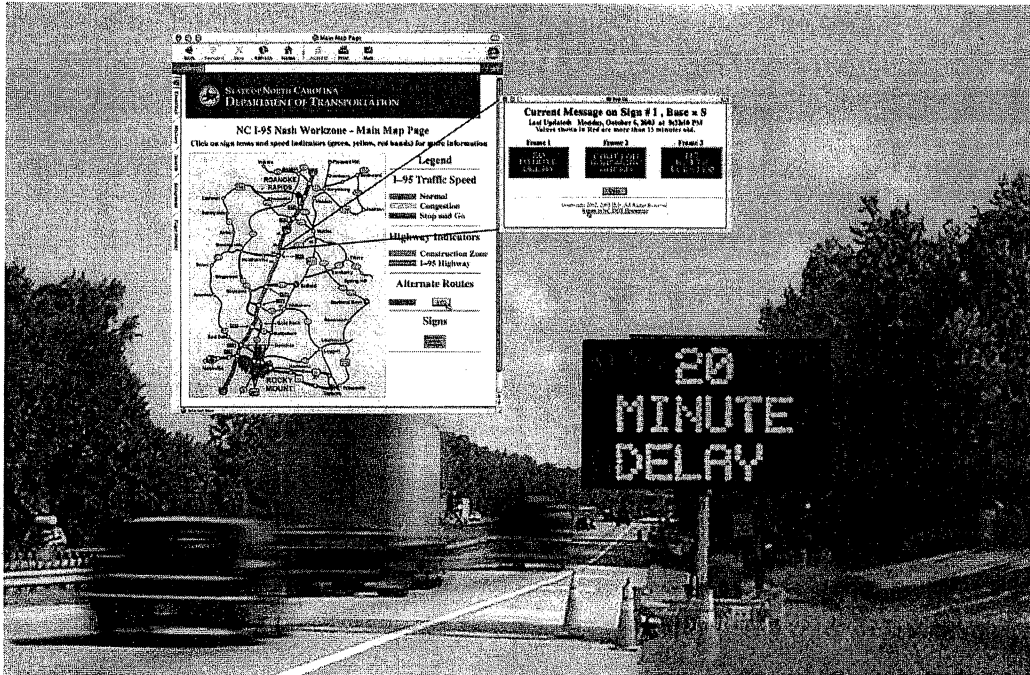


Effect of Intelligent Transportation Systems in Work Zones

Evaluation of North Carolina Smart Work Zones Final Report



Prepared for:

North Carolina Department of Transportation

Prepared by:

Transportation Research Centre

University of Saskatchewan

September 2004



Transportation
Research
Centre

**Effect of Intelligent Transportation Systems in
Work Zones**

**Evaluation of North Carolina Smart Work Zones
Final Report**

Prepared for:

North Carolina Department of Transportation

Prepared by:

Rob Bushman

Curtis Berthelot

Transportation Research Centre

University of Saskatchewan

September 2004

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the North Carolina Department of Transportation.

Table of Contents

Table of Contents.....	i
List of Figures.....	ii
List of Tables.....	ii
Executive Summary.....	iii
1. Introduction.....	1
1.1 Background.....	1
1.2 Objectives.....	3
1.3 Project Scope.....	3
1.4 Project Methodology.....	4
1.5 Layout of Report.....	5
2. Summary of System Implementation.....	7
3. Summary of Previous Research.....	9
4. Safety Analysis.....	13
4.1 Safety Analysis Methodology.....	13
4.2 Safety Analysis Results.....	14
5. Traffic Operation Review.....	18
5.1 Alternate Route Usage.....	18
5.1.1 Data Gathering.....	18
5.1.2 Alternate Route Usage: Exit 145 Northbound.....	20
5.1.3 Alternate Route Usage: Exit 154 Southbound.....	21
5.2 Travel Time.....	26
5.3 Queuing During Smart Work Zone Deployment.....	29
5.3.1 Johnston County.....	30
5.3.2 Nash County.....	31
6. User Acceptance.....	33
6.1 Local Resident Survey.....	33
6.2 Trucking Industry Survey.....	40
6.3 Roadside Survey.....	44
6.4 Resident Engineer Feedback.....	45
6.4.1 Johnston County Project.....	46
6.4.2 Nash County Project.....	47
7. Project Analysis Framework.....	50
7.1 Decision Approach and Model Structure.....	53
7.2 Qualitative Analysis.....	55
7.3 Quantitative Analysis.....	59
7.3.1 Quantitative Analysis Framework.....	60
7.3.2 Definition of Variables.....	62
7.4 Validation and Application of Project Analysis Framework.....	63
7.5 Preliminary Assessment of User Delay.....	64
8. Summary and Conclusions.....	67
9. Future Development.....	70
10. References.....	71

- Appendix A: Implementation Details
- Appendix B: Safety Analysis Details
- Appendix C: Diversion Route Data
- Appendix D: Results of Traffic Operations Review
- Appendix E: User Acceptance Survey

List of Figures

Figure 1	Smart Work Zone message sign.....	7
Figure 2	Histogram of hours between crashes with Smart Work Zone in operation.....	16
Figure 3	Portable camera trailer deployed on Interstate 95	19
Figure 4	Effect of sign message content on use of exit 145 northbound.....	20
Figure 5	Percentage of total traffic using exit 150, October 30, 2003	23
Figure 6	Percentage of total traffic using exit 150, October 28, 2003.....	25
Figure 7	Estimated reduction in delay with Smart Work Zone in operation.....	28
Figure 8	Qualitative and quantitative analysis process.....	54
Figure 9:	Sample results of a qualitative analysis of deploying a Smart Work Zone.....	58
Figure 10	Qualitative benefit cost analysis structure.....	61
Figure 11	Benefit / Cost breakeven point considering cost of deployment and value of reduced user delay.....	66

List of Tables

Table 1	Exit ramp traffic volume under varying sign messages: Exit 154 southbound ..	22
Table 2	Effects of message details and congestion on alternate route usage: Exit 154 southbound.....	24
Table 3	Summary of high occupancy occurrence by month, Johnston County.....	30
Table 4	Summary of high occupancy occurrence by month, Nash County.....	32
Table 5	Results of survey sent to local residents in Rocky Mount and Smithfield vicinity: Questions 1-5.....	34
Table 6	Results of survey sent to local residents in Rocky Mount and Smithfield vicinity: Questions 6-11.....	37
Table 7	Results of survey to trucking companies in Rocky Mount and Smithfield vicinity	41
Table 8	Results of roadside survey conducted October 2003 at Nash County rest area .	44
Table 9	Potential benefits and costs associated with a Smart Work Zone deployment.	51
Table 10	Qualitative analysis of the deployment of a Smart Work Zone.....	56
Table 11:	Results of sample qualitative analysis	59

Executive Summary

The highway infrastructure is an important asset for the transportation of people and goods to support economic activity, personal mobility, and quality of life. However, maintaining a safe and efficient transportation infrastructure requires that maintenance and preservation activities must take place. In the last few years Interstate 95 in North Carolina has been undergoing repair and resurfacing to maintain and improve the quality of the highway system. While this work is necessary to preserve the transportation infrastructure, work zones can be a cause of increased congestion and reduced safety.

To address concerns with safety and mobility while construction work is underway, NCDOT has begun using advanced technology to better manage work zone traffic. This study examines the use of new technology by NCDOT on two specific projects to improve safety and mobility in and around work zones. This technology, commonly referred to as a “Smart Work Zone”, is designed to provide motorists with better information on traffic conditions at a work site to allow them to make better driving decisions.

Portable changeable message signs located along the approach to the work site provide motorists with advisory information of delays ahead and can suggest alternate routes when appropriate. In addition, a website is provided where motorists can check current conditions. The fundamental difference between the Smart Work Zone and traditional work zone traffic control is that the information presented is based on the most current conditions which are constantly monitored by the system, ensuring accurate, reliable, and believable information is provided to motorists. By providing this type of information to motorists, the goal is to:

- Reduce queue lengths and delay
- Increase driver awareness
- Reduce aggressiveness and frustration
- Increase driver confidence in signing

- Improve mobility

Smart Work Zone technology has been deployed in several other States. Previous research on other projects has indicated that a Smart Work Zone can be effective in increasing the use of alternate routes, improving traffic flow, and improving traffic safety. Other adaptations of a Smart Work Zone have also been deployed to improve speed management and traffic merging at a work zone.

The focus of this study is two Smart Work Zone deployments that took place between April and November 2003. Both case studies took place on rural sections of Interstate 95 and included resurfacing of both driving lanes and shoulders in both the northbound and southbound directions. One of the projects took place in Nash and Halifax counties between milepost 145 and 154 near the community of Rocky Mount. The other project took place in Johnston County between milepost 101 and 107 near the community of Smithfield.

Safety Improvements

The safety improvements of having the Smart Work Zone in place were examined on the Nash project. The Smart Work Zone was considered as essential and it was not feasible to turn the system off so that data could be collected without the Smart Work Zone operating. However, there were short periods of time that occurred throughout the project when lane closures were in place, but the Smart Work Zone was not operating due to frequent relocations of the work area. Due to the limited number of crash occurrences and the variability of time between crashes no conclusive results could be drawn. Knowledge of the frequency of crashes and distribution of crashes may be useful in the design of future evaluations. To obtain meaningful results a longer study period may be required or an alternative means of determining safety employed. One possible approach is to use surrogate measures of safety such as traffic conflicts or speed variability that may be indicators of improved safety to determine the impact of a Smart Work Zone.

Alternate Route Usage Optimization

One of the key functions of the Smart Work Zone is to communicate current conditions to drivers so they can make informed decisions related to the use of alternate routes. The optimal route choice is the one that minimizes travel time for the individual motorist and minimizes total traffic delay. If traffic can be encouraged to use alternate routes during times of heavy congestion, the results will be reduced congestion on the mainline, reduced queue length, and reduced delay time. An analysis of data collected at exit 145 northbound suggests that alternate route usage is increased in the range of 10 to 15 percent with the presence of a Smart Work Zone that provides specific information about delays and alternate routes. Additional data collected at exit 154 southbound also supports the finding of an increase in alternate route usage when specific and accurate information is provided. Occasionally a traffic queue would develop of sufficient length that it was visible at the exit to the alternate route. There was indication that the presence of visible congestion at the exit ramp location resulted in increased alternate route usage. The combined effects of an alternate route advisory and visible congestion resulted in the highest usage of the alternate route.

Queuing During Operations

An analysis of queue development, based on high occupancy at detection points, was conducted to obtain an overall picture of traffic operations at both sites. For Johnston County, based on the available data, severe congestion resulting in several miles of backup was rare, only occurring a few times in March and April. Only three percent of the days had long queues that lasted for one hour or longer. Congestion occurring near the taper area was most frequent from March to June. During July and August the occurrence of congestion of any type being detected by the system was infrequent. Overall, congestion lasting for at least one hour in the vicinity of the taper area was detected on 25 percent of the days the Smart Work Zone was operational.

On the Nash County project, long queues lasting for at least one hour occurred on three percent of the days. Congestion near the taper area was also more frequent on this project. On almost half of the days for which valid data was available, at least one hour

of high occupancy was detected and on over a third of these days the high occupancy condition existed for more than three hours. At this site congestion was experienced most frequently in the month of August with 71 percent of days experiencing some level of congestion. On the Nash County project, congestion occurred least frequently in the months of May and June.

User Survey of Acceptance of Smart Work Zones

Surveys were mailed to 1468 residents in the vicinity of the construction projects and 22.7 percent were completed and returned. Survey results were broken down based on the frequency with which motorists travelled through the work zone area. Results indicate that approximately 80 percent of motorists were aware that the system was providing more up to date information than at other work zones. They perceived the information as “always accurate” or “sometimes accurate” in over 95 percent of cases. Almost 85 percent of motorists were unaware that a website existed to obtain current travel conditions. Of those that were aware of the website and had internet access approximately 20 percent made use of the website. Over 95 percent of motorists supported the future use of these types of systems in North Carolina.

A separate survey was mailed to 32 truck transport companies with operations located near the work zones. Seven surveys were completed and returned, a response rate of 21.9 percent. The system was classified as always accurate or sometimes accurate by 85.7 percent of respondents. When a delay advisory was provided, 16.7 percent of respondents indicated decisions were often influenced by the system while the other 83.3 percent of respondents were sometimes influenced by delay advisory messages. Overall, the reaction of local trucking companies to the efforts of NCDOT was highly positive with 100 percent supporting future projects of this type. Perceptions of system accuracy and the usefulness of the information to influence travel decisions were positive as well. As with the motorists, the travel information website was not utilized to its full extent by the trucking companies.

In addition to the mail-out survey, a road-side survey was conducted at a rest area located downstream of the Nash County work zone area at a point at which alternate route traffic had rejoined the Interstate. For all survey participants the origin of their trip was outside North Carolina and only two had a final destination located in North Carolina. When asked to identify the message they had seen, all of the survey respondents were able to identify the general content of the message. Regarding the accuracy of the information provided, 89 percent felt that the information was relevant and accurate to the current situation. The future deployment of Smart Work Zones was supported by 90 percent of participants.

Project Level Economic Analysis Framework

A variety of potential costs and benefits that may result from a transportation project can be considered as they affect the agency, users, and society in general. A Smart Work Zone project analysis framework is presented which looks first at costs and benefits qualitatively and then looks quantitatively at specific costs of safety, user delay, vehicle operating, and agency procurement. A preliminary analysis was conducted for the value of reduced user delay. Typical costs for the deployment of a Smart Work Zone system such as those considered in this study are approximately \$20,000 / month. Assuming an averaged value of \$20 / hour for delay to cars and trucks and that the Smart Work Zone is active 20 days per month, the breakeven point for system costs and benefits from reduced delay occurs when 50 hours of delay are saved. For every vehicle that is removed from the queue, every following vehicle receives the benefit of reduced waiting time. Therefore, from a breakeven analysis perspective, diverting as little as 150 to 200 vehicles to an alternate route at the times of greatest congestion may be enough to realize time savings to justify the use of a Smart Work Zone system.

Future Development

Research on past deployments has indicated the potential benefits for Smart Work Zones to be used to provide advanced traveler information, manage speeds, and guide driver behavior. The results of this study indicated that the public supports the use of Smart Work Zone technology and that driver behavior can be altered by providing real-time

information and route guidance. This study presents a framework for a qualitative and quantitative analysis of Smart Work Zone deployments. This type of analysis can be useful for comparison and selection of potential projects to determine what type of technology to employ and what the expected benefits may be from such a deployment. To make the analysis practical for general usage several further development steps are recommended.

The application of a Smart Work Zone can result in unique traffic conditions. Therefore, it may be useful to use modeling and simulation tools to assess the potential results of applying a Smart Work Zone. Several tools currently exist but their application for Smart Work Zones has been limited. Some of these also have graphics and animation capabilities that can be useful in demonstrating new concepts of traffic operation such as occur when a Smart Work Zone is deployed. Further development in the application of analysis tools to Smart Work Zones will help in determining when and how to best make use of Smart Work Zone technology.

1. Introduction

North Carolina Department of Transportation (NCDOT) has a goal to provide a safe, efficient and aesthetically pleasing transportation system to the traveling public. In the last few years Interstate 95 has been undergoing repair and resurfacing to maintain and improve the quality of the highway system. While this work is necessary to maintain the transportation infrastructure, work zones can be a cause of increased congestion and reduced safety. To address concerns with safety and mobility while construction work is taking place, NCDOT has begun using advanced technology to better manage work zone traffic. A “Smart Work Zone” measures current traffic conditions and provides relevant information and guidance to motorists. This study examines the use of Smart Work Zone technology by NCDOT on construction projects to improve safety and mobility in and around work zones.

1.1 Background

Work zone safety and mobility are a concern for many transportation agencies in North America. Between 2000 and 2003, the annual average number of fatalities in motor vehicle crashes in construction / maintenance zones in United States was 1057.75. In North Carolina the average number of fatalities in motor vehicle crashes in construction / maintenance zones between 2000 and 2003 was 42.75 (ATSSA, 2004). In addition to creating safety issues, work zones are also a cause of reduced mobility. Work zones are responsible for an estimated 24 percent of nonrecurring congestion on the United States highway system (Oak Ridge National Laboratory, 2002). According to an FHWA report on roadways and transportation, American drivers indicated that work zones were the second leading cause of driver dissatisfaction, second only to poor traffic flow (Keever, Weiss and Quarles, 2001).

While safety and mobility must be addressed at all highway construction projects, the work taking place on I-95 is of particular concern to NCDOT for several reasons. I-95 in North Carolina is a main connector between the highly populated regions of northeastern United States and recreation and holiday destinations in Florida. As a result more than 50

percent of the traffic on I-95 is motorists from out of state. In many cases they have been on the road for long periods and are unfamiliar with the route and temporary restrictions such as work zones. Even without work zones in place, I-95 has a traffic crash fatality rate significantly higher than any other Interstate in North Carolina (North Carolina Department of Transportation, 2003).

In an effort to alleviate some of the negative effects of work zones on high traffic freeways NCDOT has applied Intelligent Transportation Systems (ITS) technology to manage traffic on several projects on I-95. This technology, commonly referred to as a "Smart Work Zone", is designed to provide motorists with better advanced information on traffic conditions at a work site to allow them to make better driving decisions.

Portable changeable message signs located along the approach to the work site provide motorists with advisory information of delays ahead and can suggest alternate routes when appropriate. In addition, a website is provided where motorists can check current conditions. The fundamental difference between the Smart Work Zone and traditional work zone traffic control is that the information presented is based on the most current conditions which are constantly monitored by the system, ensuring accurate, reliable, and believable information is provided to motorists. By providing this type of information to motorists, the goal is to:

- Reduce queue lengths and delay
- Increase driver awareness
- Reduce aggressiveness and frustration
- Increase driver confidence in signing
- Improve mobility
- Improve safety

The first use of a Smart Work Zone in North Carolina occurred during the 2002 construction season near Fayetteville on I-95. In 2003, the use of Smart Work Zones was expanded to four locations, two of which are the subject of this study.

1.2 Objectives

NCDOT has deployed Smart Work Zones on a number of projects over the last several years. Based on observations of traffic flow and operational performance of these systems, Smart Work Zones appear to be effective in improving safety and mobility. Based on the positive experience with this technology so far NCDOT is interested in continuing to use Smart Work Zones on projects where they can provide beneficial results. An evaluation of the effects of deploying a Smart Work Zone will support future decisions on the continued use of Smart Work Zone technology.

Ultimately the goal of the study is to improve safety and mobility in future work zones. As NCDOT considers future deployments of a Smart Work Zone, the results of the study should assist in determining what technology to use and when, where and how to use it.

In support of the goal of improved safety and mobility, the objectives of this study are to:

- Document current research in the area of Smart Work Zones
- Document implementation and operation at 2 particular sites deployed in 2003
- Determine traveler use and acceptance of Smart Work Zones
- Estimate impact of Smart Work Zones in terms of reduced accidents and fatalities
- Estimate impact of Smart Work Zones in terms of reduced user delay
- Develop an analysis framework for assessment of future projects

1.3 Project Scope

The scope of the project covers three main elements, a literature review, a case study of two Smart Work Zone field deployments, and the development of an analysis framework.

The scope of the literature review is a summary of previous research on the deployment of Smart Work Zones in North America.

Two construction projects that occurred on Interstate 95 during the 2003 construction season are the focus of the case study on field deployment of Smart Work Zones. The case study covers three elements of the deployment:

- Effect of Smart Work Zone deployment on traffic safety
- Effect of Smart Work Zone on traffic operations
- Reaction of local motorists, out of State motorists, and trucking companies to the deployment of Smart Work Zones

The final element of the study is the development of a two stage analysis framework that can be used for evaluating future deployments of a Smart Work Zone. The first stage is a qualitative analysis that considers all user, agency and society costs and benefits. The second stage is a qualitative analysis that includes agency, user delay, vehicle operating and safety costs and benefits.

1.4 Project Methodology

Literature review: A literature review was conducted using several search methods to identify relevant publications related to the deployment and evaluation of Smart Work Zones. Results of the literature review are summarized and references cited.

Safety Analysis: Crash records as provided by NCDOT were examined for the Nash County project. The presence of a lane closure and the presence or absence of a Smart Work Zone at the time of crash were considered to determine the effect of a Smart Work Zone on traffic safety.

Traffic Operation Review: Traffic data logged by the Smart Work Zone system was examined to determine levels of congestion experienced during deployment of the system. Alternate route usage was observed and analyzed under various operating conditions to determine the effect of the Smart Work Zone on motorist route decision. A theoretical analysis based on queuing theory was conducted to determine the effect of a Smart Work Zone on user delay.

User Acceptance: A mail out survey was sent to residents and trucking companies in the vicinity of the two case study projects. A roadside survey was also conducted at a rest area just downstream of the work zone. The survey was used to determine perceptions, reactions, and support of motorists for the deployment of Smart Work Zones.

Project Level Analysis Framework: Based on previous research, established analysis theory and procedures, and the results of the field study, a project level analysis framework was developed.

1.5 Layout of Report

The layout of the report is as follows:

Section 1. Introduction: Provides background to the project, objectives, scope, methodology and layout of report.

Section 2: Summary of System Implementation: Provides details of the two field deployments of Smart Work Zones that are the subject of the case study.

Section 3: Summary of Previous Research: Summarizes results of the literature review on previous deployment and research pertaining to Smart Work Zones.

Section 4: Safety Analysis: Analysis of traffic safety at the case study site with and without a Smart Work Zone in place.

Section 5: Traffic Operation Review: Results of field study on alternate route usage with a Smart Work Zone, extent of queuing during operation, and analysis of change in travel time with a Smart Work Zone in operation.

Section 6: User Acceptance: Results of survey of local motorists, local trucking companies, and out of State motorists on perceptions, reactions and support of motorists for future Smart Work Zone deployments.

Section 7: Project Analysis Framework: Development of a qualitative analysis process for consideration of agency, user and society costs and benefits and an economic analysis framework for quantification of agency, user delay, safety, and vehicle operating costs and benefits.

Section 8: Summary and Conclusions: Review of the major findings and conclusions of the study.

Section 9: Future Development: Identification of additional research and development based on findings of this study.

Section 10: References: Listing of publications cited in the report.

2. Summary of System Implementation

The focus of this study is two Smart Work Zone deployments that took place between March and November 2003. Both projects took place on rural sections of Interstate 95 and included resurfacing of both driving lanes and shoulders in both the northbound and southbound directions. One of the projects took place in Nash and Halifax County between milepost 145 and 154 near the community of Rocky Mount. The other project took place in Johnston County between milepost 101 and 107 near the community of Smithfield.

As part of the Smart Work Zone, three sensor trailers were positioned upstream of the work area to monitor traffic conditions. A typical road side message is illustrated in Figure 1. Three message signs were positioned on I-95 upstream of the work area with at least one sign prior to the alternate route exit. Three additional message signs were positioned to provide route guidance to motorists on the alternate route.

