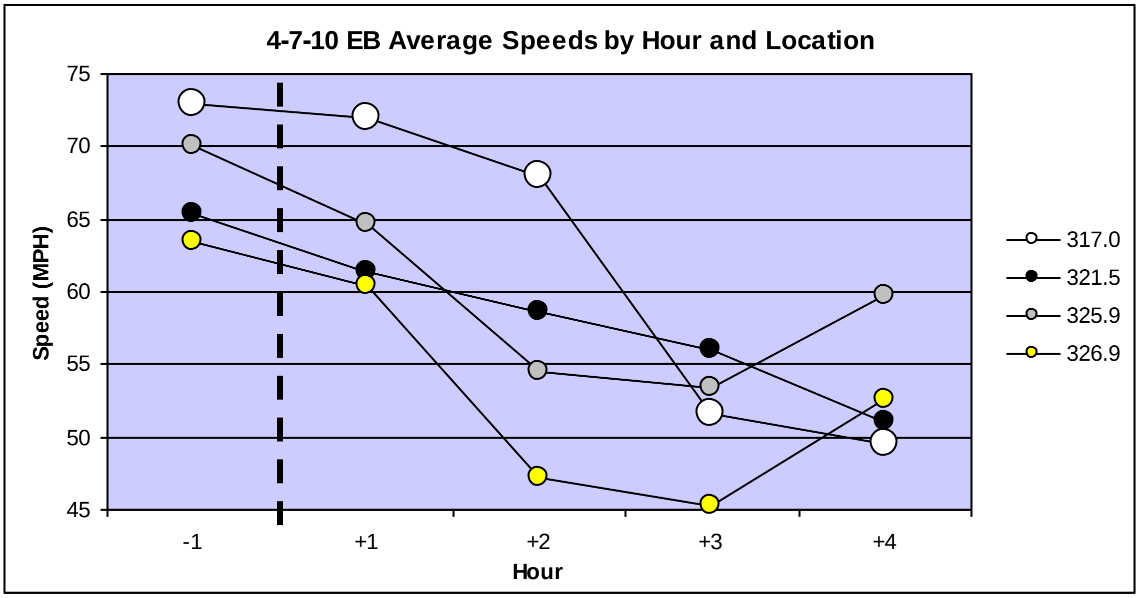


Figure A38. Average Vehicle Speeds by Hour and Location

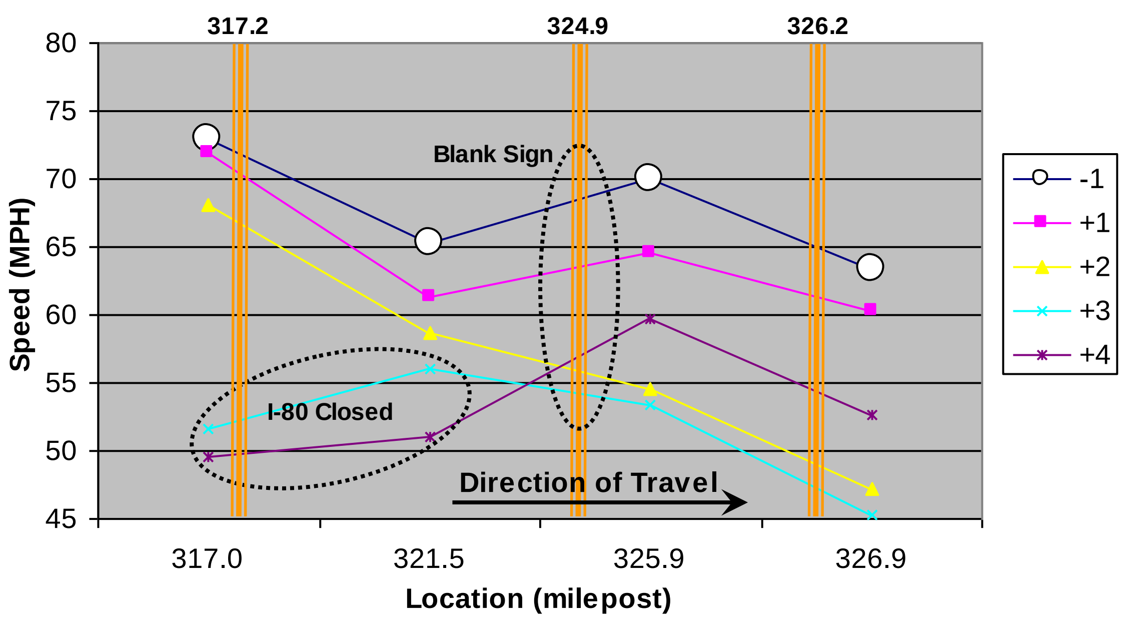


Figure A39. Average Vehicle Speeds by Location and Hour

April 17, 2010 Eastbound I-80

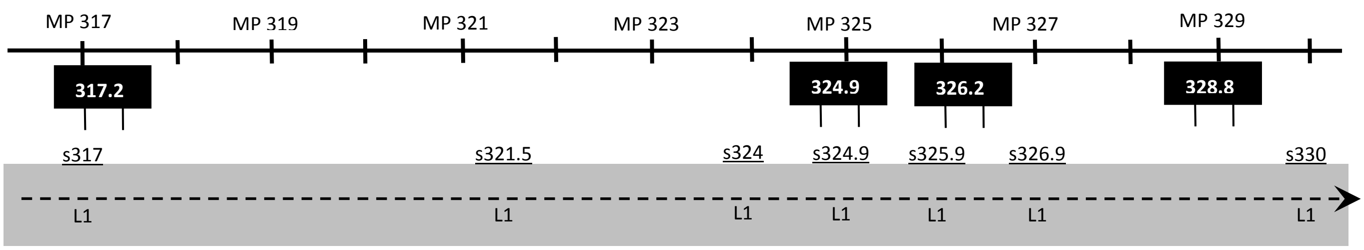


Figure A40. Speed Sensors and DMS for Eastbound I-80 between MP 317 and 330

Table A17. Eastbound I-80 DMS Messages by Time and Location for April 17, 2010

Period	Time	Sign @ MP 317.2	Sign @ MP 324.9	Sign @ MP 326.2	Sign @ MP328.8
-1 (Before)	1:22to 2:21	1:22 – Blank Sign	1:22 – Blank Sign	1:22 – Blank Sign	1:22 – Blank Sign
+1 (After)	2:22 to 3:21	2:22 – Dense Fog Reduced Visibility Reduce Speed	2:22 – Dense Fog Reduced Visibility Reduce Speed	2:23 – Dense Fog Poor Visibility Reduced Speed 2:56 - Dense Fog Poor Visibility Reduce Speed	2:22 – Dense Fog Poor Visibility Reduced Speed 2:55 - Dense Fog Poor Visibility Reduce Speed
+2 (After)	3:22 to 4:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed
+3 (After)	4:22 to 5:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed
+4 (After)	5:22 to 6:21	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Reduced Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed	Dense Fog Poor Visibility Reduce Speed

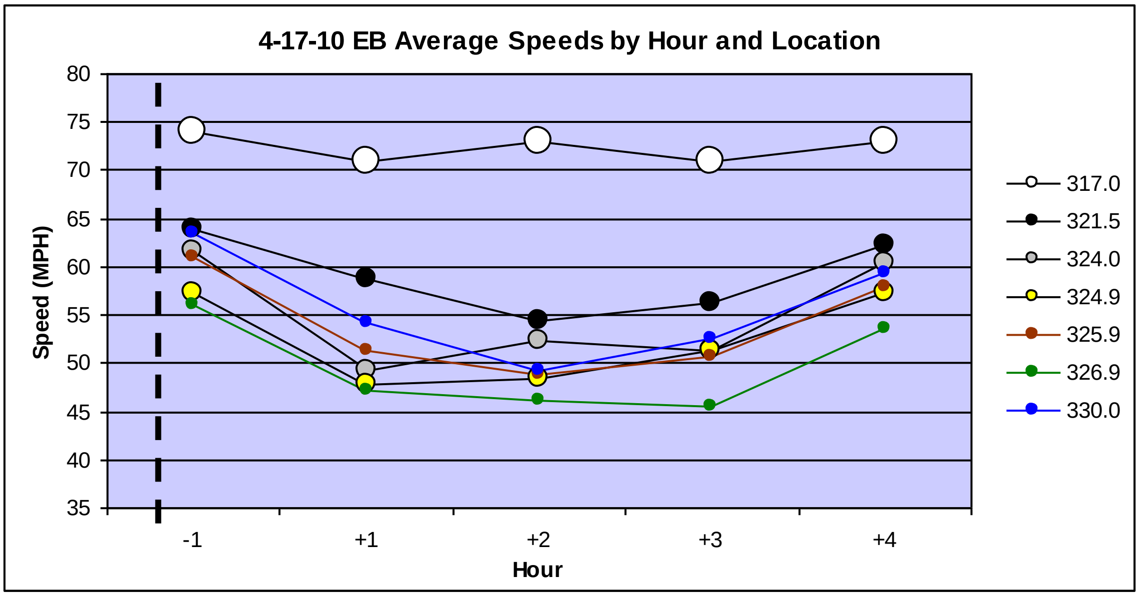


Figure A41. Average Vehicle Speeds by Hour and Location

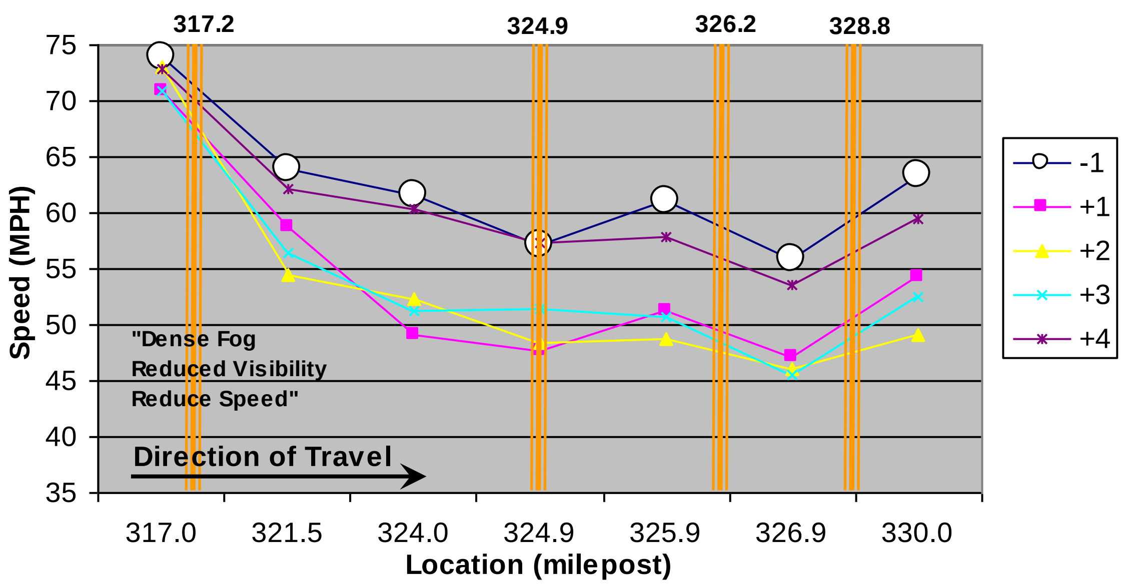


Figure A42. Average Vehicle Speeds by Location and Hour

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