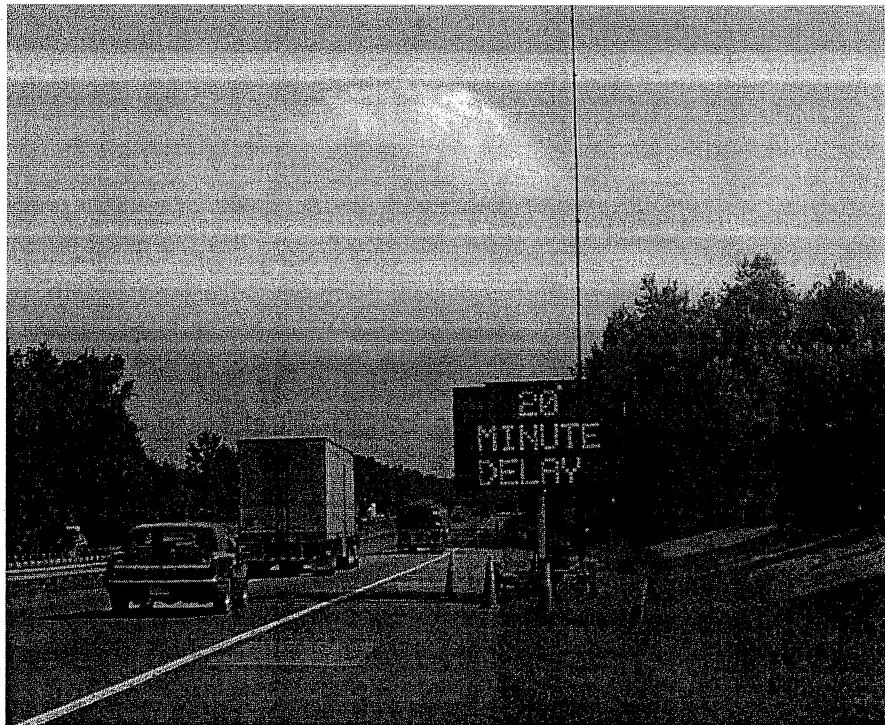


Figure 1 Smart Work Zone message sign

Three levels of messages were provided to motorists based on the traffic conditions. Messages were displayed on three lines and up to three frames in sequence. Generic messages informing motorists of a work zone ahead, such as “Traffic Slowing Ahead / Prepare To Merge” and Real Time Traffic Info / No Delay Exits 150-141”, were displayed when no delays were detected. When short delays were detected, but not long enough to warrant the use of the alternate route, the current delay estimate was displayed with a message such as “Traffic Stopped Ahead / 15 Minute Delay”. When delay time reached the point where the alternate route would offer a shorter travel time, the amount of delay and the suggested alternate route were displayed using a message such as “Traffic Stopped Ahead / 20 Minute Delay / Use Exit 141 As Alt.”.

The Smart Work Zone systems employed in this study were procured through a competitive public tender process. Copies of the tender specifications and layout drawings are provided in Appendix A. The road surfacing contract and the Smart Work Zone contract were awarded separately. Therefore, both the paving contractor and the Smart Work Zone provider had a direct contract with NCDOT, but no contractual relationship with each other. Under the requirements of the contract, the Smart Work Zone vendor was responsible for furnishing, operating, and maintaining the system in good working order. Payments were calculated on a daily basis for satisfactory performance of the system.

3. Summary of Previous Research

Smart Work Zones are a relatively new development for the management of work zone traffic. In 1996 Minnesota Department of Transportation was one of the first agencies to begin experimentation with this type of technology, but with less automation than current systems. This early work zone safety system used semi-portable field units to provide traffic data back to a traffic management center (TMC). At the TMC, the data was manually reviewed and messages were selected by an operator to be displayed on permanent and portable message signs in the vicinity of the work zone (SRF Consulting Group, 1997). In 1996 Maryland experimented with an automated Smart Work Zone system. Fontaine has identified evaluation projects of this type in Maryland, Iowa, Kentucky, Nebraska, Illinois, and Ohio (Fontaine, 2003). Other projects have also been deployed in Wisconsin, Arkansas, Michigan, and North Carolina, and California. Much of the early research was inconclusive due to technical difficulties, unsuitable test locations, and a focus on the ability of systems to meet the functional requirements, and not on the operational effectiveness.

The reaction of a motorist to an advanced traveler information message sign providing traffic information is complex and may be affected by factors such as age, gender, trip purpose, network familiarity, education and trust in message content. Previous research into the use of variable message signs for freeway management applications has shown that drivers will respond differently depending on the content of the message provided. Messages that provide specific values for expected delay were more likely to result in a motorist choosing an alternate route than messages that did not provide specific values. Likewise, messages that provide guidance to a specific alternate route resulted in a motorist choosing to use an alternate route more often. For incident caused delays, identifying the location of the crash in the message also increased responsiveness of motorists. Driver responsiveness increased when at least two specific pieces of information were provided together and the greatest response was observed when three pieces of information, location, delay and alternate route, were provided (Peeta, Ramos, and Pasupathy 2000). Other studies have also identified a link between message content

and a motorist's willingness to use an alternate route (Polydoropoulou, Ben-Akiva, Khattak, Lauprete, 1996; Benson, 1996). Previous research has focused primarily on freeway management applications and there has been relatively little research into the response of drivers to travel information in a work zone setting. Research that has been done has not included messages that provide the motorist with both expected delay and alternate route guidance.

A field study in Wisconsin investigated the response of drivers to real time information in a work zone setting in an area classified as rural, but with a number of alternate route options. The messages provided to motorists included the driving distance to the end of the work zone and the travel time to the end of the work zone. Alternate route advisories were not displayed on the variable message signs, but alternate routes were marked with static signing should motorists choose to use an alternate route. The results indicate that alternate route selection rates increased by seven to ten percent of the freeway traffic during peak periods, depending upon the location and the day of the week (Horowitz, Weisser, and Notbohm, January 2003).

A similar project in Nebraska also studied the response of drivers to advanced advisory information approaching a work zone. In this application delay advisories were provided when delays exceeded 5 minutes and when delays exceeded 30 minutes the message "CONSIDER ALT ROUTE" was also added, but no specific route was identified. Alternate route usage was eight percent when the signs were blank and increased to 11 percent of freeway traffic when an alternate route advisory was provided (Fontaine, 2003).

Previous research was conducted in Arkansas on a system similar to the one deployed in Nebraska (Tudor, Meadors, and Plant, January 2003). The crash rate at the site with the Smart Work Zone was compared with two other control sites with similar characteristics but no Smart Work Zone, using number of crashes per 100 million vehicle miles traveled as the measure. The fatality rate was 2.2 for the site with a Smart Work Zone, compared to 3.2 and 3.4 at the sites without a Smart Work Zone, an average reduction of 33

percent. The rate of rear-end crashes was 33.7 for the site with a Smart Work Zone, compared to 29.5 and 43.2 at the sites without a Smart Work Zone, an average reduction of 7 percent. Traffic counts taken on an alternate route showed an increase in traffic when a back-up advisory message without identifying an alternate route was displayed. The increased traffic on the alternate route was estimated to represent in the range of two to six percent of the mainline traffic.

A study in Missouri examined the use of an automated system which advised drivers when delays and reduced speeds were occurring at a work zone site. Analysis showed that the system had a positive effect on the reduction of mean speed and speed variance as the traffic neared the work zone. This is considered to be an indication of improved safety of the work zone (King, Sun, and Virkler, January 2004).

The Smart Work Zone applications discussed so far have focused on providing information to motorists to advise of delay and assist them in the deciding whether to use an alternate route. Smart Work Zones have also been applied to address concerns with speed management and lane merging conflicts in work zones.

In Michigan a variable speed limit (VSL) system was deployed to manage speeds through work zones relevant to traffic and road conditions. The system monitors traffic flow and the road surface to detect the presence of water, ice or snow. Based on current conditions appropriate speed limits are determined and posted as vehicles approach and travel through the work zone. Parameters can be set to control the range of speeds displayed, the maximum difference between adjacent signs, and the minimum time that must elapse before speed limits are updated. The conclusion from an evaluation by Michigan State University was that “the VSL system can present far more credible information (realistic speed limits) to the motorist, responding to both day-to-day changes in congestion as well as significant changes in congestion and geometry as motorists go through a given zone” (Lyles, Taylor, Lavansiri and Grossklaus, 2004).

A very common work zone configuration is a lane reduction from two lanes down to a single lane. This configuration requires that many motorists make lane changes and speed adjustments, creating the potential for conflicts and crashes. Aggressive driving behavior that often takes place at work zones can increase the potential for crashes. While many drivers will change lanes in a timely and orderly fashion, some will stay in the closing lane, drive at high speeds to the taper area, and then force a merge into the queue in the open lane.

One approach to minimize traffic merging conflicts is to encourage all motorists to merge upstream of the congested area. A dynamic lane merge traffic control system was evaluated by Wayne State University in Michigan in 2001 (Datta, Schattler, and Hill, 2001). The system monitors current traffic conditions on the approach to the work zone and activates a "Do Not Pass" zone in advance of the end of the traffic queue. With the system in place average peak period travel time decreased by over 30 percent resulting in time savings for drivers. The average number of stops and duration of stops were decreased, reducing fuel consumption and emissions. The number of aggressive driver maneuvers (late merges) during peak hours was reduced by 50-75 percent, significantly reducing the potential for crashes and road rage.

In Maryland, an approach was taken which encouraged motorists to use both lanes up to the merge point under congested conditions. Portable message signs are used to advise drivers when the late merge traffic control is in effect. When congestion is no longer present, the system is deactivated and traffic resumes normal operation. An evaluation by the University of Maryland found an increase in throughput, more uniform volume distribution, and a reduction in the maximum queue length. There may be an increase in the number of stop-and-go maneuvers and merging at several locations (Chang, Kang, Horvath, 2004).

4. Safety Analysis

Safety is an important issue in work zones, as indicated earlier by the number of crashes and fatalities that occur in work zones every year. Smart Work Zones may have a beneficial effect on safety by improving driver awareness, improving driver attitudes, and reducing queue lengths which can increase the possibility of rear-end collisions. To predict the impact of the Smart Work Zone on traffic safety an analysis was performed to determine if there was any change in the occurrence of fatalities and crashes. To make a determination of whether there was any effect, an analysis was performed to compare crashes with and without the Smart Work Zone in place.

4.1 Safety Analysis Methodology

The evaluation of safety effects of an applied treatment or system can be a challenging task for any type of project. Typically, it is preferred to have statistical data for a three year period prior to applying the treatment, followed by a three or five year observation period for comparison. During the before and after period, all other factors should be held constant. In reality, it is impossible to hold all other factors constant as traffic, weather, demographics, road conditions, other road improvements, and many other factors can all influence the study site.

Evaluation of work zone treatments is particularly difficult. As many projects last for only a single construction season, long periods of before and after observation are not possible. The presence of a work zone results in a significant change in driving conditions from the no construction condition and so comparisons to the period before the start of a work zone can not be made. Despite the challenges, it is desirable to have an indication of the effect of a Smart Work Zone deployment on traffic safety.

A within project safety comparison was conducted on the Nash project. The importance of having the Smart Work Zone in place was felt to be very high, and it was not feasible to turn the system off so that data could be collected without the Smart Work Zone

operating. However, there were short periods of time that occurred throughout the project when lane closures were in place, but the Smart Work Zone was not operating.

The nature of the resurfacing work occurring over a length of approximately nine miles and in both southbound and northbound directions resulted in frequent relocation of the work location within the project limits. If the paving contractor decided to move from a southbound location to a northbound location on short notice, there was sometimes some lag time before the Smart Work Zone could be reset for the new location. Periods of system downtime for maintenance also resulted in short periods where lane closures were in place, but the Smart Work Zone was not operational.

Crash records were studied over the entire deployment period in Nash County and were separated out as to whether they occurred with or without the Smart Work Zone present. The recorded crashes for the period of operation are provided in Appendix B. The presence of the Smart Work Zone was determined based on the logbook entries of the site inspector. Only crashes that were coded as occurring in the same direction as the lane closure and while a construction or maintenance project was occurring were considered. This approach provided 92 days of operation with the Smart Work Zone in place and 13 days without.

4.2 Safety Analysis Results

The Smart Work Zone system was first deployed on the Nash County construction project at the end of April 2003 and was used until project completion in November 2003. Crash records were analyzed up to the end of September 2003, as incidents after that period had not yet been recorded in the database. The study period therefore covers April 29 to September 30, 2003. The normal closure schedule for the project was Monday to Friday from 6 am to 6 pm. Any crashes that occurred outside this time window were not considered. Crashes that occurred in the same direction as the closure and that were coded as occurring in a construction or maintenance work area were considered.

The Smart Work Zone system was operational for approximately 92 days when lane closures were in place. 22 crashes were recorded when the Smart Work Zone was in operation. During the study period there were also approximately 13 days when lane closures were in place but the Smart Work Zone was not in operation. This provides a comparison period with and without the use of the Smart Work Zone. Two crashes were recorded when the lane closures were in place without a Smart Work Zone.

Given the stochastic and time-dependent occurrence of crashes within a work zone, analyzing the results is not straight forward. One measure of effectiveness is the average days per crash. With the Smart Work Zone in place, crashes occurred at a rate of one crash every 4.2 days, while without the Smart Work Zone in place, crashes occurred at a rate of one crash every 6.7 days. However, two things should be noted about these results. First, this measure provides no way to quantify the variability of results, such as the standard deviation. Second, given the small sample size the outcome is highly sensitive and even a single crash event could significantly alter the results.

Another measure is to look at each crash as a unique event and consider the time of operation since the last crash. Using this approach, the variability and distribution of crash times can be considered.

Considering the 22 crash events that took place when the Smart Work Zone was in place, the average operating hours between crashes was 50.2 hours with a standard deviation of 43.9, a minimum value of 1.2 hours and a maximum of 145.4 hours. The time between crashes does not follow a normal distribution as illustrated in the histogram in Figure 2.

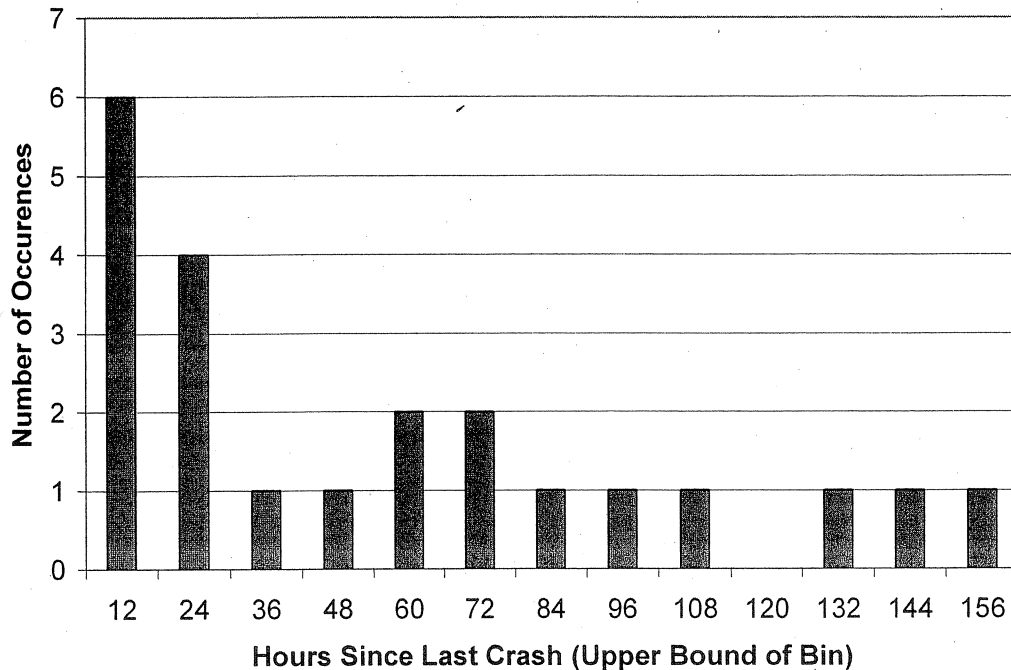


Figure 2 Histogram of hours between crashes with Smart Work Zone in operation on Nash County project

Since there were only two crashes that occurred when the Smart Work Zone was not operating, analyzing time between crashes is problematic. With only two crash events, there is only one true time between crash measurement, which was 27.7 hours. However, there was a period of 55.2 hours from the start of the study period until the first crash occurred and a period of 77.2 hours after the last recorded crash until the end of the study period. Assuming that the beginning and end time periods represented between crash times would alter the results. Given the available data and its variability, it appears there is not enough evidence to determine the effects of a Smart Work Zone on safety. Understanding something of the distribution and variability of crash times may be useful in the design of future evaluations to yield results with significance.

The research conducted in this portion of the study was inconclusive as to the effects of a Smart Work Zone on safety. Due to the high value placed on having the system operating and in place, limited time periods for comparison without the Smart Work Zone occurred. Knowledge of the frequency of crashes and distribution of crashes may be

useful in the design of future evaluations. To obtain meaningful results a longer study period may be required or an alternative means of determining safety employed. One possible approach is to use surrogate measures of safety such as traffic conflicts or speed variability that may be indicators of improved safety to determine the impact of a Smart Work Zone.

5. Traffic Operation Review

The presence of a work zone on a rural freeway has a detrimental effect on traffic operations, often resulting in reduced capacity, reduced speeds, and increased queuing and delay. Several aspects of traffic operations were looked at to determine the characteristics of traffic operations with the implementation of a Smart Work Zone.

5.1 Alternate Route Usage

One of the key functions of the Smart Work Zone is to communicate current conditions to drivers so they can make informed decisions related to the use of alternate routes. If traffic can be encouraged to use alternate routes during times of heavy congestion, the results will be reduced congestion on the mainline, reduced queue length, and reduced delay time.

5.1.1 Data Gathering

Recording was conducted using a portable camera trailer that was already deployed as part of the Smart Work Zone system, as illustrated in Figure 3. Additional recording was conducted using a hand-held video camera.

To the motorist, there was no change in the look or configuration of the system that would affect driving behavior. Recordings were then analyzed to obtain the required information for the evaluation. Traffic counts were determined on one minute intervals for the quantity of cars and trucks on the mainline and the quantity of cars and trucks using the exit ramp to the diversion route. Traffic flow was also observed and periods of visible traffic congestion, characterized as slow moving or stop and go traffic, were noted. The point of observation was at the exit ramp to the alternate route, so is an indication of what motorists would see at the time of deciding whether to use the alternate route. The Smart Work Zone system automatically records and archives video images from the camera and maintains a log of all messages displayed on message signs. This information was used to correlate traffic volumes, traffic conditions, and sign messages for all time intervals. Count data for the analysis of alternate route usage is provided in Appendix C.

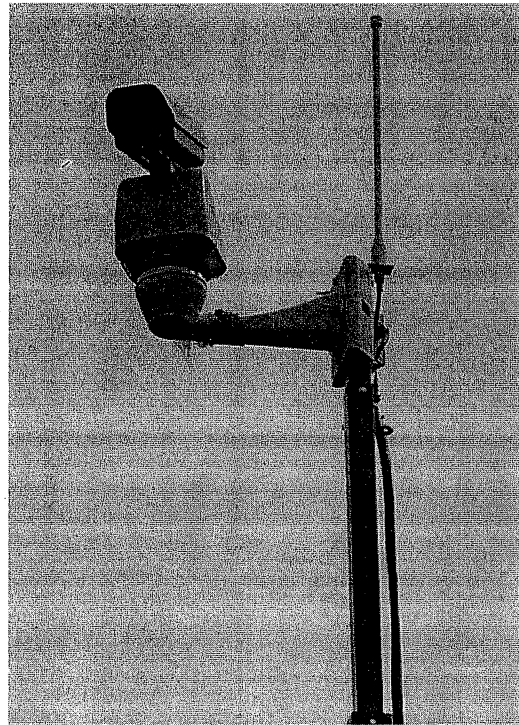
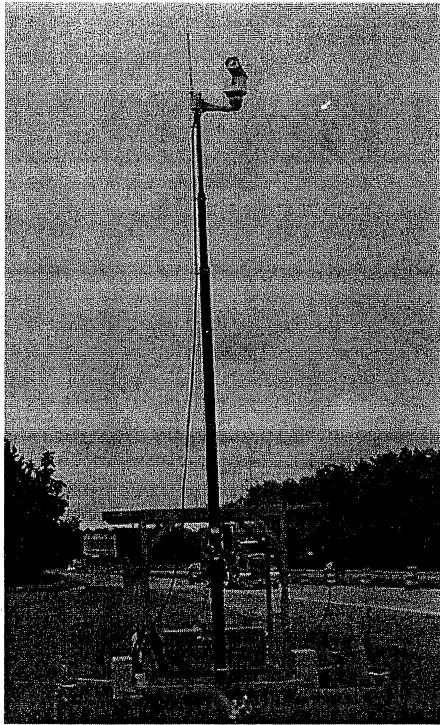


Figure 3 Portable camera trailer deployed on Interstate 95

To measure the effects of the Smart Work Zone on motorists using an alternate route, data was collected under three sign conditions. The three sign conditions considered and typical message wording were:

Sign Condition 1: Generic message: "TRAFFIC SLOWING AHEAD / PREPARE TO MERGE" or "DRIVE WITH CAUTION / ROAD WORK AHEAD"

Sign Condition 2: Delay message: "TRAFFIC STOPPED AHEAD / 10 MINUTE DELAY"

Sign Condition 3: Delay message and route advisory: "TRAFFIC STOPPED AHEAD / 30 MINUTE DELAY / USE EXIT 150 AS ALT."

The reaction of drivers to the Smart Work Zone messages were evaluated at two locations: exit 145 northbound and exit 154 southbound.

5.1.2 Alternate Route Usage: Exit 145 Northbound

Traffic data was collected at exit 145 on October 21, 22, and 23, 2003 while the Smart Work Zone was deployed on the northbound lanes of Interstate 95. Approximately one hour of data was collected for each day. Exit 145 was the last exit that drivers could use prior to the construction area and was the designated alternate route. The distance between exit 145 and the start of the construction area was sufficient to maintain free flow traffic at all times at exit 145, so the presence of congestion should have had no effect on driver's route choices. The only known influence was the content of the sign messages. The results of the three days of observations are presented in Figure 4 below.

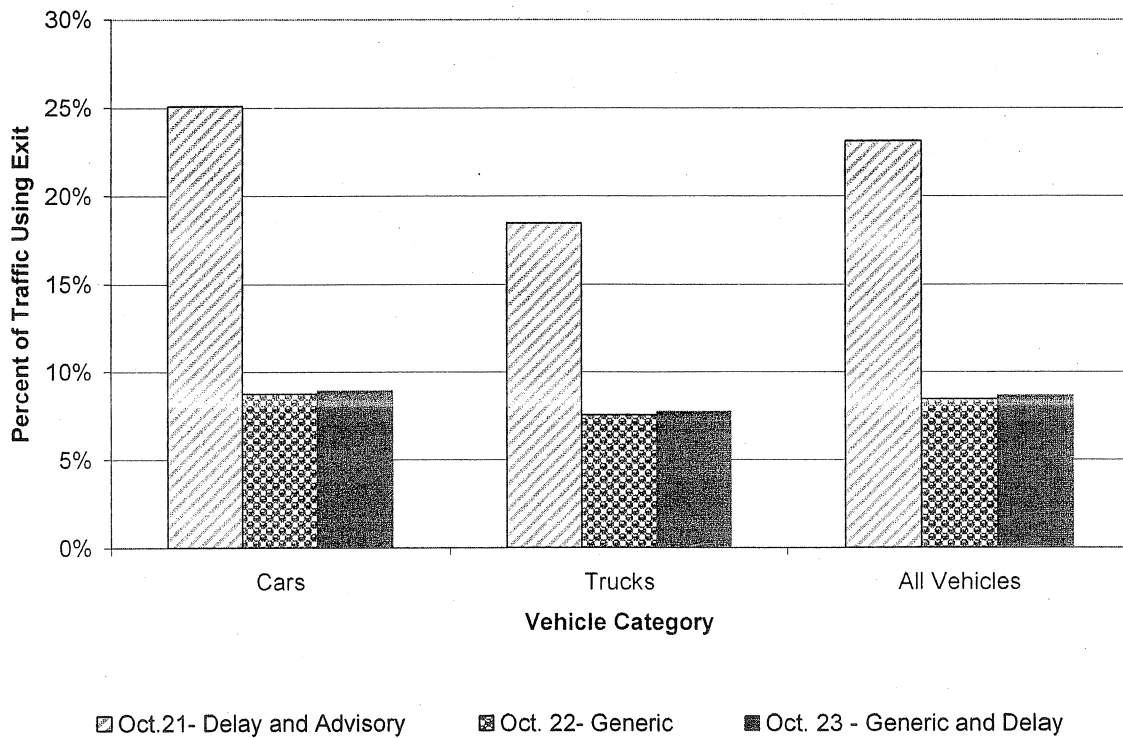


Figure 4 Effect of sign message content on use of exit 145 northbound

On October 21st, the Smart Work Zone signs were activated due to congestion and showed messages that either informed motorists of delays ahead or advised the motorist to use an alternate route. Exit 145 was chosen by 25.1 percent of cars, 18.5 percent of trucks, and overall by 23.1 percent of drivers during this period.

October 22nd and 23rd provide a comparison in driver response, that can be considered the base case. On October 22nd the Smart Work Zone displayed only generic work zone messages, and on October 23rd primarily generic messages were displayed with some short periods where delay information was posted. Driver route decisions were quite similar for the two days. Exit 145 was chosen by 8.7 percent of cars, 7.5 percent of trucks, and overall by 8.4 percent of drivers on October 22nd. On October 23rd, 8.9 percent of cars, 7.7 percent of trucks, and overall 8.6 percent of drivers chose to use exit 145. This analysis suggests that alternate route usage is increased in the range of 10 to 15 percent with the presence of a Smart Work Zone that provides specific information about delays and alternate routes.

5.1.3 Alternate Route Usage: Exit 154 Southbound

Traffic data was collected at exit 154 on October 28 and 30, 2003 while the Smart Work Zone was deployed on the southbound lanes of Interstate 95. Exit 154 was the last exit that drivers could use prior to the construction area and was the designated alternate route. The distance between exit 154 and the start of the construction area was such that under some conditions, traffic congestion occurred in the vicinity of exit 154, with reduced speeds and stop-and-go traffic being observed.

Comparisons were made over several days under similar time and traffic conditions. Results from the mornings of Tuesday October 28th and Thursday October 30th are presented in Table 1.

Table 1 Exit ramp traffic volume under varying sign messages: Exit 154 southbound

Status	Cars On Exit (Vehicles / hour)	Trucks on Exit (Vehicles / hour)	Vehicles on Exit (Vehicles / hour)
1. Oct. 30, 9:37 am to 10:33 am, no advisory	25.7	8.6	34.3
2. Oct. 28, 9:37 am to 10:33 am, delay and alternate route advisory	73.7	11.6	85.3
3. Oct. 28 am, delay advisory	75	11.8	86.8
4. Oct. 28 am, alternate route advisory	100.0	28.9	128.9

Line 1 shows that for a period of approximately one hour when only a generic message was posted, there were 25.7 cars and 8.6 trucks per hour on the exit ramp. For the same time period on October 28th when sign condition 2 or 3 were present, as shown in line 2, 73.7 cars and 11.6 trucks per hour used the exit ramp. The car volume on the exit ramp was almost three times higher when an advisory message of some type was present compared to a generic message. Truck volumes on the exit were only slightly higher under the advisory condition. Due to technical difficulties, the total traffic count for the mainline could not be obtained, so only the ramp volume counts can be compared. Traffic data recorded by the system indicated that congestion was not present at the decision making point and therefore traffic conditions are assumed to have no affect on driver choice.

Line 3 and 4 of Table 1 present a comparison of the reaction to the two types of advisory messages, one that only indicates delay (sign condition 2) and the other that indicates both delay and alternate route (sign condition 3). Usage of the exit by cars increased by 33 percent, while usage by trucks increased by 145 percent when the delay and alternate route were both provided. From these results it appears that longer delays and the designation of an alternate route affects both cars and trucks, but is of greater significance to trucks. When only delay times were posted, trucks were not as likely to alter travel plans. Under sign condition 3, the delay time indicated is greater than condition 2, as well as the alternate route advisory is added. Under condition 3 delays of 15 to 20 minutes were posted, while under condition 2 the posted delay was less than 15 minutes.

It was not determined whether drivers were reacting to the increased delay time, the alternate route advisory, or a combination of both.

The results of observations on the afternoon of October 30th are presented in Figure 5. Each point on the graph represents the percentage of vehicles using the alternate route over a five minute interval starting at the time indicated. The traffic condition is indicated as either congested or uncongested by the line along the base of the graph. Traffic conditions were uncongested during the period from 12:02 to 14:30 and intermittently congested after 14:30. The sign status is indicated by the line along the top of the graph as either generic (condition 1) or advisory (condition 2 or 3). A generic message was posted prior to 14:30 while after 14:30 there were three short periods where an advisory message was provided.

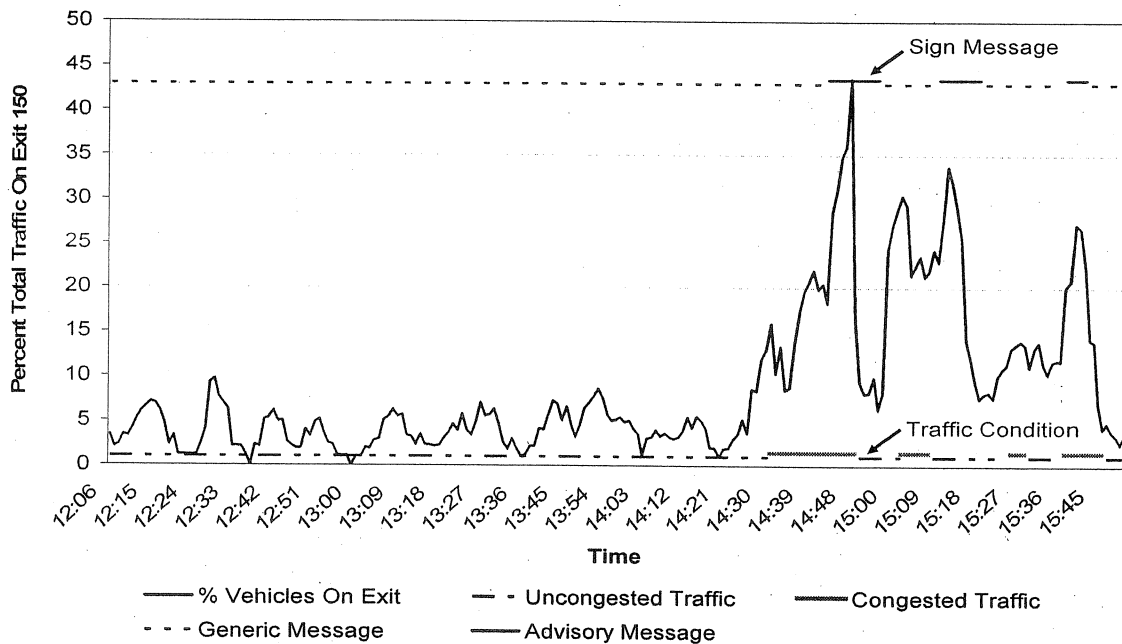


Figure 5 Percentage of total traffic using exit 150, October 30, 2003

Table 2 presents a breakdown of alternate route usage for variations of time, traffic, and sign message. Lines 1 to 3 are based on a generic warning being presented on the signs. Alternate route usage was lowest during the period of 12:00 to 14:30 when no congestion

and no advisory was present (status 1) with an overall rate combining cars and trucks of 6.4 percent. After 14:30 intermittent periods of congestion and advisory sign messages began to occur. After 14:30 when congestion was not present (status 2) the alternate route was used by 10.9 percent of traffic. Although not categorized as “congested”, it is reasonable to assume that conditions were closer to congested than during the period before 14:30 since intermittent congestion was occurring, so this period may represent an intermediate level of congestion. During periods where congestion was present, but only a generic message was provided (status 3), the alternate route usage jumped to 20.2 percent. From these results it appears that a motorist’s decision to use an alternate route is affected by the presence of visible congestion at the decision point.

Table 2 Effects of message details and congestion on alternate route usage: Exit 154 southbound

Status	% Cars On Exit	% Trucks on Exit	% of all Vehicles on Exit
1. Oct. 30, Uncongested prior to 14:30, no advisory	6.6	5.5	6.4
2. Oct. 30, Uncongested after 14:30, no advisory	11.5	8.0	10.9
3. Oct. 30, Congested after 14:30, no advisory	19.7	22.4	20.2
4. Oct. 30, Uncongested after 14:30, delay advisory	10.8	4.3	9.3
5. Oct. 30, Uncongested after 14:30 pm, delay and alternate route advisory	21.1	50.0	25.5
6. Oct. 28, Uncongested, delay advisory	12.4	8.2	11.4
7. Oct. 28, Uncongested, Delay and alternate route advisory	21.6	27.3	22.8

Lines 4 and 5 of Table 2 indicate the response of drivers to the two forms of message signs during uncongested conditions and provide a comparison to uncongested conditions with no advisory in line 1 and 2. It is noted that these results are based on a small sample size due to the intermittent periods when these conditions occurred. The sample size was further reduced by the use of a five minute buffer period in which data was not used after each change in sign status to allow for the time from when a motorist read the message to

when they reached the exit. Exit usage was 9.3 percent during periods when a delay message was posted (status 4), an increase over usage prior to 14:30 when a generic message was displayed (status 1), but a decrease from usage after 14:30 when a generic message was displayed (status 2). When the alternate route message was displayed under uncongested conditions (status 5), exit usage increased to 25.5 percent.

The results of observations on the afternoon of October 28th, 2003 are presented in Figure 6. System operation was the same as for October 30th but there were periods of rainfall on October 30th which did not occur on October 28th. During the period from 12:00 to 14:00 the Smart Work Zone system displayed either a delay message or a delay and alternate route message. Congestion was only observed during a short period of time. Therefore this period provides a good contrast in operation to the period of generic messages over a similar time period on October 30th, as presented earlier.

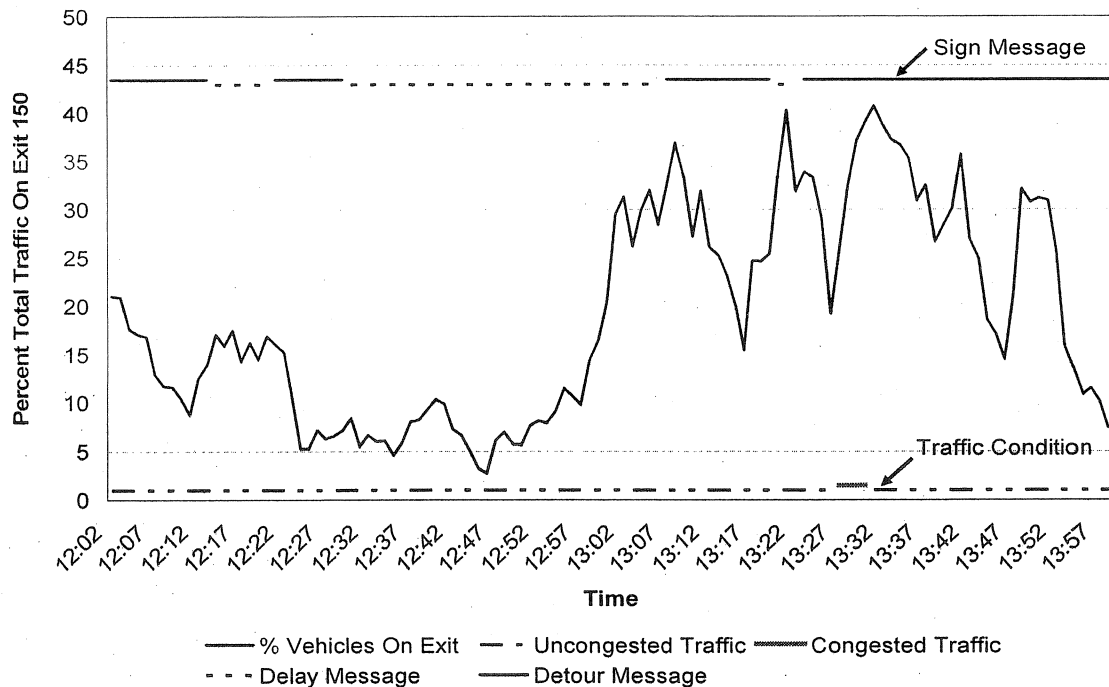


Figure 6 Percentage of total traffic using exit 150, October 28, 2003

There are two predominant conditions that existed during this time period, ignoring the short interval when congestion occurred. Analysis of exit ramp usage for October 30th is presented in lines 6 and 7 of Table 2. When the Smart Work Zone system displayed a delay message without providing an alternate route (status 6), 12.4 percent of cars, 8.2 percent of trucks and 11.4 percent of all vehicles used the alternate route. Comparing to results in line 1 and 2 in Table 2, there is an increase in ramp usage when a delay message is posted. When the Smart Work Zone displayed both the current delay and the suggested alternate route (status 7), 21.6 percent of cars, 27.3 percent of trucks, and 22.8 percent of vehicles overall used the exit ramp leading to the alternate route. This is a significant increase over the ramp usage when a generic message or a delay message was given under uncongested conditions. It is also of interest that in this case trucks were more likely to use the exit ramp. Lines 3 and 5 of Table 2 also showed trucks using the exit ramp more than cars, when congestion was present and when an alternate route advisory was given. For all other conditions cars used the exit at a greater rate than trucks. This may be an indication of the greater value placed on time by the trucking industry, and where it is clear that travel time is being impacted truckers are more eager to find a time saving alternative than car drivers.

5.2 Travel Time

The purpose of a Smart Work Zone system is to manage traffic flow and assist motorists in making appropriate routing decisions. When traffic flows on the mainline and alternate routes is modified by the presence of a Smart Work Zone a change in travel times and user delay is expected. Since the Smart Work Zone was considered an essential traffic control element on the project, it was not feasible to do a field comparison of travel times with and without the Smart Work Zone. Instead, a theoretical analysis was conducted to estimate the effects of changing driver behavior on travel time.

A deterministic queue calculation spreadsheet was developed to analyze the effects of deploying a Smart Work Zone. The spreadsheet is based on principles of queuing theory (May, 1990, Jiang, 2003) applied to incorporate characteristics of traffic diversion with a Smart Work Zone in place.

The following assumptions are made in the determination of user delay:

- The only factor affecting alternate route use is the Smart Work Zone
- Trip cancellation and travel time shifting are not explicitly considered, but can be considered by adjusting the input traffic volume
- All incremental delay is due to congested queue delay time. Delay due to deceleration, reduced speed, and acceleration is constant over both options
- Constant arrival and service rates on an hourly basis
- First in, first out queue discipline

Hourly demand and capacity values are determined based on the input values. On an hourly basis the incoming demand and free flow capacity are compared. If demand exceeds free flow capacity the excess vehicles are stored in the vehicle queue. Delay time is determined based on the average number of vehicles in the queue for the one hour time interval and the queue service rate.

When the queue reaches a size such that delay time exceeds the delay threshold value, the use of the alternate route is activated. Vehicles are allocated to the alternate route to maintain the mainline queue at a size that will not result in the delay threshold being exceeded. The number of vehicles diverted to the alternate route is restricted by the available capacity on the alternate route and the maximum percentage of mainline traffic that will respond to the Smart Work Zone and divert to an alternate route.

Operating conditions and parameters for the travel time analysis were assumed as follows:

- Capacity of work zone 1200, 1300, or 1400 vehicles / hour
- Without Smart Work Zone, no use of alternate route
- Travel time through work zone under uncongested conditions is 10 minutes
- Travel time on alternate route is 20 minutes
- With Smart Work Zone, use of alternate route begins when delay exceeds 15 minutes

- When delay exceeds 15 minutes, traffic will use alternate route up to a maximum of 5 percent or 10 percent of mainline traffic
- Trucks represent 20 percent of traffic, and are adjusted using a passenger car equivalency factor of 1.7
- Daily traffic pattern follows a typical pattern based on traffic counts prior to the start of the construction project
- Alternate route capacity is sufficient to accommodate diverted traffic volume

A delay analysis was conducted for the scenario described above across a range of traffic volumes from 16000 to 22000 vehicles per day, under three different capacity conditions (1200, 1300 and 1400 vehicles per hour) and two alternate route use conditions (maximum diversion of five percent and ten percent). The results of this analysis are illustrated in Figure 7.

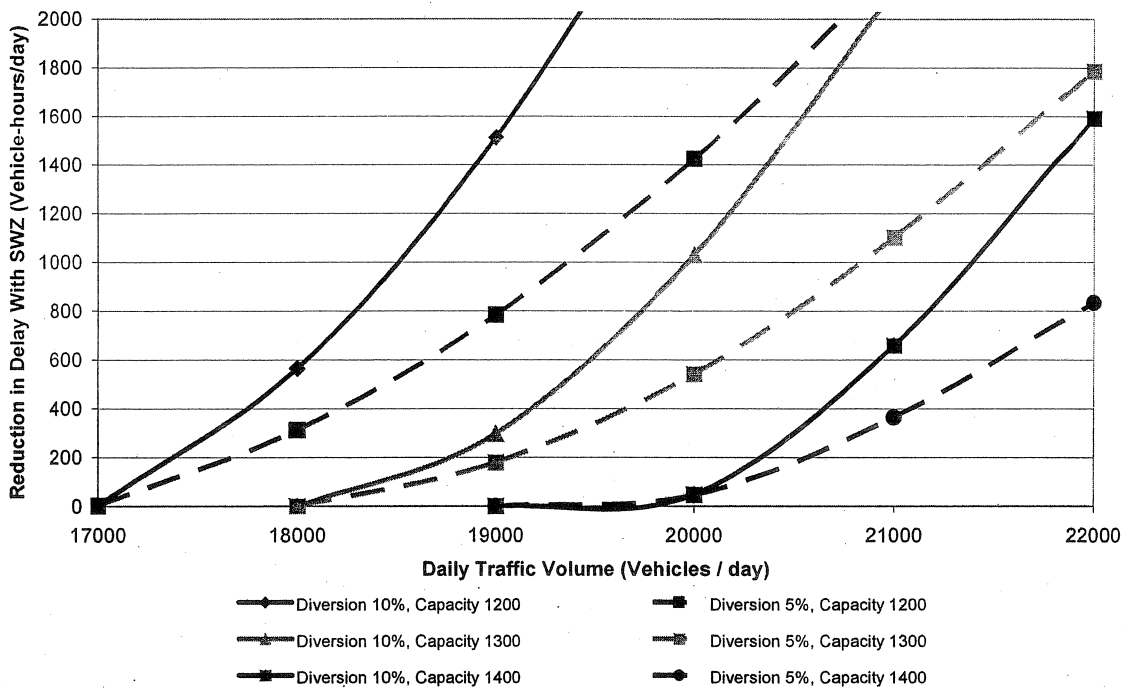


Figure 7 Estimated reduction in delay with Smart Work Zone in operation

Three pairs of curves are shown in Figure 7, each determined by the work zone capacity. In the case of a work zone capacity of 1200 vehicles / hour, congestion exceeding the 15 minute threshold begins to occur at a traffic volume of 17,000 and the Smart Work Zone begins to have an effect on traffic delay. For a capacity of 1200 vehicles, the effectiveness of the Smart Work Zone in reducing delay is limited by the allowable diversion rate. A higher expected maximum diversion rate results in more of the excess traffic demand being relieved via the alternate route and therefore the reduction in delay is greater. The diversion rate is not controlled by the system, but is based on the reaction of traffic to guidance messages provided by the system as discussed in Section 3.1.

As work zone capacity is increased, the traffic volume at which the Smart Work Zone begins to have an effect is also increased. A similar pair of curves is obtained for each capacity value, as the effectiveness of the system to deal with the excess demand is affected by the maximum diversion to the alternate route.

5.3 Queuing During Smart Work Zone Deployment

The extent of queuing that occurred at the two project sites was assessed based on data collected from the sensor trailers that were part of the Smart Work Zone. The extent of queuing was determined in terms of approximate physical distance from the taper area and the length of time that it was present on a daily basis.

The measure used to determine if congestion was occurring was the occupancy rate. Three sensor trailers collected occupancy data separately in each of the two lanes of travel. The exact physical positioning of the trailers changed frequently during the project and was not recorded in detail that would allow the distance between units to be determined. Typically, the trailers were positioned at the taper area, one mile upstream, and two miles upstream.

Occupancy is a measure of the amount of time that a vehicle was present in the detection zone. The percentage of time that a vehicle was present out of the total time interval is the occupancy for that time period. An occupancy of 15 percent was used as the

threshold for defining congested conditions. If the occupancy was 15 percent or higher in either lane one or two at the sensor location, congestion was considered to be present during the time interval.

5.3.1 Johnston County

Results of the queue analysis for Johnston County are presented in Appendix D, Figures D-1 to D-8. For each day of the month, the total accumulated time with occupancy exceeding the threshold is shown. The Smart Work Zone was not operated on weekends and therefore these days should not be considered. As well, there are days during the week when data was not available, either because the system was not operating these days, there were errors in the recording of the data, or the data was not recorded to the log-files. Weekends and days without data are indicated as “No Info” in the charts. The results from each month are summarized below in Table 3.

Table 3 Summary of high occupancy occurrence by month, Johnston County

Month	Days with valid data	Trailer 1, Days with > 1 hr	Trailer 1, Days with > 3 hr	Trailer 2, Days with > 1 hr	Trailer 2, Days with > 3 hr	Trailer 3, Days with > 1 hr	Trailer 3, Days with > 3 hr
March	20	2 10%	0 0%	2 10%	2 10%	6 30%	3 15%
April	20	2 10%	1 5%	4 20%	3 15%	7 35%	7 35%
May	12	0 0%	0 0%	1 8%	0 0%	4 33%	2 17%
June	17	0 0%	0 0%	1 6%	1 6%	10 59%	4 24%
July	14	0 0%	0 0%	1 7%	0 0%	2 14%	0 0%
August	19	0 0%	0 0%	1 5%	0 0%	0 0%	0 0%
September	19	0 0%	0 0%	0 0%	0 0%	3 16%	1 5%
October	17	0 0%	0 0%	0 0%	0 0%	2 12%	1 6%
Total	138	4 3%	1 1%	10 7%	6 4%	34 25%	18 13%

High occupancy at trailer 1 indicates the most severe congestion, as trailer 1 was positioned furthest upstream from the work area. Based on the available data, congestion at trailer 1 was rare, only occurring a few times in March and April. Mild levels of congestion, detected at Trailer 3 closest to the work area, were most frequent from March to June. During July and August the occurrence of congestion of any type being detected by the system was very infrequent.

Given that traffic volumes increased in July and August, it would be expected that occurrences of congestion should be most frequent in these months, but the data indicates the opposite occurred. There is no apparent reason for this, but there are several possible explanations:

- The increased traffic in July and August may be primarily recreational traffic that is distributed through out the day, so although the daily volume increases, the peak traffic volumes do not increase.
- The type of work being done or the configuration of lane closures and alternate routes may have been different in July and August and affected traffic flow in a different way.
- The system configuration may have changed. Typically, Trailer 1 was approximately two miles upstream, Trailer 2 was one mile upstream, and Trailer 3 was at the taper area. However, these distances varied and therefore may have affected the results.

5.3.2 Nash County

Results of the queue analysis for Johnston County are presented in Appendix D, Figures D-9 to D-15. For each day of the month, the total accumulated time with occupancy exceeding the threshold is shown. The Smart Work Zone was not operated on weekends and therefore these days should not be considered. As well, there are days during the week when data was not available, either because the system was not operating these days, there were errors in the recording of the data, or the data was not recorded to the log-files. Weekends and days without data are indicated as “No Info” in the charts. The results from each month are summarized below in Table 4.

The occurrence of severe congestion, indicated by high occupancy detected at Trailer1, was relatively rare over the duration of this project. Moderate levels of congestion, indicated by Trailer 2, occurred more frequently on this project than on the Johnston project. Mild congestion was also more frequent on this project. On almost half of the days for which valid data was available, at least one hour of high occupancy was detected and on over a third of these days the high occupancy condition existed for more than three hours. At this site congestion was experienced most frequently in the month of August with 71 percent of days experiencing some level of congestion. Congestion occurred least frequently in the months of May and June.

Table 4 Summary of high occupancy occurrence by month, Nash County

Month	Days with valid data	Trailer 1, Days with > 1 hr	Trailer 1, Days with > 3 hr	Trailer 2, Days with > 1 hr	Trailer 2, Days with > 3 hr	Trailer 3, Days with > 1 hr	Trailer 3, Days with > 3 hr
May	20	1 5%	0 0%	3 15%	1 5%	6 30%	5 25%
June	18	1 6%	1 6%	2 11%	2 11%	5 28%	4 22%
July	18	0 0%	0 0%	2 11%	1 6%	9 50%	5 28%
August	21	0 0%	0 0%	9 43%	5 24%	15 71%	13 62%
September	5	0 0%	0 0%	0 0%	0 0%	2 40%	2 40%
October	15	1 7%	1 7%	6 40%	2 13%	8 53%	8 53%
November	5	0 0%	0 0%	0 0%	0 0%	2 40%	0 0%
Total	102	3 3%	2 2%	22 22%	11 11%	47 46%	37 36%

6. User Acceptance

One of the primary purposes of the Smart Work Zone deployment is to communicate with motorists and assist them in driving safely and making informed travel decisions. To gain an understanding of the views of motorists on the performance and value of a Smart Work Zone, several surveys were conducted. Three motorist groups were targeted in the survey process; local residents, local trucking companies, and out of State travelers. In addition, feedback was received from the Resident Engineers that were responsible for the projects on which the Smart Work Zones were deployed.

6.1 Local Resident Survey

In the vicinity of the two construction projects are the communities of Smithfield and Rocky Mount. 1486 local residents were selected to participate in the survey, with the only criteria being residence in one of the two communities. Frequency of travel was determined from survey responses. No further separation of respondents was made, such as age, gender, experience, or other factors.

Survey participants received a mail-out survey within two months after the conclusion of the construction projects. The survey package included a cover letter on NCDOT letterhead from the Director of Construction asking for the recipient's participation in the survey, a brief description of the system and its use during the 2003 construction season and a one page survey with 11 multiple choice response questions. A copy of the material mailed to motorists is provided in Appendix E. A postage paid return envelope addressed to NCDOT was also included. 333 surveys were completed and returned, a response rate of 22.7 percent.

The survey contained two types of questions. Some questions were used to determine characteristics of the motorist such as the frequency of their travel through the work zone, their access to the internet, and their awareness of a travel information website. Other questions were used to determine perceptions, response, and opinions regarding the travel information system. Responses to survey questions one to five are presented in Table 5.

Table 5 Results of survey sent to local residents in Rocky Mount and Smithfield vicinity: Questions 1-5.

1. During the period of April to October 2003 work zones were located on I-95 near Smithfield and Rocky Mount. Which of the following best describes how often you drove through the area of one of these work zones? (332)	Several or many times per week	Several times per month	Once per month or less	Never	
	11.7 %	29.8 %	47.9 %	10.5 %	
2. Do you remember seeing the changeable message signs which provided information about expected delays and alternate routes? (296)			Yes	No	
			90.9 %	9.1 %	
	2.a. Travel Frequency: Several or many times per week (39)		94.9 %	5.1 %	
	2.b. Travel Frequency: Several times per month (99)		96.0 %	4.0 %	
2.c. Travel Frequency: Once per month or less (158)		86.7 %	13.3 %		
3. Did you know or perceive that the sign messages were based on current traffic condition information rather than pre-programmed messages? (262)			Yes	No	
			80.9 %	19.1 %	
	3.a. Travel Frequency: Several or many times per week (36)		91.7 %	8.3 %	
	3.b. Travel Frequency: Several times per month (93)		79.6 %	20.4 %	
3.c. Travel Frequency: Once per month or less (133)		78.9 %	21.1 %		
4. Based on your driving experience through these work zones, do you feel the delay information presented on the signs was accurate and reliable? (263)	Always accurate	Sometimes accurate	Seldom accurate	Never accurate	
	42.6 %	54.4 %	3.0 %	0.0 %	
	4.a. Travel Frequency: Several or many times per week (37)	51.4 %	48.6 %	0.0 %	0.0 %
	4.b. Travel Frequency: Several times per month (94)	30.9 %	66.0 %	3.2 %	0.0 %
4.c. Travel Frequency: Once per month or less (132)	48.5 %	47.7 %	3.8 %	0.0 %	
5. When a delay advisory was shown on the changeable message signs, did this information influence your decision whether to choose an alternate route to avoid the area of the work zone? (264)	Often	Sometimes	Seldom	Never	
	26.1 %	41.7 %	17.4 %	14.8 %	
	5.a. Travel Frequency: Several or many times per week (37)	40.5 %	45.9 %	13.5 %	0.0 %
	5.b. Travel Frequency: Several times per month (94)	27.7 %	43.6 %	17.0 %	11.7 %
5.c. Travel Frequency: Once per month or less (133)	21.1 %	39.1 %	18.8 %	21.1 %	

* Number in brackets indicates number of survey responses meeting criteria

Question 1 determined the frequency of travel of survey respondents through the area of the work zone. Interstate 95 is not a regular commuter route for many of the residents of this area, as only 11.7 percent of respondents indicated using the route several or many times per week. The majority of respondents indicated traveling the route either several times per month (29.8 percent) or once per month or less (47.9 percent). Surveys returned from residents who never traveled through the area of the work zone were 10.5 percent of the total surveys returned. In addition to providing some indication of local travel patterns, responses to question 1 will be used in breaking down responses to other questions according to frequency of travel. Through the remainder of the discussion, respondents will be categorized based on the frequency of travel as frequent, occasional, and infrequent.

Question 2 asked motorists if they remembered seeing the changeable message signs as they travelled through the work zone. For this question, respondents who had indicated never traveling through the work zone were excluded. 90.9 percent of respondents indicated they remembered seeing the signs. The percentage of respondents recalling seeing the signs was similar for frequent (94.9 percent) and occasional (96.0 percent) travellers, but dropped off slightly for infrequent (86.7 percent) travellers.

The purpose of question 3 was to determine if motorists realized that they were observing a real-time information system as opposed to pre-programmed messages that they might see at other construction sites. For this question, those respondents who indicated never travelling through the work zone and those indicating not remembering seeing the signs were excluded. This same subset was also used for analyzing responses to questions 4 through 9. When the whole subset was considered, 80.9 percent indicated that they realized this was a real-time information system. Frequent motorists (91.7 percent) were more likely to recognize that the system was based on current traffic information than occasional (79.6 percent) and infrequent (78.9 percent) motorists.

Question 4 dealt with the perceived accuracy of the system. The system was classified as always accurate by 42.6 percent of respondents, sometimes accurate by 54.4 percent of

respondents, and seldom accurate by 3.0 percent of respondents. The frequent users perceived the system as being more accurate than the occasional and infrequent users. Of the frequent users, who would have more experience with the system on which to base their judgment, 51.4 percent indicated the system was always accurate, 48.6 percent sometimes accurate and no respondents indicated seldom or never accurate.

Question 5 addressed the influence of the system on route choice. Frequent travelers were highly likely to be influenced by the system, with 40.5 percent indicating they were often influenced and another 45.9 percent indicating they were sometimes influenced, which combined includes 86.4 percent of frequent travelers. This is noticeably higher than the occasional (70.3 percent) and infrequent (60.2 percent) travelers who indicated being influenced sometimes or often. Considering the results of question 3, 4 and 5 together, the results suggest that as motorists realized the system was providing real-time information to them and gained trust in the accuracy of the information, the system had a greater influence on the travel choices.

Responses to survey questions 6 to 11 are presented in Table 6. Question 6 asked motorists if they were able to read and understand the messages presented by the system. In all categories the ability to read and understand the message was near 100 percent, with the lowest response being 98.5 percent.

In addition to the roadside message signs, a travel information website was also available where motorists could check the current status of traffic at the work zone. Responses to question 7 indicated that 75.4 percent of motorists had convenient access to the internet. This information was used in breaking down the responses to question 8 and 9.

When asked in question 8 if they were aware a website existed to obtain travel information only 15.7 percent of respondents indicated they were aware of the travel information website. An unexpected result was that more respondents without internet access (26.2 percent) indicated they were aware of the website than respondents with internet access (12.4 percent).

Table 6 Results of survey sent to local residents in Rocky Mount and Smithfield vicinity: Questions 6-11.

			Yes	No
6. Were you able to read the messages on the signs and understand their meaning? (268)			98.9 %	1.1 %
6.a. Travel Frequency: Several or many times per week (37)			100.0 %	0.0 %
6.b. Travel Frequency: Several times per month (94)			98.9 %	1.1 %
6.c. Travel Frequency: Once per month or less (137)			98.5 %	1.5 %
7. Do you have convenient access to the internet, such as at home or in your workplace? (268)			Yes	No
			75.4 %	24.6 %
8. Were you aware a website was available where information on current traffic conditions and delays on these specific projects could be obtained? (267)			Yes	No
			15.7 %	84.3 %
8.a. Internet access (202)			12.4 %	87.6 %
8.b. No Internet access (65)			26.2 %	73.8 %
9. How often did you check this website before making a trip through the area of the work zone? (259)	Often	Sometimes	Seldom	Never
	0.4 %	1.5 %	5.0 %	93.1 %
9.a. Internet access (193)	0.5 %	2.1 %	4.7 %	92.7 %
9.b. Access and aware of website (25)	4.0 %	16.0 %	28.0 %	52.0 %
10. Did you ever alter the start of your travel by more than one hour in an attempt to avoid delays on I-95? (290)	Often	Sometimes	Seldom	Never
	7.2 %	16.6 %	16.6 %	59.7 %
10.a. Travel Frequency: Several or many times per week (39)	5.1 %	10.3 %	20.5 %	64.1 %
10.b. Travel Frequency: Several times per month (97)	6.2 %	20.6 %	20.6 %	59.7 %
10.c. Travel Frequency: Once per month or less (154)	8.4 %	15.6 %	13.0 %	63.0 %
11. Do you think NCDOT should continue to deploy more of these kinds of systems in the future to keep travellers informed of current conditions? (317)			Yes	No
			95.3	4.7
11.a. Travel Frequency: Several or many times per week (38)			100.0 %	0.0 %
11.b. Travel Frequency: Several times per month (95)			96.8 %	3.2 %
11.c. Travel Frequency: Once per month or less (155)			92.9 %	7.1 %
11.d. Travel Frequency: Never or no response (28)			96.4 %	3.6 %
11.d. Travel Frequency: Never (27)			96.3 %	3.7 %
11.e. Information always accurate (110)			96.3 %	3.7 %
11.f. Information sometimes accurate (140)			97.1 %	2.9 %
11.g. Information seldom accurate (9)			77.8 %	22.2 %

* Number in brackets indicates number of survey responses meeting criteria

The subject of question 9 was the amount of use that respondents made of the travel information website. It was indicated by 93.1 percent of respondents that they never used the website. When those without convenient internet access were removed from consideration, the percentage never using the website only decreased slightly to 92.7percent.

Until motorists are aware that the website information is actually available and they have a way to access that information, they can not really be considered as potential users. When only potential users, those who were aware of the travel information website's existence and had convenient internet access, are considered the rate of usage shifts considerably. The percentage of respondents never using the website decreased from over 90 percent of all respondents to 52.0 percent when only potential users are considered. In the group of potential users, 4.0 percent used the website often, 16.0 percent sometimes and 28.0 percent seldom checked the website.

Question 10 is a more general question regarding the alteration of trip planning by changing departure time. The response is not necessarily directly related to the presence of the information system, although the website could influence the decision making process. When a traffic disruption is known to exist, such as a lane closure in a work zone, some motorists will choose to change their travel plans to avoid periods of expected delay. The amount of travel time shifting will affect traffic demand at the work zone and change the amount of delay experienced by motorists. Estimates of expected delay that take into account travel time shifting may be more accurate, therefore it is useful to have an indication of how much travel time shifting occurs.

Any motorist that travelled through the work zone could have shifted travel time without actually having seen the roadside signs. Therefore question 10 is based on all respondents except those that never travelled through the work zone. Travel time shifting was used often (7.2 percent) and sometimes (16.6 percent) by 23.8 percent of motorists. Time shifting often or sometimes was only indicated by 15.4 percent of frequent travellers, which is less than the amount of time shifting by occasional (26.8 percent) and

infrequent (24.0 percent) users. It may be that the frequent travelers represent more work related trips with less flexibility while the occasional and infrequent trips are more personal with greater flexibility in timing.

The final question was a summary question to determine, all things considered, whether respondents felt that NCDOT should continue deploying real-time information systems. Since this was a policy question all survey responses were considered including those who had never travelled through the work zone. NCDOT should continue to use systems of this type according to 95.3 percent of survey respondents. The frequent travelers, who had the most exposure to the system, were 100 percent in favor of NCDOT deploying more systems of this type. Support was slightly less but still very high for other motorist groups as well, with 96.8 percent of occasional and 92.9 percent of infrequent users supporting future use. Also of interest was the effect of perceived system performance on support for future use. Respondents who felt the system was sometimes accurate or always accurate indicated more than 96 percent support for future use of the system. When system accuracy was perceived as seldom accurate support for future deployment dropped to 77.8 percent. Referring back to question 4, it was only 3.0 percent of respondents that felt the system was seldom accurate.

Overall, the reaction of local residents to the efforts of NCDOT was highly positive with more than 95 percent supporting future projects of this type. Perceptions of system accuracy and the usefulness of the information to influence travel decisions were positive, especially for frequent travelers through the work zone. All responses from frequent travelers indicated that the system was either sometimes accurate or always accurate. The travel information website which provided motorists with the opportunity to check conditions prior to beginning a trip appears to be under utilized with more than 93 percent of respondents never using it. Based on the survey responses, the lack of website usage appears to be primarily due to a lack of awareness and accessibility. Motorists who were aware of the website and had access to the internet made moderate use of this service.

6.2 Trucking Industry Survey

Since the trucking industry may have different needs and travel patterns than the typical motorist, a separate survey was mailed to 32 truck transport companies with operations located near the communities of Smithfield and Rocky Mount. Survey participants received a mail-out survey within two months after the conclusion of the construction projects. The survey package included a cover letter on NCDOT letterhead from the Director of Construction asking for the recipient's participation in the survey, a brief description of the system and its use during the 2003 construction season and a one page survey with 11 multiple choice response questions. The questions were similar in scope to those used for the motorist survey. A copy of the material mailed to the trucking industry is provided in Appendix E. A postage paid return envelope addressed to NCDOT was also included. Seven surveys were completed and returned, a response rate of 21.9 percent.

Results of the survey are presented in Table 7. The limited number of responses should be taken into account when considering the significance of the results. Due to the low number of responses, it was not feasible to break down the results further beyond the initial questions as was done for the motorist survey.

Question 1 determined the frequency of travel of trucks from the company of the survey respondents through the area of the work zone. 14.3 percent of respondents indicated trucks travelled through the work zones several or many times per day, while the remaining 85.7 percent indicated travelling through several times per week.

Question 2 asked motorists if they remembered seeing the changeable message signs as they travelled through the work zone. 100 percent of respondents indicated they remembered seeing the signs.

Table 7 Results of survey to trucking companies in Rocky Mount and Smithfield vicinity

1. During the period of April to October 2003, work zones were located on I-95 near Smithfield and Rocky Mount. Which of the following best describes how often trucks from your company drove through the area of one of these work zones? (7)	Several or many times per day	Several times per week	Once per week or less	Never
	14.3 %	85.7 %	0.0 %	0.0 %
2. Do you remember seeing the changeable message signs which provided messages about expected delays and alternate routes? (7)			Yes	No
			100.0 %	0.0 %
3. Did you know or perceive that the sign messages were based on current traffic condition information rather than pre-programmed messages? (7)			Yes	No
			71.4 %	28.6 %
4. Based on your driving experience through these work zones, do you feel the delay information presented on the signs was accurate and reliable? (7)	Always accurate	Sometimes accurate	Seldom accurate	Never accurate
	28.6 %	57.1 %	14.3 %	0.0 %
5. When a delay advisory was shown on the changeable message signs, did this information influence your decision whether to choose an alternate route to avoid the area of the work zone? (6)	Often	Sometimes	Seldom	Never
	16.7 %	83.3 %	%	%
6. Were you able to read the messages on the signs and understand their meaning? (7)			Yes	No
			100.0 %	0.0 %
7. Do you have convenient access to the internet, such as at home or in your workplace? (7)			Yes	No
			71.4 %	28.6 %
8. Were you aware a website was available where information on current traffic conditions and delays on these specific projects could be obtained? (7)			Yes	No
			42.9 %	57.1 %
9. How often did you check this website before making a trip through the area of the work zone? (7)	Often	Sometimes	Seldom	Never
	0.0 %	28.6 %	14.3 %	57.1 %
10. Did you ever alter the start of your travel by more than one hour in an attempt to avoid delays on I-95? (7)	Often	Sometimes	Seldom	Never
	14.3 %	85.7 %	0.0 %	0.0 %
11. Do you think NCDOT should continue to deploy more of these kinds of systems in the future to keep travellers informed of current conditions? (7)			Yes	No
			100.0 %	0.0 %

* Number in brackets indicates number of survey responses meeting criteria

The purpose of question 3 was to determine if drivers realized that they were observing a real-time information system as opposed to pre-programmed messages that they might see at other construction sites. 71.4 percent indicated that they realized this was a real-time information system while the remaining 28.6 percent did not.

Question 4 dealt with the perceived accuracy of the system. The system was classified as always accurate by 28.6 percent of respondents, sometimes accurate by 57.1 percent of respondents, and seldom accurate by 14.3 percent of respondents.

Question 5 addressed the influence of delay advisories provided by the system on route choice. 16.7 percent of respondents indicated decisions were often influenced by the system while the other 83.3 percent of respondents were sometimes influenced by delay advisory messages.

Question 6 asked if the driver was able to read and understand the messages presented by the system. All respondents indicated they were able to read and understand the message.

In addition to the roadside message signs, a travel information website was also available where motorists could check the current status of traffic at the work zone. Responses to question 7 indicated that 71.4 percent of respondents had convenient access to the internet.

When asked in question 8 if they were aware a website existed to obtain travel information 42.9 percent of respondents indicated they were aware of the travel information website. The website awareness in the trucking companies was almost three times higher than the 15.7 percent of local residents that were aware of the website.

The subject of question 9 was the amount of use that respondents made of the travel information website. The website was checked sometimes by 28.6 percent and seldom by 14.3 percent. It was indicated by 57.1 percent of respondents that they never used the website. However, it should be noted that all of the respondents that never checked the

website had also indicated that they were not aware of the website, so could not be expected to have used the website.

Question 10 is a more general question regarding the alteration of trip planning by changing departure time. The response is not necessarily directly related to the presence of the information system, although the website could influence the decision making process. When a traffic disruption is known to exist, such as a lane closure in a work zone, some motorists will choose to change their travel plans to avoid periods of expected delay. The amount of travel time shifting will affect traffic demand at the work zone and change the amount of delay experienced by motorists. Estimates of expected delay that take into account travel time shifting may be more accurate, therefore it is useful to have an indication of how much travel time shifting occurs. Travel time shifting was indicated as either used often (14.3 percent) or sometimes (85.7 percent) by all of the trucking company responses received.

The final question was a summary question to determine, all things considered, whether respondents felt that NCDOT should continue deploying real-time information systems. All respondents indicated that they were in favour of continued deployment of travel information systems at work zones.

Overall, the reaction of local trucking companies to the efforts of NCDOT was highly positive with 100 percent supporting future projects of this type. Perceptions of system accuracy and the usefulness of the information to influence travel decisions were positive as well. As with the motorists, the travel information website was not utilized to its full extent by the trucking companies.

6.3 Roadside Survey

The two mail-out surveys were targeted to obtain feed-back from local residents. In addition to the mail-out survey, a road-side survey was conducted to obtain feed-back directly from road users that had just exited the work-zone. The survey was conducted at a rest area located just downstream of the Nash County work zone area at a point at which alternate route traffic had rejoined the Interstate.

The responses of motorists surveyed at the rest area to questions related to the Smart Work Zone are shown in Table 8. As with the trucking company survey, the number of responses is relatively small and this should be taken into account when considering the significance of the results.

Table 8 Results of roadside survey conducted October 2003 at Nash County rest area

	Yes	No
Did you take a detour route to avoid the construction on I-95? (11)	36.4 %	63.6 %
NCDOT has installed a system to measure current traffic conditions and provide messages to drivers before they reach the work area, advising drivers of expected delay and use of alternate routes. Did you notice several trailer mounted signs on the shoulder of the road as you approached the work zone? (11)	90.9 %	9.1 %
What was the message on the signs, as you remember it? (Yes indicates that respondent correctly identified message content) (10)	100.0 %	0.0 %
Did you consider the message on the sign to be relevant, accurate, and up to date? (9)	88.9 %	11.1 %
Did you know construction would be taking place on this section of I-95 before you started your trip? (10)	40.0 %	60.0 %
Do you think NCDOT should deploy more systems of this type to keep travelers informed of current conditions? (10)	90.0 %	10.0 %

* Number in brackets indicates number of survey responses meeting criteria

All of the motorists were asked to identify the origin and destination of the current trip that they were on. For all survey participants the origin of their trip was outside North Carolina and only two had a final destination located in North Carolina. This survey represents a distinctly different sector of road users than the mail-out surveys which targeted local residents.

The detour route was used by 36 percent of the drivers surveyed, while 64 percent chose to remain on Interstate 95 and drive through the work zone. When asked if they noticed the trailer mounted message signs on the road shoulder, 91 percent indicated they had noticed the signs.

The survey was conducted during a time period when the message signs were posting a delay message. When asked to identify the message they had seen, all of the survey respondents were able to identify the general content of the message.

Regarding the accuracy of the information provided, 89 percent felt that the information was relevant and accurate to the current situation.

Although most of the survey participants were not regular travelers of this highway, 40 percent did indicate that they were aware that construction was taking place in the area of the work zone prior to starting their trip. The survey was conducted in October 2003 and the construction project began in March 2003, so even infrequent travelers had passed through the work zone before.

On the final question of whether to deploy more systems of this type, 90 percent of participants supported future deployment. Only one participant was against future deployment and this was because he saw problems as being due to poor driver behavior, such as late lane changes, which would not be improved by more signing.

6.4 Resident Engineer Feedback

In October of 2003, as the construction projects with the Smart Work Zone were nearing completion, interviews were conducted with the resident engineer in charge of each project. A summary of the discussion is provided in the following sections. The resident engineer is involved in the overall construction project on a daily basis and therefore has frequent experience with the operation of the Smart Work Zone.

6.4.1 Johnston County Project

Overall the system was effective in assisting to manage traffic and reduce queues in relation to the work zone and it is recommended for continued deployment on projects of this type. Queues still developed when lane closure in place, but the length of the queues appeared to be shorter than on similar projects where the system had not been used.

The alternate routes had no significant problems in dealing with the additional traffic volume created by diverting traffic off I-95. The only occurrence of serious traffic issues on the alternate routes was when an accident forced the closure of the entire southbound direction. In this case troopers and DOT personnel needed to assist with traffic management. The presence of the Smart Work Zone system allowed DOT to react quickly and efficiently to this incident. The detour route was already in place and the signing was used to divert traffic around the stoppage for a period of 4-5 hours. Without the system the backups would have been much worse.

Unfortunately there was one fatality that occurred while the Smartzone was in place. The signs were active, advising of a short delay, but the accident was caused by speeding and inattention as a car rear-ended the back of a truck.

Coordination of scheduling and system setup and relocation was a challenge as the Smartzone was not a part of the main construction contract. Therefore the prime contractor did not have a vested interest in the implementation and operation of the system. This was compounded by poor weather during the construction season which caused delays, schedule changes, and numerous changes in the work location by the contractor. Keeping up with these frequent moves required an intensive effort from the support technician. Having the Smartzone included as part of the paving project would address some of these issues.

Additional information that would be useful from a management point of view would be the volumes of traffic measured and speeds measured by the system on a historic basis.

6.4.2 Nash County Project

There was skepticism at first when this project was discussed. It was feared that there would be no benefit from the system, and that it would be difficult to manage and maneuver, and that it would get in the way of completing the project. However, once the system was operational it was found to be a good tool for traffic management.

The most important thing from a construction workers perspective is to slow drivers down and reduce the amount of accidents as drivers approach the end of a queue. To do this, signing that is relevant will get the desired reactions. During this project there were no traffic fatalities, when a project of this size and duration would have been expected to have 1 or 2. Although no hard numbers are available, it was felt that the number and severity of crashes were reduced.

There were accuracy issues noted, not because of the operation of the system but because of the logistics of the operation. The project was fast moving which meant frequent moves of the lane closure. With the technical support available, it was not possible to relocate the system quickly enough to keep up with the moving operation. One solution would be to increase the number of sensors in the system so that the entire stretch where closures are taking place is covered. As the work moves, the trailers would already be in position. This would also address another issue. The lane closure could be 2-3 miles long. If the workers were at the downstream end of the closure, queuing might begin there. Several miles of backup could go undetected since the first sensor trailer was located at the taper. The system was adjusted to react more quickly and respond even to a slow down at the taper area. Care should be taken to make sure that times shown on the signs are as accurate as possible (update every minute) and that an upstream sign does not show a time later than a downstream sign.

Administering the project as a State contract through Raleigh rather than as a purchase order through the division would assist in managing the invoicing and payment, as Raleigh is better equipped for processing and payment. The pay scheme and

requirements should be set out more clearly in the contract, such as how many days and which days are payable for website operation and technician support.

Having the Smartzone system as a separate contract not included in the prime contract for road work created some management issues. The prime contractor had no interest in the success of the Smartzone system and may have perceived it as an inconvenience that got in the way of his progress on the project. If it was part of his contract, he would have a vested interest in ensuring that the system was relocated and operational in a timely manner and would ensure proper communication to this end.

Spare message boards, or at least spare key parts, available on site would be helpful in reducing down time due to vandalism or lightning strikes. Vandalism problems were less than anticipated.

There is a need to be able to edit and display over-ride messages on the boards in a very quick manner. It was not clear how this could be achieved when the technician was not available, so the system was sometimes turned off. Pagers were not found useful in their current form as they went off too frequently. They would be helpful if they provided information only on significant conditions such as complete failure of a sign or extreme backups occurring.

Before deploying, the location and setting needs to be considered. Johnston County is a semi-urban setting and a back-up on the freeway very quickly impacts the surrounding street network. However, drivers on the freeway have more options to escape from queues since exits are much more frequent. In Nash County, a rural setting, exits are 4 to 6 miles apart so once driver's get in the queue there are no more options for escape.

Local traffic was observed to make good use of the system and quickly responded to delay messages to seek alternate routes. Commercial vehicles also reacted well to the presence of the system. Drivers were most responsive when there was a delay message and they could actually physically see the queue. The increased number of message

boards and their relevance to the current situation increased the awareness with drivers more than static signing.

Cameras would have been helpful in monitoring current conditions at the site. The ability to integrate and communicate with the State-wide system, including freeway message signs, would be helpful during severe back-up conditions. Also, a simple and easy way for the on-site inspector to control sign messages under special circumstances would be helpful.

7. Project Analysis Framework

One of the objectives of this study was to develop a framework for determining the suitability of Smart Work Zone technology for a specific project. When transportation infrastructure projects such as road construction, road maintenance, and bridge construction and maintenance are being considered there is well documented historic information on which to base the analysis. With ITS projects, especially Smart Work Zones, the history of benefit and cost data is limited. Progress is being made in this regard, as available information from ITS projects is gathered and made available through the FHWA ITS benefit / Cost database (US DOT, 2004).

The evaluation of an ITS project will require a combined approach utilizing historical information and modeling and prediction of unknown parameters. Where it is available, historical and research data from previous projects should be drawn upon. The data and analysis performed under this study adds to the body of research that can be drawn upon for future projects. However, given limited experience and evaluation of projects of this type, other methods will also be required. The use of models including simulation models is one approach to fill in the required information that is not otherwise available. Modeling has limitations and requires assumptions to be made which may affect the outcome of the analysis. The assumptions and limitations of the analysis should be understood and discussed in the evaluation (Gillen, 1999). With the lack of historic information there will also be an element of uncertainty involved in the analysis which should be facilitated to allow comparison over the range of possibilities. Uncertainty can be dealt with by applying risk analysis, using a probabilistic approach, or by performing a sensitivity analysis of the results (Ozbay, 2004)

A variety of potential costs and benefits that may result from a transportation project have been identified. The costs and benefits vary depending on the purpose, approach and project. A listing of benefits and costs that may be relevant for a Smart Work Zone project is given in Table 9 below, categorized into Agency, User and Society. Some of the items listed may actually cross the category boundaries, and may be either a benefit or

a cost depending on the specifics of the application. Some evaluation approaches have attempted to monetize most or all of the benefits and costs of a project, while others treat many of the factors in a subjective and qualitative manner. This is addressed in the model formulation.

Table 9 Potential benefits and costs associated with a Smart Work Zone deployment

Agency	User	Society
Construction efficiency	Travel time delay	Air pollution
Construction schedule flexibility	Travel time variability	Noise pollution
Public relations	Vehicle operating costs	Alternate route congestion
Incident management / mitigation	Driver aggressiveness reduction	Business/economy impact
Benefits to other agencies	Fatal crash reduction	
Worker safety	Injury and property crash reduction	
Project management		
Data collection		
Right of way requirements		
Future innovation		

(Al-Kaisy, A., 2004, Transport Canada, 1994, Kratofil, 2001, Jiang, 2003)

The current approach to Smart Work Zone deployment has been for the agency to pay for the provision of the services from a vendor or contractor on a daily or monthly usage basis without the agency purchasing or owning any equipment. Since the agency will own no equipment at the end of the project, and benefits are received during the actual time of deployment, the time value of money is not a significant factor in assessing this type of project. Since all of the significant benefits and costs are accrued at the time of deployment the pay-back period and internal rate of return are not meaningful for the evaluation of a Smart Work Zone.

Guidelines for evaluation of transportation projects provided through the National Cooperative Highway Research Program (NCHRP) also provide relevant background for determining an evaluation approach. If the broad range of effects of a project are to be considered, attempting to combine them all into a single cumulative index or measure is discouraged. Relatively well-established methods exist for estimating effects, in economic terms, of changes in travel time, safety, and vehicle operating costs. However, attempting to convert all effects into monetary units should be avoided (Forkenbrock and Weisbrod, 2001).

Many evaluations of transportation projects, including ITS, have been based on some form of a Benefit Cost Analysis (BCA). This has been supported as a valid means of evaluation of ITS projects by most researchers. Although a specialized form of transportation system, it is contended that ITS projects must still compete with more traditional construction projects for limited resources. In order to support and justify an ITS project and secure funding there must be some evidence provided that it will provide favourable results in comparison to competing alternatives (Gillen and Dahlgren, 1999). In the scope of this study, the analysis is restricted to a comparison with the do-nothing option, but in reality a candidate project, even if beneficial, will need to be compared with other projects.

Two issues arise with attempting to use a BCA as the decision making method in the case of Smart Work Zones. First, not all costs and benefits lend themselves to a monetary quantification, which is necessary for a benefit/cost comparison. Second, there is limited available experience and research into the benefits of work zone ITS, and therefore it is difficult to predict with certainty the benefits that will be realized.

Of the potential costs and benefits identified only the agency cost can be measured directly in hard dollars. User delay and vehicle operating costs are often assigned a monetary value, but the benefits are attributed to road users and not to the agency. Although there may be economic effects, the other benefits and costs are not directly monetary in nature. Since BCA has been established as a common evaluation method for

transportation projects, monetary values and guidelines have been established for some of the key objectives. For example, the Federal Highway Administration has established guidelines for the value of a statistical life to be used in assigning a value to safety improvements (FHWA, 1994). Likewise, agencies have established guidelines for the value of user delay and crashes of varying severity.

The United States Department of Transportation (USDOT) uses the Highway Economic Requirements System (HERS) Model for assessment of transportation investments. The HERS model estimates three types of direct highway user benefits which can be quantified in monetary terms: 1) travel time savings, 2) vehicle operating costs and 3) safety effects (Hodge, Buxbaum, Stewart, and Hand, 2004).

ITS also has potential benefits that are difficult to quantify and where established guidelines do not exist. For example, a successful Smart Work Zone project could have benefits not directly related to the project itself. The responsible transportation agency may gain a benefit in good will and a perception from road users as being progressive and concerned with motorist needs by deploying new technology. On the other hand, an unsuccessful ITS project may be viewed as a waste of tax-payers money when it could have been spent on roads, health care or education instead. The increased publicity drawn to work zone issues and awareness of motorists may improve the safety of drivers at other sites as well. As well, there may be more significant benefits that will be realized from ITS in the future as technology develops and the scale of deployment increases, but that future potential can only be realized by deploying systems that are currently available.

7.1 Decision Approach and Model Structure

Several alternatives were considered in determining the measures and format of the decision making model. As the decision is whether to allocate additional funds to deploy a Smart Work Zone, some form of economic analysis is required. An appropriate model must also deal with the reality that there is little historical data on which to base the decision. Based on the objectives for the application of the model, it is not practical to

explicitly quantify all the potential benefits and costs in a monetary form. However, for the model to be comprehensive an assessment of all potential benefits and costs should be facilitated in the model. To achieve the required results, a two stage evaluation process was developed as illustrated in Figure 8.

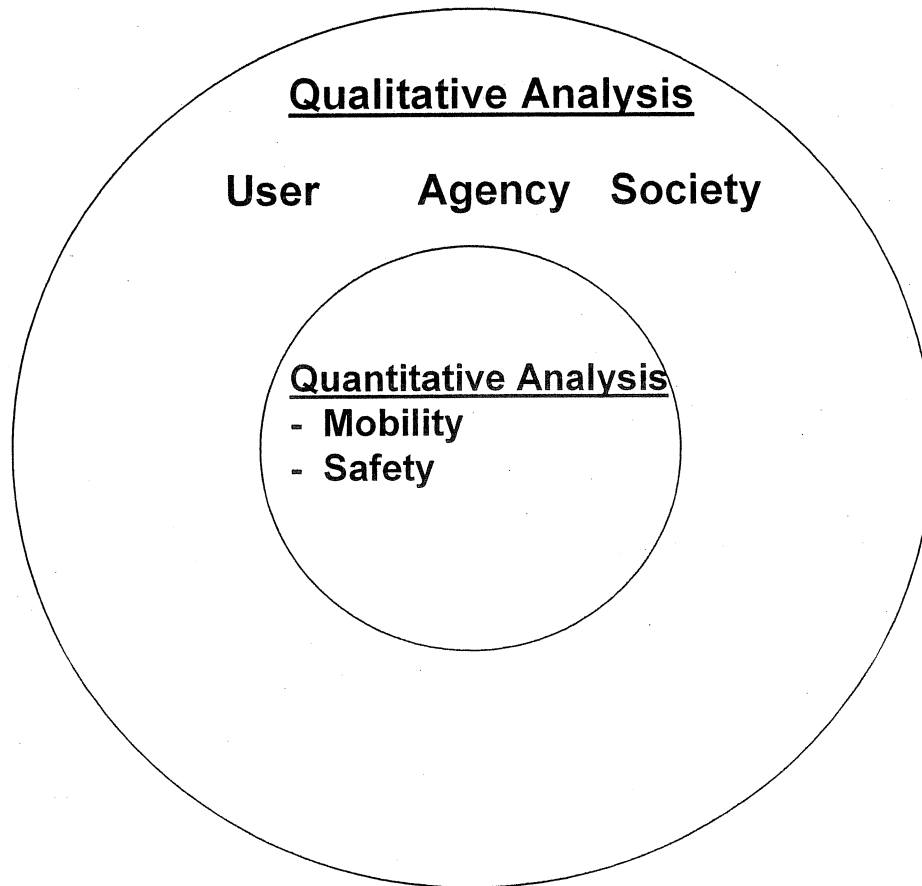


Figure 8 Qualitative and quantitative analysis process

The first stage of the evaluation is an overall qualitative analysis of all the expected benefits and costs associated with the project. The first stage is comprehensive and considers agency, user, and society factors. The second stage of the evaluation deals with the costs and benefits expected to be most significant on common projects and for which some established approaches and values for monetization exist. If the first stage analysis reveals an important cost or benefit that is not considered in the second stage, then a further investigation can be considered. Where multiple projects are being considered,

both the qualitative and quantitative analysis can be brought together for comparison. The two part evaluation ensures that all potential benefits and costs, as identified earlier in Table 9, are considered.

7.2 Qualitative Analysis

The qualitative analysis addresses all the effects that may result from deployment of a Smart Work Zone. Potential benefits and costs experienced by road users, the transportation agency, and society are included in the impact analysis model. The analysis can easily be expanded to take into consideration other effects of deploying a Smart Work Zone.

At this stage all effects are rated subjectively even if there are some measures of effectiveness that could be applied to them. The purpose of this stage is to consider all aspects of the project and identify areas of greatest concern or benefit and the overall perceived value of the project under consideration. The qualitative analysis may identify requirements for further investigation and quantification of expected results. The quantitative analysis developed in this study can be used to address some of the most commonly considered costs and benefits. It is not possible to cover all scenarios in a single model, therefore additional methods may need to be developed for analysis of costs and benefits which are not explicitly covered by this research. The qualitative analysis follows a general method that has been applied for such decisions as infrastructure development (City of Saskatoon, 1993) and the use of night time road closures for construction work (Al-Kaisy, 2004).

The first step in the impact assessment is to weight the importance of each of the benefits and costs. Each item is assigned its own value based on the priorities and objectives of the agency on a scale of zero to five, with five representing the highest importance. For example, an agency with an extensive data collection program may place a low value on data collection, while an agency with a minimal data collection program may place a high value on the need for traffic data. If several Smart Work Zone projects are to be

compared with each other, the weighting scheme should remain consistent across all projects.

The second step is to subjectively assess the impact of deploying a Smart Work Zone system for each benefit or cost on a scale from minus three to plus three. Minus three represents a severe negative impact, such as the noise pollution created by diverting a large volume of traffic through a residential area. Plus three represents a very positive impact such as reducing air pollution by keeping traffic flowing smoothly.

The questions listed in Table 10 provide guidelines to assist in assigning a weighted value to the importance of each category and determining the impact of a Smart Work Zone in each category.

Table 10 Qualitative analysis of the deployment of a Smart Work Zone

Weight (0-5) : 0: not important; 5: very important.	Impact (-3 to +3): -3: highly negative; -2: moderately negative, -1: somewhat negative, 0: neutral, 1: somewhat positive, 2: moderately positive, 3: highly positive.
Is increasing the efficiency of the construction operation important?	Will the deployment of a Smart Work Zone increase the efficiency of the construction operation (i.e. better access by asphalt delivery trucks, relocation of additional equipment)?
Is the ability to do work during periods currently restricted due to traffic concerns be important?	Will the deployment of a Smart Work Zone manage traffic flows in a manner that would allow work to occur at times that would otherwise be restricted?
Is the public perception of the agency as being innovative and user friendly, but also fiscally responsible important?	Will the deployment of a Smart Work Zone have a positive impact on the public's perception of the agency?
Is incident management and mitigation a concern on the project?	Will the deployment of a Smart Work Zone assist in the identification, response and mitigation of incidents in the work zone?
Are there other agencies that may be able to benefit from availability of information or changes in traffic operations?	Will the deployment of a Smart Work Zone provide benefits to other agencies (police, fire, emergency response, other)?

Table 10 Qualitative analysis of the deployment of a Smart Work Zone (Continued)

Is worker safety a concern on this project?	Will the deployment of a Smart Work Zone improve worker safety?
Is efficient project management a priority on this project?	Will the deployment of a Smart Work Zone improve the ability to manage this project?
Is there a value to traffic data from the project, either in real time or as historic data?	Will the deployment of a Smart Work Zone provide the type, quantity and quality of data desired by the agency?
Are right of way requirements a concern for the project?	Will the deployment of a Smart Work Zone affect the right of way requirements for the project?
Is there a need for innovation in traffic management approaches and technology?	Will the deployment of a Smart Work Zone contribute to the development of new traffic management approaches and technology?
Is the variability of travel time through the work zone a concern to motorists?	Will the deployment of a Smart Work Zone reduce the variability of travel time for motorists?
Are travel time delays due to the presence of a work zone a concern?	Will the deployment of a Smart Work Zone reduce the delays experienced by motorists at the work zone?
Is the increase of vehicle operating costs due to the presence of a work zone a concern?	Will the deployment of a Smart Work Zone reduce vehicle operating costs for motorists?
Is the reduction of fatal crashes in work zones important?	Will the deployment of a Smart Work Zone reduce the probability of a fatal crash occurring in the work zone?
Is the reduction of injury and property damage crashes in work zones important?	Will the deployment of a Smart Work Zone reduce the probability of injury and property damage crashes occurring in the work zone?
Is aggressive driving in the work zone a concern?	Will the deployment of a Smart Work Zone reduce aggressive driving behaviour in the work zone?
Is noise pollution on the mainline or alternate routes a concern?	Will the deployment of a Smart Work Zone reduce noise pollution?
Is air pollution / emissions a concern?	Will the deployment of a Smart Work Zone reduce air pollution?
Is congestion on the alternate route(s) a concern?	Will the deployment of a Smart Work Zone reduce congestion on the alternate route?
Is the impact on local businesses and the local economy a concern?	Will the deployment of a Smart Work Zone impact local businesses and the local economy?

For each benefit or cost category, the weighted impact is determined based on the category weighting and the estimated impact. Summing the individual values provides the overall net impact, an indication of the expected results of the project. However, individual measures should not be lost in the net impact. Therefore, the maximum negative and positive impact values are also identified, both weighted and unweighted. This is used to identify if there are some impacts that are severe that may affect the decision, even though the net impact may be favourable. For example, a deployment that is anticipated to provide positive benefits in most areas, but will divert commercial vehicle traffic past a residential neighbourhood at night, may not be chosen because the noise pollution impact is beyond acceptable limits. Sample results of the impact analysis are presented graphically in Figure 9 to illustrate the magnitude of projected benefits and costs. This graph is used to identify if there are any benefits or costs of large magnitude that might affect the decision and should be examined in greater detail. The hypothetical values that were used to generate Figure 9 are presented in Table 11 to illustrate the process.

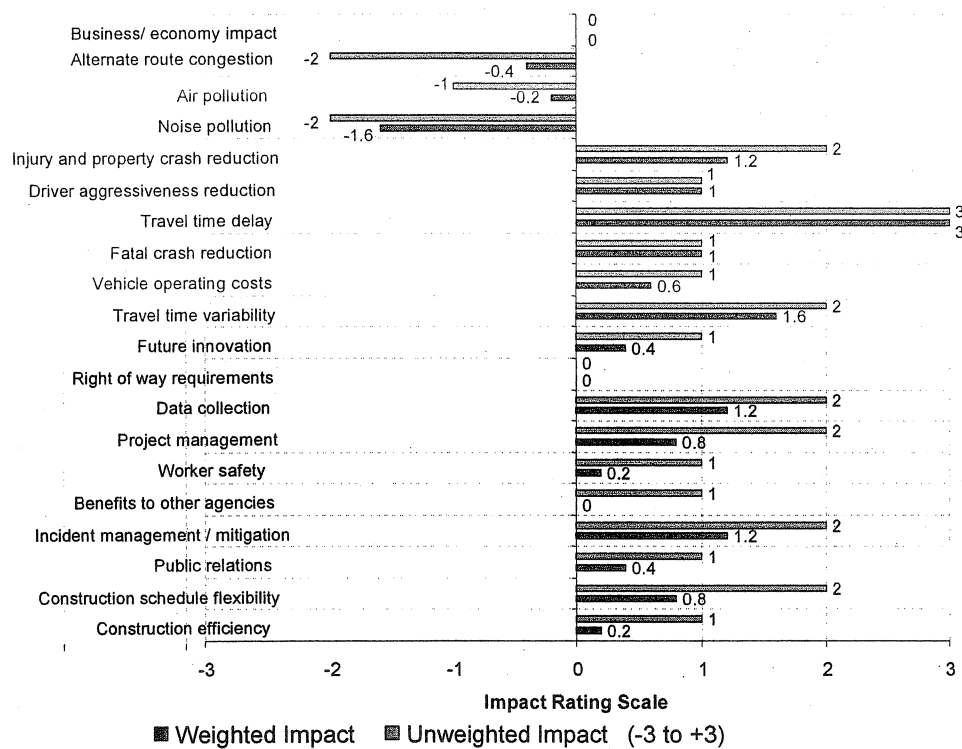


Figure 9: Sample results of a qualitative analysis of deploying a Smart Work Zone

Table 11: Results of sample qualitative analysis

	Benefit/Cost	Weight (0-5)	Unweighted Impact (-3 to +3)	Weighted Impact
Agency	Construction efficiency	1	1	0.2
	Construction schedule flexibility	2	2	0.8
	Public relations	2	1	0.4
	Incident management / mitigation	3	2	1.2
	Benefits to other agencies	0	1	0
	Worker safety	1	1	0.2
	Project management	2	2	0.8
	Data collection	3	2	1.2
	Right of way requirements	0	0	0
	Future innovation	2	1	0.4
User	Travel time variability	4	2	1.6
	Vehicle operating costs	3	1	0.6
	Fatal crash reduction	5	1	1
	Travel time delay	5	3	3
	Driver aggressiveness reduction	5	1	1
	Injury and property crash reduction	3	2	1.2
Society	Noise pollution	4	-2	-1.6
	Air pollution	1	-1	-0.2
	Alternate route congestion	1	-2	-0.4
	Business/ economy impact	1	0	0
	Net Impact		18	11.4
	Maximum Positive Effect		3	3
	Maximum Negative Effect		-2	-1.6

7.3 Quantitative Analysis

The qualitative analysis identified approximately 20 costs and benefits associated with the deployment of a Smart Work Zone. The quantification of each of these costs and benefits is possible, but it is not practical for every project under consideration. Safety and mobility are two important concerns on most construction projects and are therefore

the focus of the quantitative analysis. This approach is in line with the USDOT Highway Economic Requirements System model which considers three direct highway user benefits: 1) Travel time savings, 2) Vehicle operating costs and 3) Safety effects. Recognizing that for a specific project there may be other factors of concern provision is made for the inclusion of additional inputs into the analysis.

7.3.1 Quantitative Analysis Framework

The chosen method for assessing the value of a Smart Work Zone project is a decision making model using a benefit / cost analysis approach supported by inputs from modeling of specific aspects of Smart Work Zone operation. Expected benefits and costs are assigned monetary values for purposes of analysis on an incremental basis as compared to the base case without a Smart Work Zone. Benefits considered in this part of the analysis consist of reduced user costs (delay and vehicle operating costs) and improved safety. Costs will be considered as the monetary cost of deploying and operating the Smart Work Zone. The method of procurement currently being used by agencies is to pay for the system to be furnished and operated by a contractor or vendor rather than a system purchase. Therefore, no capital costs are incurred by the agency for use of a Smart Work Zone. This approach facilitates the consideration of the agencies multiple objectives based on monetary values established from analysis of other transportation projects.

Since Smart Work Zones are a relatively new concept the historical information and research to date is insufficient to quantify with certainty the impacts that the system will have on traffic flow, traffic safety and driver behaviour. The lack of historical information and research is not unique to Smart Work Zones, and applies to the analysis of all ITS projects. In the absence of complete historical information the analysis will depend on modeling to provide the measures of expected results. The decision model structure is shown below in Figure 10.

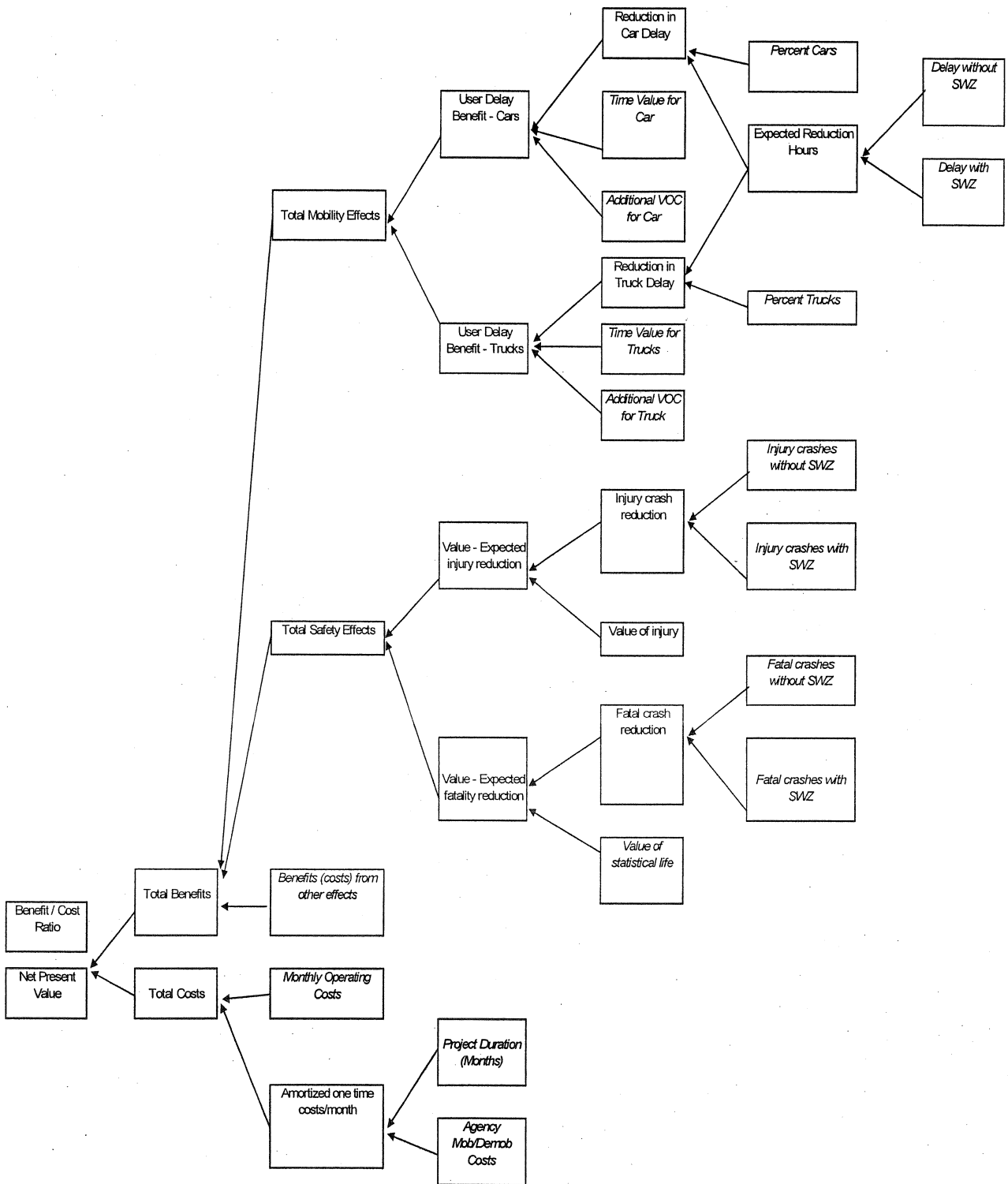


Figure 10 Qualitative benefit cost analysis structure

For this research, the model was implemented in Excel. Excel has the capabilities necessary to handle the analysis as the only decision is whether to proceed with the project and therefore the results are not dependent on other decisions that might be made. Since the goal is to provide practitioners a tool for making this type of decision, Excel is advantageous since it is universally available and most practitioners will have experience with its use.

Input variables are shown in italics, while all other values are computed based on the inputs. Determining appropriate inputs for each project will require specific knowledge of the project and relies on the expertise of the practitioner to select appropriate input values. Previous research can be used as a source of information and is supplemented by additional research conducted for this project. The three main segments of the decision structure are discussed in the following sections.

7.3.2 Definition of Variables

The quantitative analysis framework looks at three main areas to determine the benefit cost ratio and net present value for a project: mobility, safety and agency costs. The dependent and independent variables for each of these areas are defined below.

Mobility Effects

Dependent variable:

- Incremental value of mobility effects (\$ / month of operation)

Independent variables:

- User Delay with Smart Work Zone (hours / month)
- User Delay without Smart Work Zone (hours / month)
- Percent trucks (Truck volume / total traffic volume)
- Value of user delay time – cars (\$ / hour delay)
- Incremental vehicle operating cost – cars (\$ / hour delay)
- Value of user delay time – trucks (\$ / hour delay)
- Incremental vehicle operating cost – trucks (\$ / hour delay)

Safety Effects

Dependent variable:

- Incremental value of safety effects (\$ / month of operation)

Independent variables:

- Statistical value of fatal crash (\$ / fatal crash)
- Statistical value of injury crash (\$ / injury crash)
- Fatal crashes without Smart Work Zone (crashes / month of operation)
- Injury crashes without Smart Work Zone (crashes / month of operation)
- Fatal crashes without Smart Work Zone (crashes / month of operation)
- Injury crashes with Smart Work Zone (crashes / month of operation)
- Fatal crashes with Smart Work Zone (crashes / month of operation)

Agency Costs

Dependent variable:

- Agency cost for system (\$ / month of operation)

Independent variables:

- Mobilization cost (\$ / mobilization)
- Monthly operation cost (\$ / month of operation)
- Months of operation (Months)

7.4 Validation and Application of Project Analysis Framework

The validation and application of the project analysis framework is beyond the scope of this project. The framework provides a structure that can be used as a basis for evaluation of Smart Work Zone projects.

Prior to applying the framework to a specific Smart Work Zone project the framework should go through a validation process to ensure confidence in the results. This process should include:

- A sensitivity analysis to identify the most important variables.

- Identification of sources of input variables and reasonable values from previous research. The literature review and field study conducted under this project contributes to the existing information.
- Test application under controlled conditions to verify reasonableness of results.

Given that Smart Work Zones are a relatively new concept and that each application will vary, there may be insufficient historical data to provide values for the input variables in the analysis framework. Therefore, other methods will need to be employed in the application.

The sensitivity analysis will identify variables that can have a significant influence on the results. If these variables can not be defined with confidence then an analysis using a worst and best case approach may be required. Another alternative is to assign probabilities to the range of expected input values used in the analysis.

When input variables are not readily defined modeling and simulation techniques may also be useful to determine appropriate values. For example, determining the hours of delay with and without a Smart Work Zone is expected to be a key variable. The application of queuing theory either through direct calculation or through a software package such as QuickZone can provide this analysis. QuickZone is a work zone delay estimation tool developed under the direction of the FHWA to assess various approaches to construction phasing and traffic control so that traveler delay can be better assessed and addressed in construction planning. Hour by hour assessment is conducted using a simple deterministic queuing model for each segment of the network being examined (MitreTek Systems, 2002). Since Smart Work Zones are a special case of work zone traffic, adaptations may be required to address the specifics of the application.

7.5 Preliminary Assessment of User Delay

This section will focus on one measure that is commonly used and quantified in economic terms when projects involving changes in traffic operations are considered, that being user delay. Previous research has shown that the economic benefit of reduced user

delay can be considerable and make the value of other benefits relatively insignificant (Bushman and Berthelot, 2004). As described in the evaluation framework, other costs and benefits should be considered in the overall decision making process on whether to proceed with a Smart Work Zone project.

Typical costs for the deployment of a Smart Work Zone system such as those considered in this study are \$20,000 / month. To determine the benefits due to reduction in traffic delay, an economic value must be placed on the time of road users. A 1998 survey of typical user-delay costs used by transportation agencies for traffic operation analysis determined a range of \$8.70 to \$12.60 / vehicle hour for cars and \$21.14 to \$50.00 / vehicle hour for combination trucks (Daniels, Ellis, and Stockton, 1999). Using monetary values of \$10 / hour for cars and \$50 / hour for trucks and assuming 25 percent trucks, the blended value of vehicle delay is estimated at \$20 / hour. Assuming that the Smart Work Zone is active 20 days per month, the breakeven point for system costs and benefits from reduced delay occurs when 50 hours of delay are saved per day of operation. Using 50 hours as a threshold point, the travel time graph developed earlier is used in Figure 11 to illustrate the potential conditions where the expected benefit cost ratio will be greater than 1.

Figure 11 shows that there is a very large potential up-side to the deployment of a Smart Work Zone as traffic volumes increase. As traffic volumes and congestion increase, the value of reducing user delay becomes significantly larger than the cost of system deployment. Because of the compounding effects of traffic delay, the amount of traffic that needs to be diverted to reduce traffic delay by 50 hours / day is not large. For every vehicle that is removed from the queue, every following vehicle receives the benefit of reduced waiting time. Diverting as little as 150 to 200 vehicles to an alternate route at the times of greatest congestion may be enough to realize time savings to justify the use of a Smart Work Zone system.

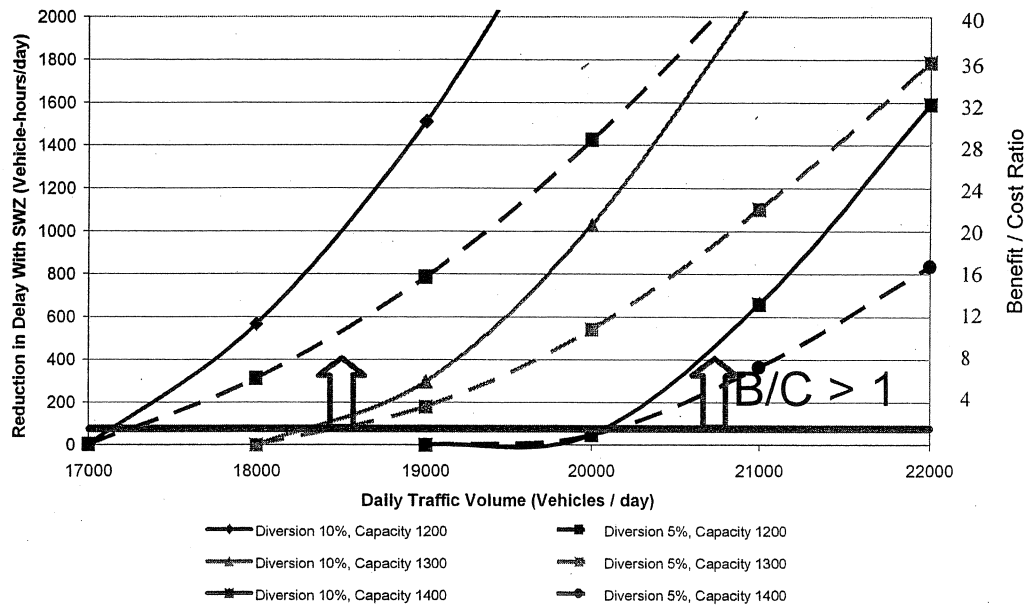


Figure 11 Benefit / Cost breakeven point considering cost of deployment and value of reduced user delay

Reducing the amount of user delay represents just one of the potential benefits of deploying a Smart Work Zone. As identified earlier, there are a number of other costs and benefits that may be of importance, depending on the characteristics of the project under consideration.

8. Summary and Conclusions

Two Smart Work Zone deployments that occurred on Interstate 95 in the 2003 construction season were the subject of this study. These systems were deployed by NCDOT to address concerns with safety and mobility while construction work is taking place.

The Smart Work Zone was considered as essential and it was not feasible to turn the system off so that data could be collected without the Smart Work Zone operating. However, there were short periods of time that occurred throughout the project when lane closures were in place, but the Smart Work Zone was not operating. Due to the limited number of crash occurrences and the variability of time between crashes no conclusive results could be drawn.

The configuration of Smart Work Zone system studied in this project had the primary purpose of providing travel information and route guidance. Smart Work Zone technology that addresses speed management and traffic conflicts such as lane merging may provide additional benefits in terms of increased capacity and safety.

The presence of a Smart Work Zone that provides specific information about delays and alternate routes was found to increase alternate route usage by 5 to 15 percent of mainline traffic. There was also indication that the presence of visible congestion at the exit ramp location resulted in increased alternate route usage. The combined effects of an alternate route advisory and visible congestion resulted in the highest usage of the alternate route.

Based on the available data, severe congestion resulting in several miles of backup was rare on both of the projects. Although project characteristics were similar the occurrence of congestion was highly variable between projects and from day to day. Overall, congestion lasting for at least one hour in the vicinity of the taper area was detected on 25 percent of the days the Smart Work Zone was operational in Johnston County. For the Nash County project, on almost half of the days for which valid data was available, at

least one hour of high occupancy was detected and on over a third of these days the high occupancy condition existed for more than three hours. At this site congestion was experienced most frequently in the month of August with 71 percent of days experiencing some level of congestion.

Surveys of local motorists, local trucking companies, and motorists at a rest area were used to obtain feedback on the operation and use of a Smart Work Zone. The system was well received by motorists using the system. The perception of system accuracy was generally high from all of the responses. Although a website was available to obtain information on current conditions, many motorists were unaware that it existed and it was not utilized to its full potential. Overall, most respondents indicated that they were in favor of more Smart Work Zones being used in the future.

Considering the cost of system deployment, the value of reduced user-delay and the potential savings in travel time by diverting traffic to an alternate route, an estimate of the benefits of deploying a Smart Work Zone was developed. For equal traffic volumes, the benefits of deploying a Smart Work Zone are greater for cases where the capacity of the work zone are lower and when a larger percentage of traffic can be diverted to the alternate route.

The limited study period did not yield conclusive results regarding safety. Future evaluations of safety should consider the use of a longer study period or the use surrogate measures of safety such as traffic conflicts or speed variability that may be indicators of improved safety to determine the impact of a Smart Work Zone.

The user website can be a useful tool to inform motorists of current conditions and allow them to alter their travel plans to avoid periods of congestion and reduce demand. It is expected that primary users of a website would be local commuter traffic, of which there was only a small proportion at the sites that were studied. At sites with high proportions of commuter traffic public awareness and easy accessibility to the website should be promoted to increase usage by motorists.

Determining safety benefits on a single project is difficult because of the limited amount of data available and stochastic nature of crashes and fatalities. As NCDOT continues to deploy Smart Work Zones, safety should be monitored for each of these projects to provide a broad base of information to be used in determining the effects on safety. A conflicts analysis and speed study may also be useful in future evaluations as a measure of the effect of a Smart Work Zone on safety.

The Smart Work Zone is an effective tool for encouraging the use of alternate routes when congestion occurs due to a work zone. Research on past deployments has indicated the potential benefits for Smart Work Zones to be used to provide traveler information, manage speeds, and guide driver behavior. Support for the use of Smart Work Zones on future projects was strong from motorists. Future projects should be examined to determine if congestion is expected to occur and where appropriate Smart Work Zones used a part of a mitigation strategy. The project analysis framework and the results of the study may be applied to decision making on future projects to determine on which projects to deploy Smart Work Zone technology, what type of technology to deploy, and what the expected benefits may be from such a deployment.

9. Future Development

This study has presented a framework for a qualitative and quantitative analysis of Smart Work Zone deployments. This type of analysis can be useful for comparison and selection of potential projects. To make the analysis practical for general usage several further development steps are recommended including the following:

- Sensitivity analysis to identify key variables
- Definition of range of appropriate input values
- Guidelines for application of methodology
- Development of a user friendly interface to increase ease of usage
- Development of nomographs, tables, etc. that can be used for analysis of typical situations

The application of a Smart Work Zone can result in unique traffic conditions. Given that Smart Work Zones are a relatively new development there is limited experience and historic results to draw upon. Therefore, it may be useful to use modeling and simulation tools to assess the potential results of applying a Smart Work Zone. QuickZone is a macroscopic analysis tool that has been developed for the assessment of work zone delays. Several microscopic analysis tools are also available for more detailed analysis of traffic management situations. Some of these also have graphics and animation capabilities that can be useful in demonstrating new concepts of traffic operation such as occur when a Smart Work Zone is deployed. Further development in the application of analysis tools to Smart Work Zones will help in determining when and how to best make use of Smart Work Zone technology.

10. References

Al-Kaisy, A., Nassar, K., Developing a Decision-Making Assisting Tool for Nighttime Construction in Highway Projects, 5th Transportation Specialty Conference of the Canadian Society for Civil Engineering, Saskatoon, SK, June 2004

ATSSA, <http://www.atssa.com/public/stats.asp>, accessed Sept. 9, 2004

Benson, B., Motorist Attitudes about Content of Variable Message Signs, Transportation Research Record #1550, Washington, D.C., November 1996

Bushman, R., Berthelot, C., Estimating The Benefits Of Deploying Intelligent Transportation Systems In Work Zones, Transportation Research Board 83rd Annual Meeting Compendium of Papers, Washington, D.C., January 2004

City of Saskatoon, Saskatoon Transportation Study: Working Paper #5, August 1993

Chang, G., Kang, K., Horvath, P., Evaluation of a Dynamic Late Merge System for Work Zone Operations, unpublished, 2004

Daniels, G., Ellis, D.R., and Stockton, W.R., Techniques for Manually Estimating Road User Costs Associated with Construction Projects, Texas Transportation Institute, Texas A & M University, TX, December 1999.

Datta, T., Schattler, K., Hill, C. Development and Evaluation of the Lane Merge Traffic Control System at Construction Work Zones, Wayne State University Department of Civil and Environmental Engineering, 2001

Federal Highway Administration *Technical Advisory – Motor Vehicle Accident Costs – T7570.2*. Federal Highway Administration, US Department of Transportation, October 31, 1994

Fontaine M., Guidelines for the Deployment of Portable Work Zone Intelligent Transportation Systems, Transportation Research Board 82nd Annual Meeting Compendium of Papers (CD ROM), Washington, D.C., January 2003

Forkenbrook, D., Weisbrod, G., Guidebook for Assessing the Social and Economic Effects of Transportation Projects - NCHRP Report 456, Transportation Research Board, National Academy Press, 2001

Gillen, D., Dahlgren, J., Operation Manual for Decision Analysis in Assessing the Economic Value of Intelligent Transportation System Projects, University of California, Berkeley, 1999

Hodge, D., Buxbaum, J., Stewart, B., Hand, C., Macroeconomic Impacts of Program-level Transportation Investments, *Transportation Research Board 83rd Annual Meeting Compendium of Papers* (CD ROM), Washington, D.C., January 2004

Horowitz, A., Weisser, Ian, Notbohm, T., Diversion From a Rural Work Zone Owing to a Traffic Responsive Variable Message Signing System, Transportation Research Board 82nd Annual Meeting Compendium of Papers (CD ROM), Washington, D.C., January 2003

Jiang, Y., The Effects of Traffic Flow Rates at Freeway Work Zones on Asphalt Pavement Construction Productivity, Journal of the Transportation Research Forum, 2003.

Keever, D., Weiss, K., Quarles, R., *Moving Ahead: The American Public Speaks on Roadways and Transportation in Communities*, Publication FHWA-OP-01-017. FHWA, U.S. Department of Transportation, 2001

King, T. Sun, C., Virkler, M., Evaluation of a Freeway Work Zone Advance Speed Advisory System Using Multiple Measures, Transportation Research Board 82nd Annual Meeting Compendium of Papers, Washington, D.C., January 2004

Kratofil, J., A Benefit-Cost Analysis For The Use Of Intelligent Transportation Systems Technology For Temporary Construction Zone Traffic Management On The I-496 Reconstruction In Lansing, Michigan, Central Michigan University, 2001

Lyles, R., Taylor, W., Lavansiri, D., and Grossklaus, J., A Field Test and Evaluation of Variable Speed Limits in Work Zones, Transportation Research Board 82nd Annual Meeting Compendium of Papers, Washington, D.C., January 2004

MitreTek Systems. *QuickZone Delay Estimation Program User Guide*. Prepared for Federal Highway Administration, February 2002

North Carolina Department of Transportation, Traffic Safety Services Management Unit, Unpublished, 2003

Oak Ridge National Laboratory, *"Temporary Losses of Highway Capacity and Impacts on Performance"*, May 2002

Ozbay, K., Jawad, D., Parker, N., Hussain, S., Life Cycle Cost Analysis: State of the Practice vs State of the Art, *Transportation Research Board 83rd Annual Meeting Compendium of Papers* (CD ROM), Washington, D.C., January 2004

Peeta, S., Ramos, J.L., Pasupathy, R., Content Of Variable Message Signs And On-Line Driver Behavior, Transportation Research Record #1725, Washington, D.C., November 2000

Polydoropoulou, A., Ben-Akiva, M., Khattak, A., Lauprete, G., Modeling Revealed and Stated En-Route Travel Response to Advanced Traveler Information Systems, Transportation Research Record #1537, Washington, D.C., November 1996

SRF Consulting Group Inc. Portable Traffic Management System Smart Work Zone Application: Operation Test Evaluation Report, Prepared for Minnesota Department of Transportation, May 1997

Transport Canada, Guide to Benefit Cost Analysis in Transport Canada, September 1994

Tudor, L., Meadors, A., Plant, R., Deployment of Smart Work Zone Technology in Arkansas, Transportation Research Board 82nd Annual Meeting Compendium of Papers, Washington, D.C., January 2003

United States Department of Transportation, <http://www.benefitcost.its.dot.gov>, accessed May 13, 2004

Appendix A: Implementation Details

Appendix B: Safety Analysis Details

Appendix C: Diversion Route Data

Appendix D: Results of Traffic Operations Review

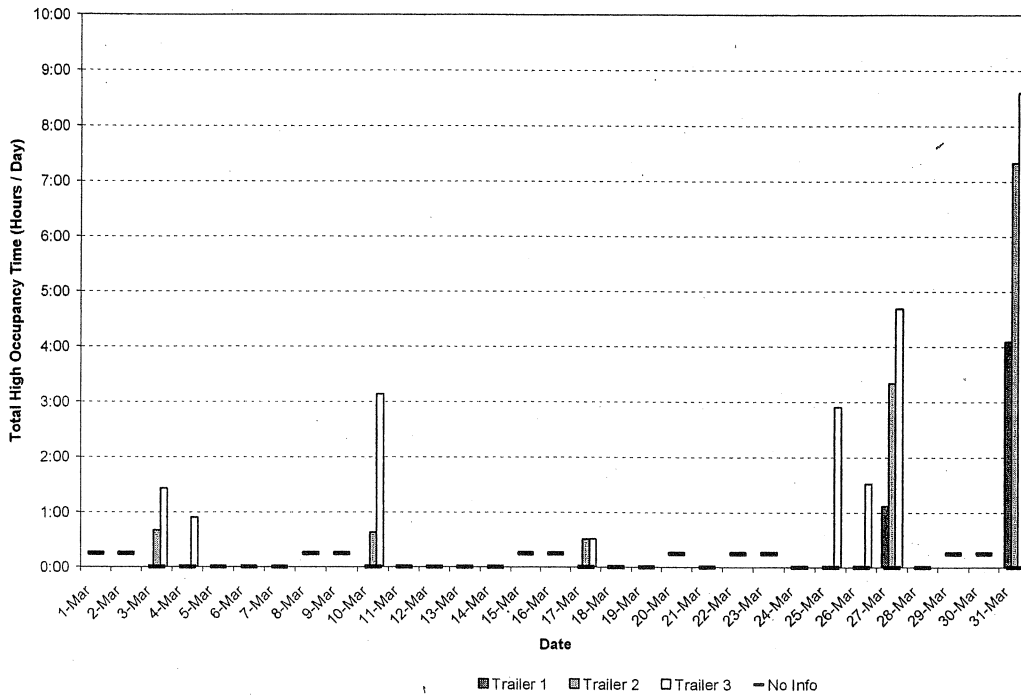


Figure D-1: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, March 2003.

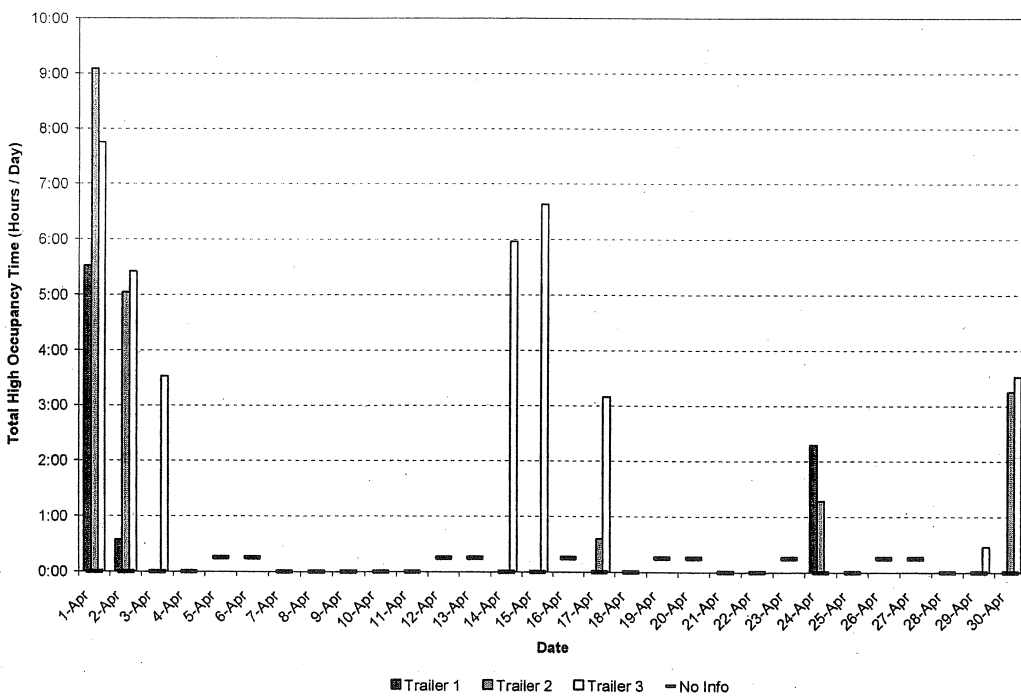


Figure D-2: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, April 2003.

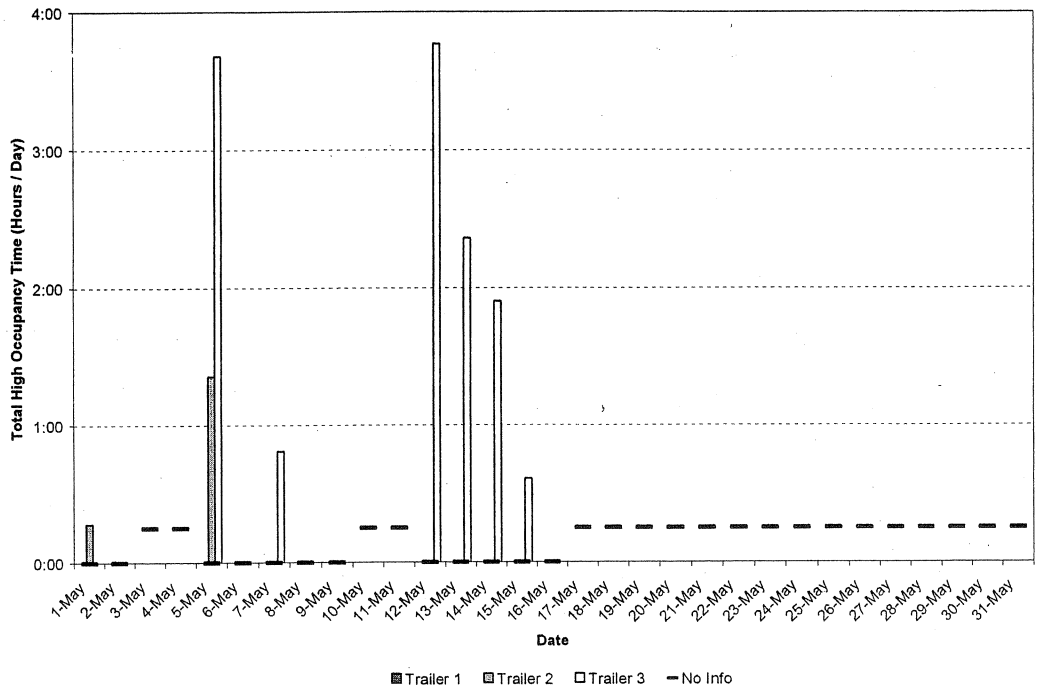


Figure D-3: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, May 2003.

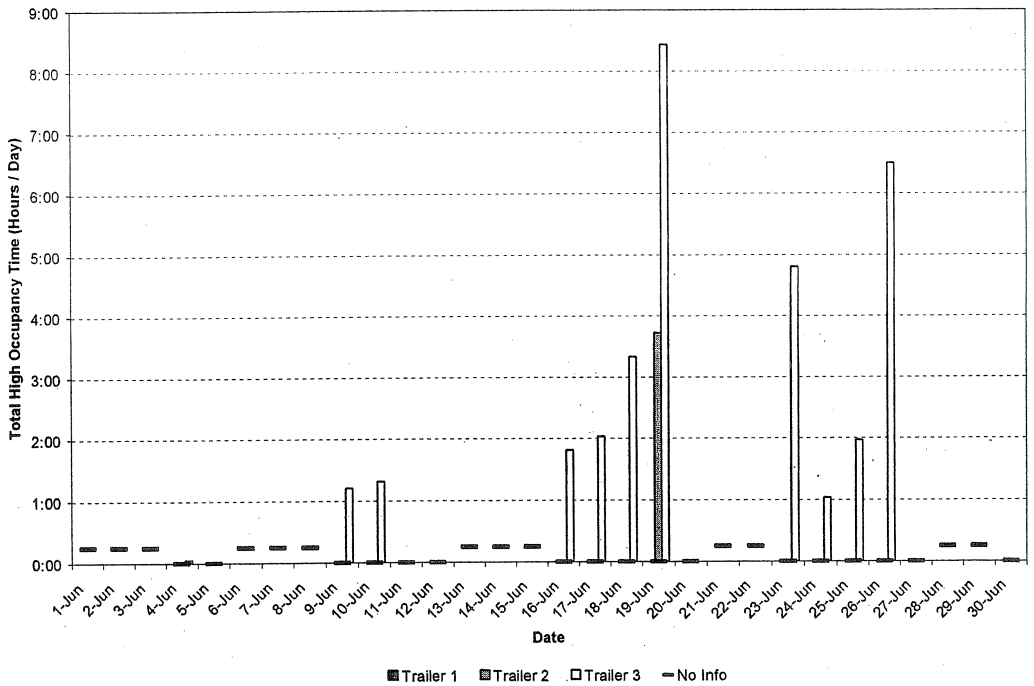


Figure D-4: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, June 2003.

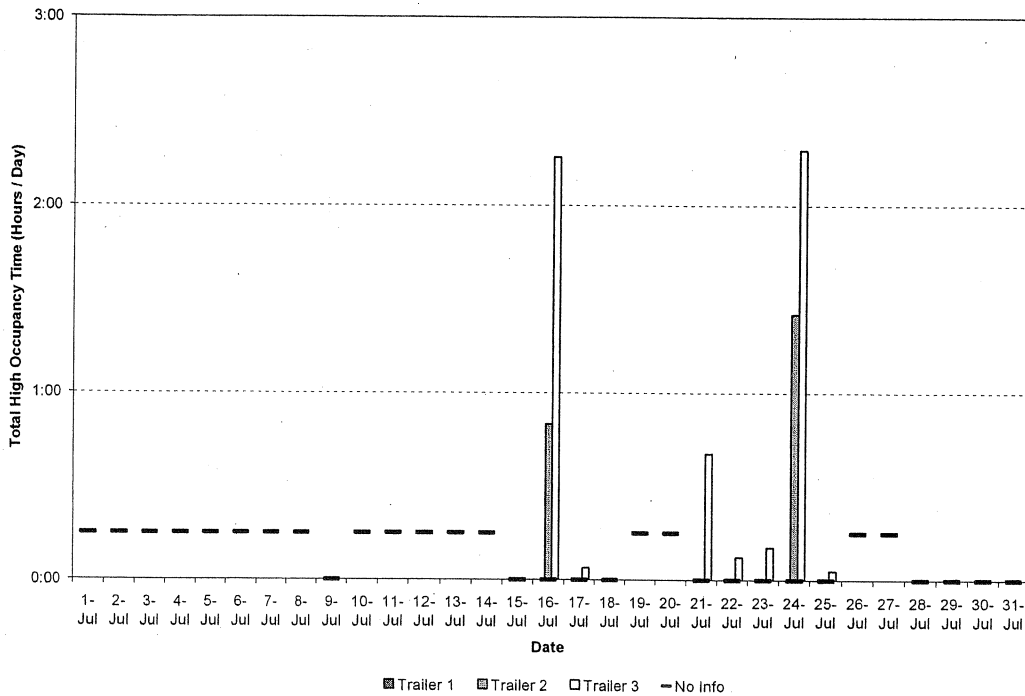


Figure D-5: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, July 2003.

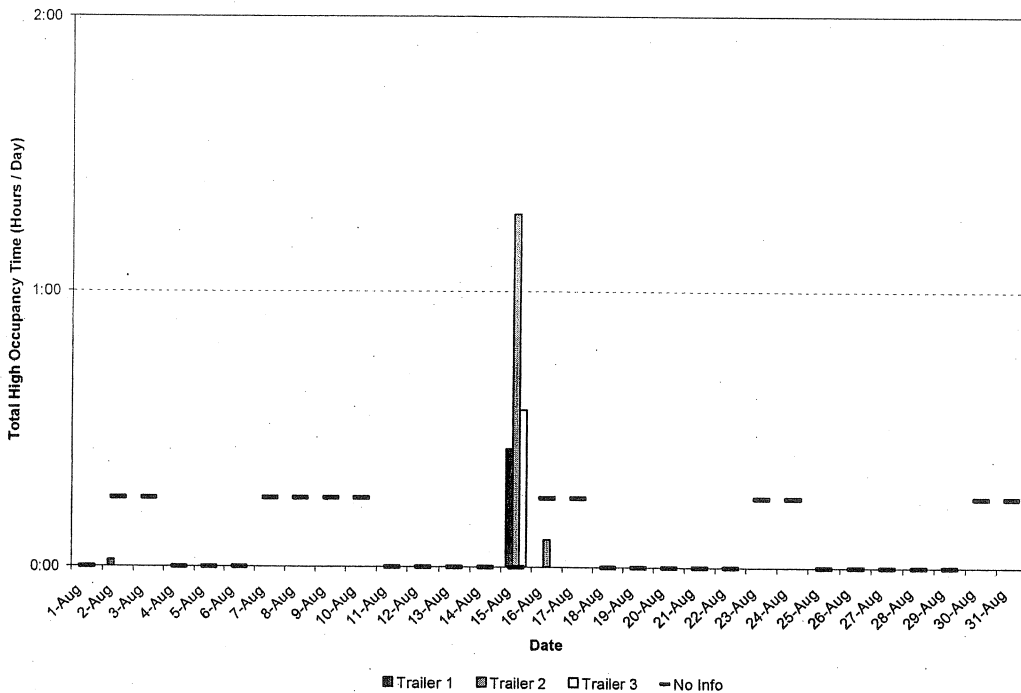


Figure D-6: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, August 2003.

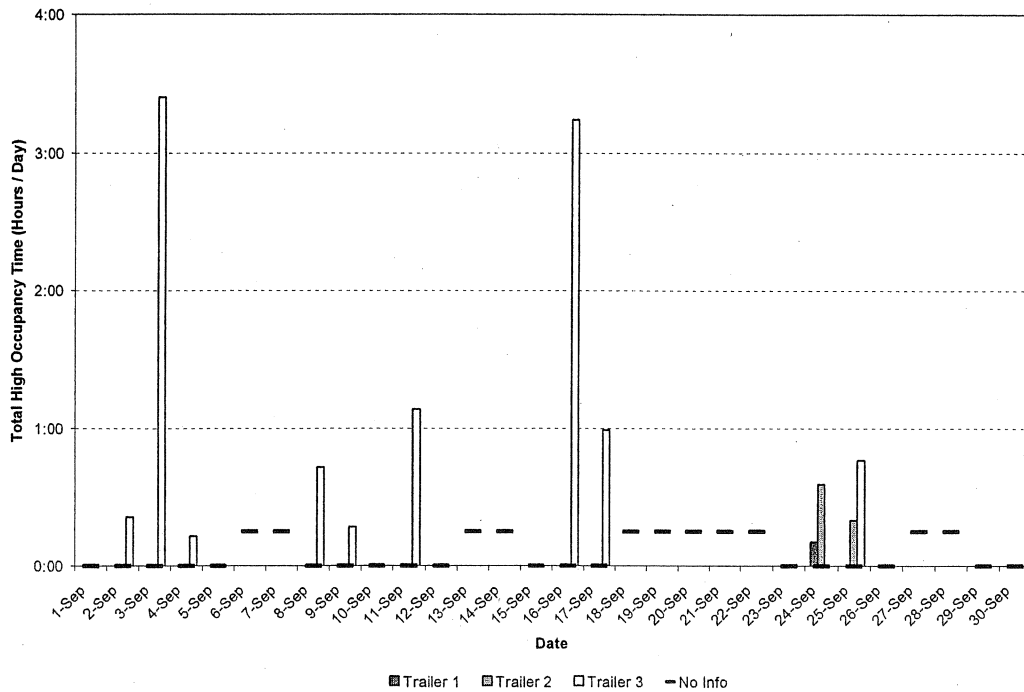


Figure D-7: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, September 2003.

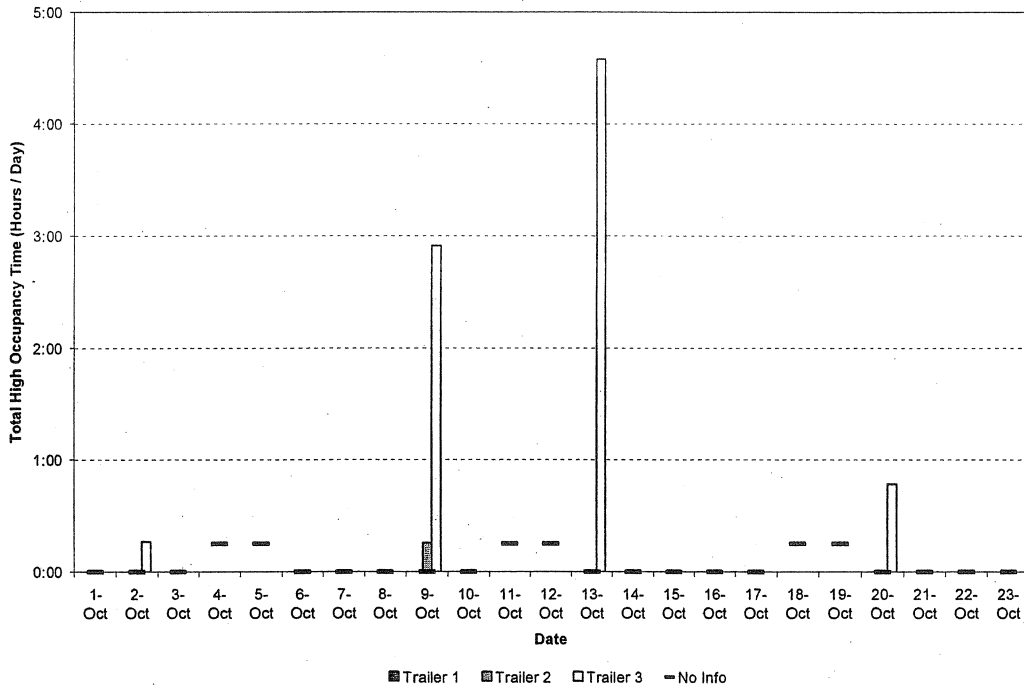


Figure D-8: Daily Occurrence of High Occupancy at Trailer Locations – Johnston County, October 2003.

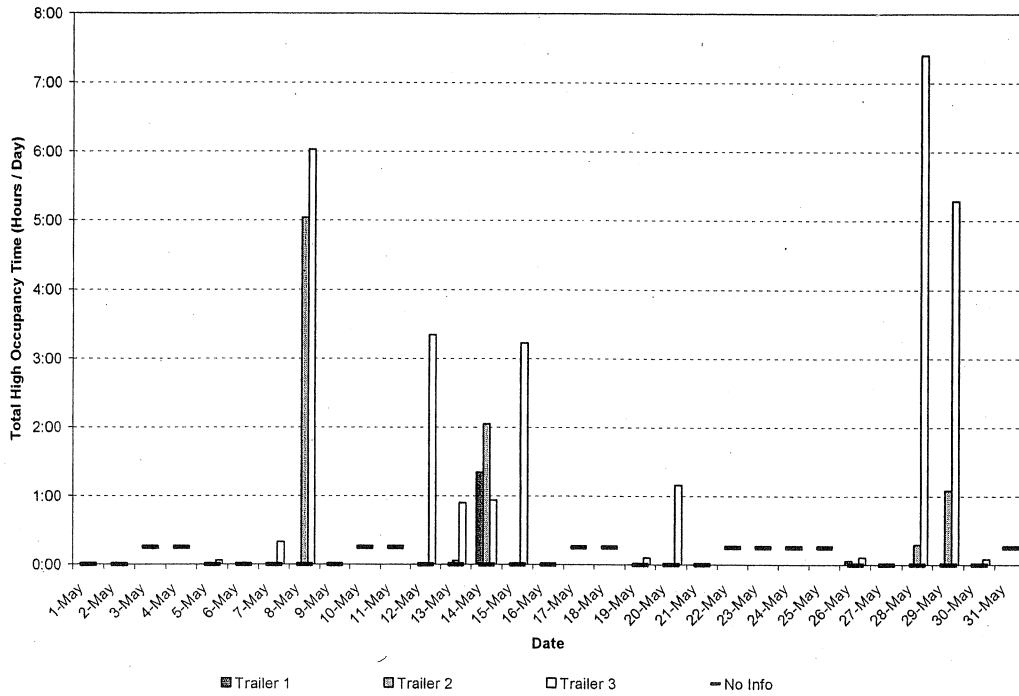


Figure D-9: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, May 2003.

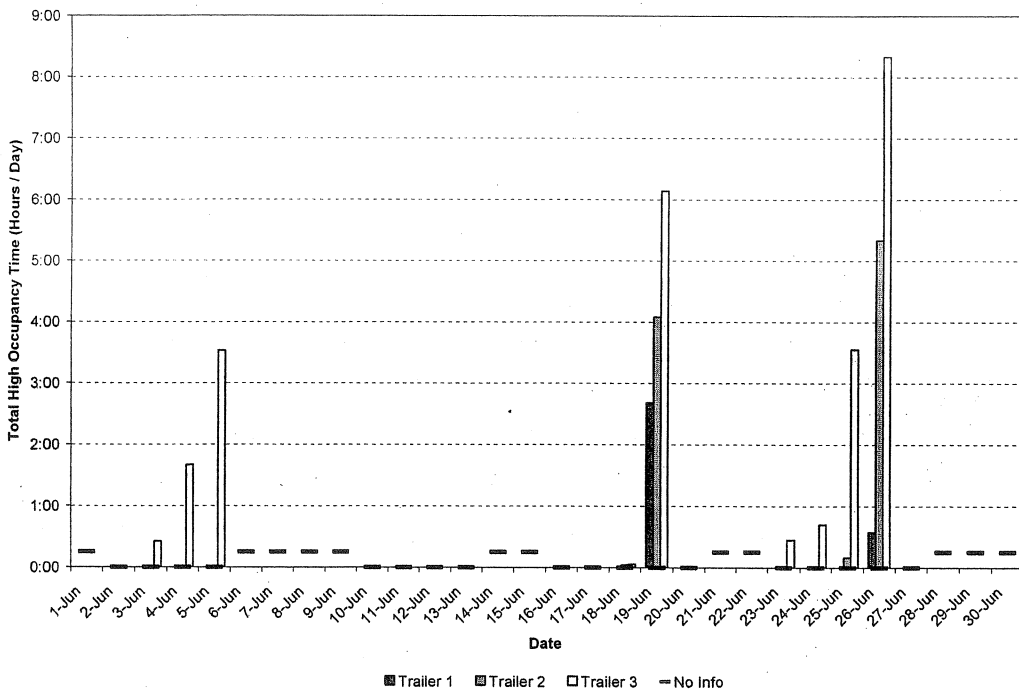


Figure D-10: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, June 2003.

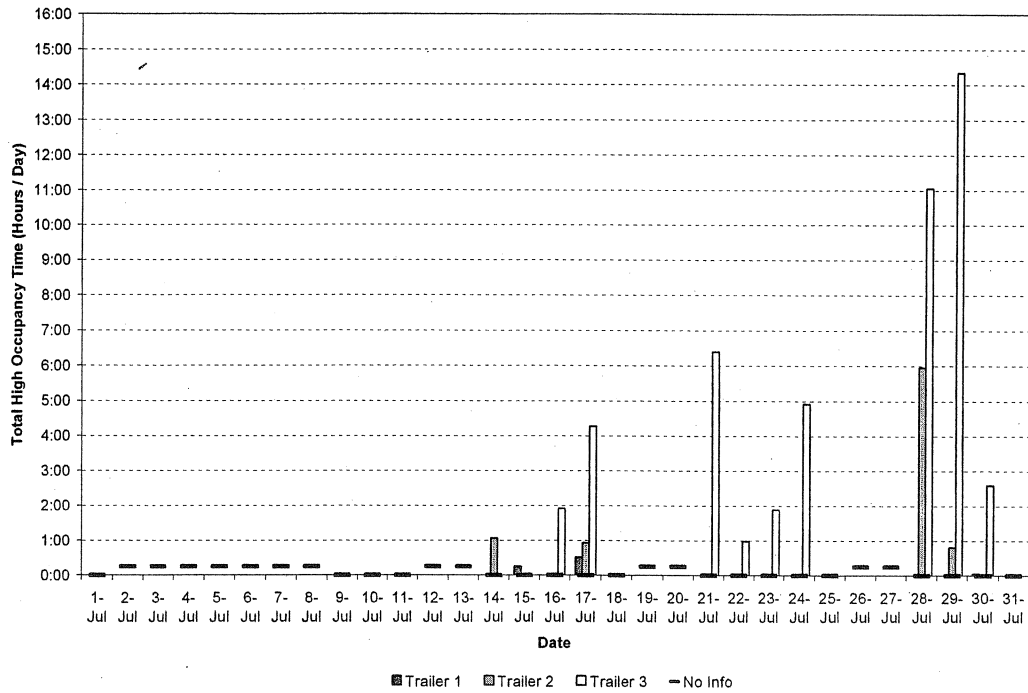


Figure D-11: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, July 2003.

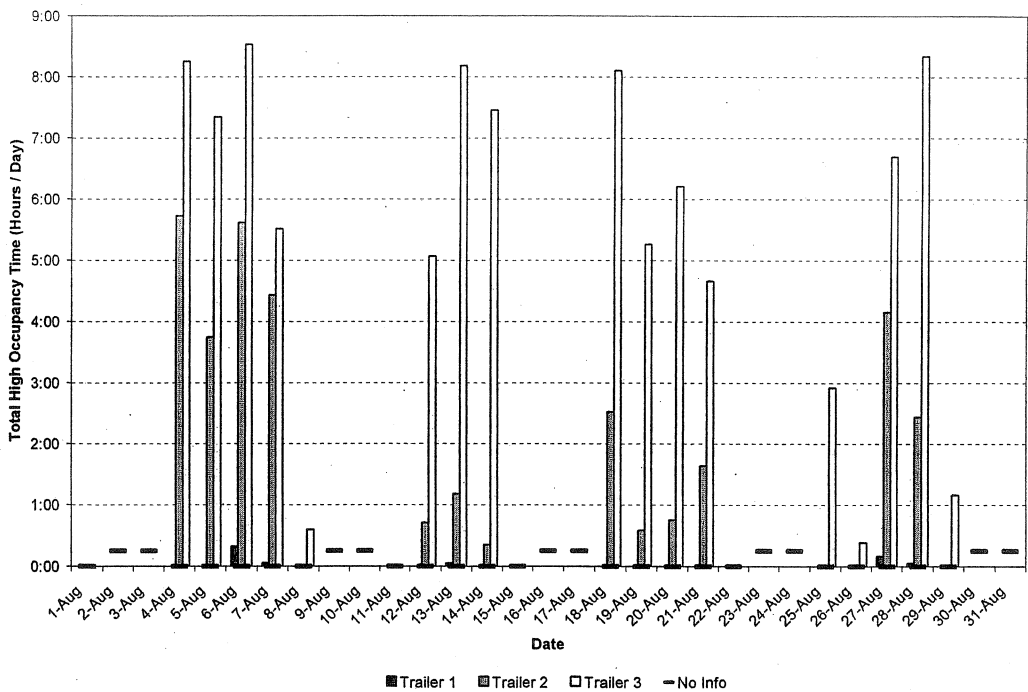


Figure D-12: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, August 2003.

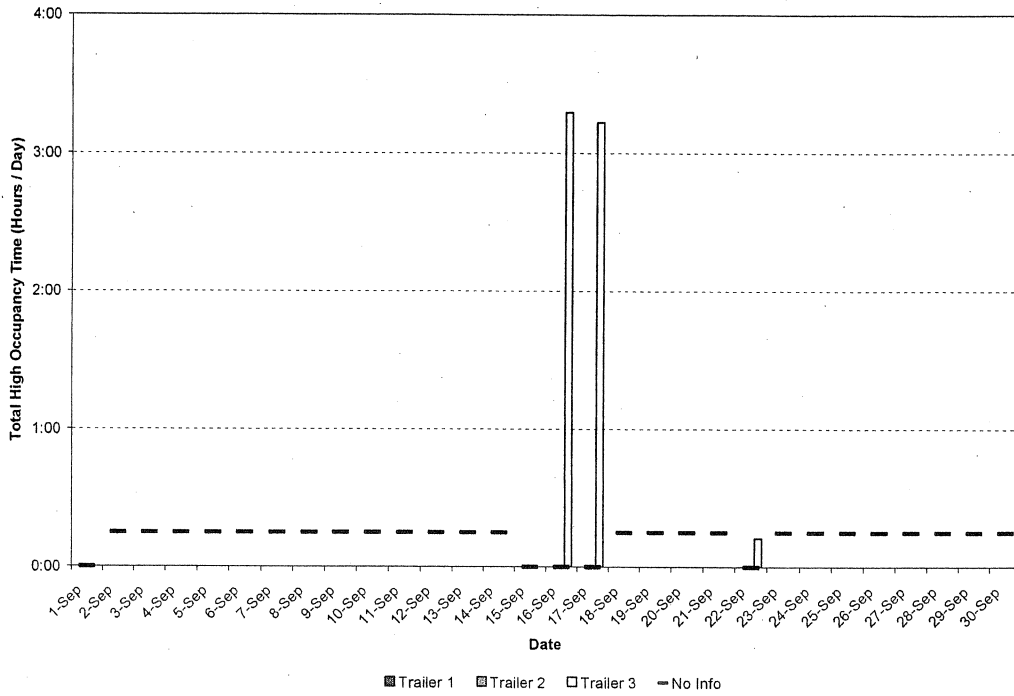


Figure D-13: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, September 2003.

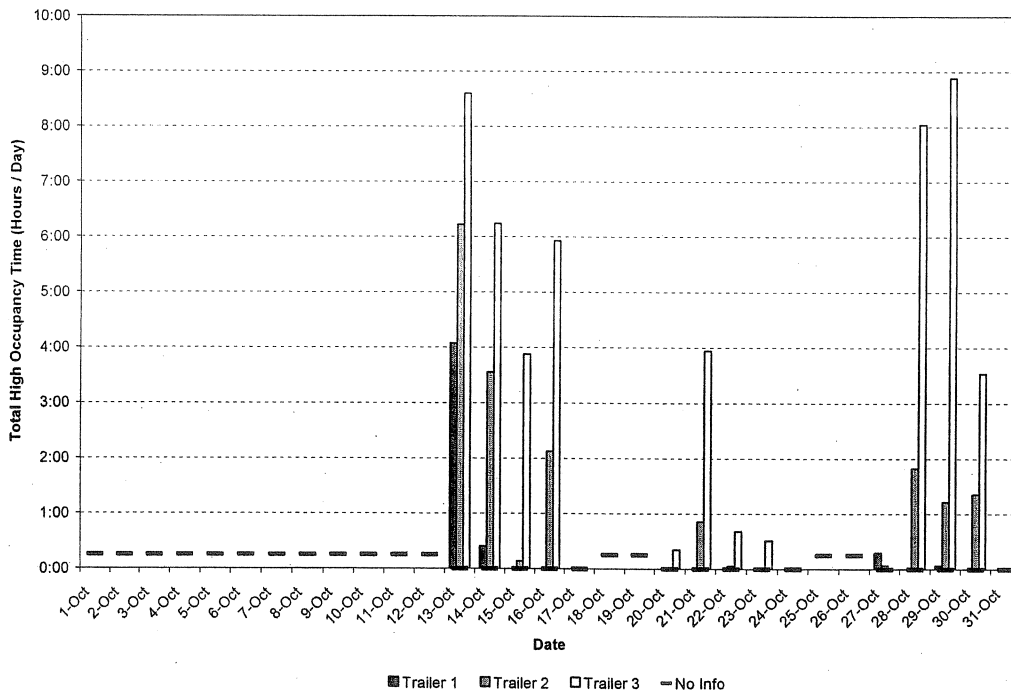


Figure D-14: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, October 2003.

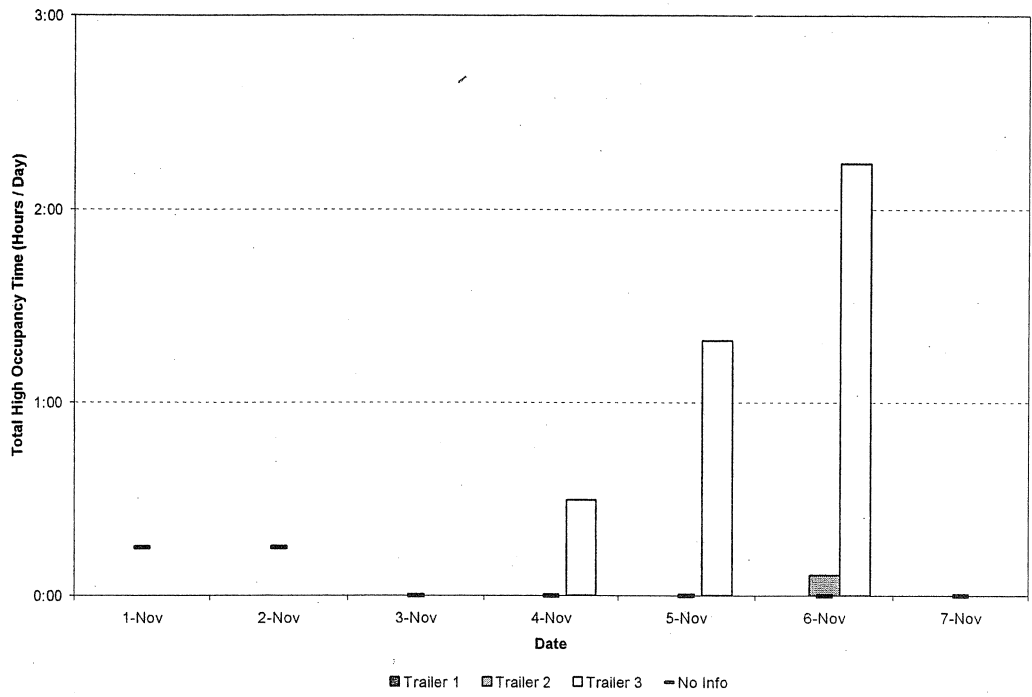


Figure D-15: Daily Occurrence of High Occupancy at Trailer Locations – Nash County, November 2003.

Appendix E: User Acceptance Survey

Survey respondents were given the opportunity to provide written comments at the end of the survey. These comments are recorded below. The comment number corresponds to the survey response data.

T: Response from Trucking Industry

S: Response from Smithfield residents

R: Response from Rocky Mount residents

T1: Traffic backup 2-3 miles before you see signs.

T4: It is especially helpful to cars, as most truckers know far ahead of time via CB radio. I hope NC and other States cont to repave their roads because a a safe road is as important as a safe truck, and safe and well rested driver.

T6: Very good information. Keep it up. Thanks

S4: As a DOT employee I am probably more aware of these things and may skew the results.

S17: Lane change signs place to far in advance of lane change necessary to avoid congestion. Not enough lane change signs placed at least 2 miles prior to lane blocked this occurred at mile post 38 area where overpass bridge was being torn down.

S18: Sorry – I did not go north on 95 – only south to the Georgia line and I try my best not to travel on I-95 on weekends – it is just to busy and people drive too fast. More drivers speeding in work zones – should be stopped. Thanks for asking.

S24: There should be permanent signs every so many miles to warn of situations ahead... far enough to be able to exit and detour around it.

S25: Need more of them so you can get off I-95 before you are stuck in traffic.

S28: More frequently traveled between Smithfield and Benson on I-95. Message signs were a big help on these trips.

S34: They are very good – continue. Thanks.

S38: Keep up the good work!

S46: I'm XXXX and I don't drive but the van riding has been grate they were ... careful they do a grate job thank you for being concern

S48: Please continue this sign system. I only used from Smithfield to Bagley Road. Very helpful when they paved north of Smithfield on I95.

S49: The Internet is useless due to the time variance involved. Traffic updates on the radio are much more helpful. My biggest "gripe" is all the high profile trucks driving to my right that do not allow you to see the signs. I know you cannot do anything about this problem but it has created a huge problem for me. Overall, you have done a good job. Thanks.

S50: #8 You should let people know what website you are talking about. #9 Can't check if not known. PS – Thanks for the survey.

S55: Re #4 never hit a delay period. 5. Took alternate on 95 S of Dunn as sign suggested – but it was worse than 95.

S62: Never noticed the signs stating a delay for a wreck or other extemporaneous delay.

S66: Current sign at Four Lakes construc. site are very helpful as to time but no detour routes are posted. I know the way 'cause I'm from around here but there's no delay sign when I enter at exit 90 to warn me not to go there. Also Re- Miss. Child Signs need signs in both lanes.

Saw a sign in May re a delay and last exit prior something but no clear alternate route posted ... Due to an accident earlier in day. Wish we'd known about website cause we saw the sign almost too late to exit and were afraid we'd get lost. We were delayed 2-3 hours and missed part of graduation weekend activities.

S71: Sometimes the signs wouldn't change fast enough so I could read the whole message before I passed it. It's a great system, keep up the good work!

S72: I don't travel this route often – A sign on 140 W prior to the 70W exit would be helpful (From Tolnston to Wake)

S77: I'm doubtful the internet is an effective method for many motorist. Your erected signs for construction work appear well planned and informative. One sign I have seen at construction sites in some western States that is very eye-catching and sends a great message to motorist is this "Let 'em Live". This wording to me says be careful, cautious, stay alert, drive smart.

S83: Advertise to web site so we can obtain information

S90: I drive north to Fayetteville every day! Wrong way.

S95: There is nothing I hate worse than being backed up in construction traffic, especially when I have had no warning. There was an instance around Thanksgiving (in another State) with no warning. We had waited for a particular exit to stop @ a rest area. We could not exit for several more miles and were all more than uncomfortable as we had also planned to have our evening meal there. Any notice you can give is appreciated.

S97: No construction delays during my travel. Usually weekend travel. "No Delays" – can't really answer for heavy traffic times. In all cases I would have taken an alternate route being familiar with the area. The Internet and sign information being correlated sounds fantastic in theory. Wish we could be more helpful with answering above questions.

S98: Would like to know web address.

S99: Though costly, more work should be done at night and certainly not during rush hours. Work on I-40 in Chapel Hill during football season was ridiculous!

S100: I think you are doing a good job.

S107: Had no idea website was available – no PR done to promote that we've seen! Travel 95 daily – info good! Thanks!

S111: We traveled frequently I-95 south from Smithfield to Florence SC, and encountered the construction near Fayetteville, I-95 and US13. The signs were always current and were very helpful in determining whether we should take an alternate roads. I will make use of the Internet site now that I know it exists. I will address travel times and alternate routes based on this information. It would be beneficial if the website address was listed on questionnaire of this type.

S115: Should be on I-95 from Maine to Fla. – Big help in NC.

S119: Keep up the good work!

S122: Thank you for all of your help.

S126: I found no problem with the signs or information displayed.

S129: I think the signs should be put on higher poles so you could see them at a farther distance – especially on 70A and 70. Also I hope the speed limit on the beltline should be 55 mph because people fly and me and my son almost got killed because the car in front of us stopped suddenly and if we had not been on inside lane and turned to median we would be dead now. On way to my Dr.

S136 I was returning home into Smithfield on US70 from Raleigh and was amazed that no sign indicated that the right lane was closed near the Neuse River Bridge. Someone was kind enough to let me in. A large arrow was flicking at the close-off site – much too late for me to line up properly. Sorry, we don't travel Rocky Mount – Smithfield on 95 often. Hope the above helps.

R1: I know road work is necessary and I am very appreciative of the message signs.

R5: I-95 is a disaster waiting to happen. Terrible, terrible road.

R8: Need to charge a toll, but not \$18.00 for travel eg. Out-of –state vehicles using I95. Other states do – i.e. Delaware, Maine, etc. to help pay for maintenance.

R11: These information systems can help with material deliveries to the job / work areas also.

R14: Keep up the good work!

R16: Only if they can be more accurate.

R26: Letter was dated Dec 3, 2003. Was delivered Jan 8, 2004.

R29: Most of the information relayed was accurate but sometimes in the afternoons the sign would not say working or delay and they would be working on the road. Some

afternoons they were through working but still the messages were saying there was a delay.

R38: Information very valuable if given before an exit so alternate route may be taken if desired.

R41: Took alternate routes to avoid delays the signs indicated but got back on I95 within same, delayed traffic that stayed on I95, which was now moving at highway speeds. The alternate route saved no time.

R43: Need a non applicable choice or use a skip pattern. Non answered questions are base on no experience with system. DOT needs an awareness campaign to increase driver knowledge.

R50: The messages should better describe the affected areas of the delays such as exist numbers.

R53: I never saw a delay message, but there was once that a board said no delays to mile marker whatever (about 8-10 miles away) and within 3 miles we were at a stand still.

R56: Provide more alternate route information and sooner (at a greater distance from delay area). I think you are on the right track.

R62: Thank you for this survey.

R63: I may not have seen these particular work projects, but all information is helpful if it is not too complicated. Yes, if costs can be met without increases in taxes, fees, and other forms of government revenue. Also inform TV news and radio if feasible.

R72: I usually elect to accept the delay rather than seek an alternate route because I am unfamiliar with alternate routes. One time I tried an alternate route and got lost. Spent more time on back roads than I would have if I had accepted the delay.

R74: I think most people perceive the messages as pre-programmed and thus not very reliable or accurate.

R78: I think the Highway Patrol should be seen in these area more and ticket the speeder, that don't slow down through and respect the posted speed limits. The NC Dept. of Transportation is doing a good job in these areas.

R80: Any information furnished to motorists either signs or electronic which may be received by electronic devices in cars would give benefits to DOT and traffic immeasurable.

R82: Wonderful Job! Thanks.

R86: If these signs are to be deployed, they should indicate current traffic conditions and tell drivers which lane is closed ahead.

R87: Very good system. Keep up the good work.

R91: These types of signs are useful and helpful since I travel I-95 frequently. They help me avoid delays so I may choose to switch to alternate routes N to S. i.e. US301.

R92: Did not travel this road often enough to comment in survey. But I do agree that message signs serve their purpose of time and safety.

R106: Very helpful in determining reason for delay which also improves overall safety. Yes we need more info of this type. Thanks.

R119: I was glad to help make driving anywhere safer. Please let me know if I can help anymore.

R121: I95 from Wilson to NC/SC line is a dangerous drive. Needs 3 lanes per direction.

R126: On survey question #9 – only recently acquired computer and was not aware of website concerning traffic conditions until I received you letter of 12-3-03 with website.

R127: First time I took an alternate route it was not good. The traffic from 95 was flowing adequately when I got to the 95 connection. #6 Several times trucks were in the way. #10 Travel early before traffic builds up. How often is the message updated in real-time? Inaccurate info is no info.

R128: I travel to Wilson on I95 everyday and during the construction there was never any ... signs between Rocky Mount and Wilson. The other problem was that they would change the speed limit to 55 mph long before you ever got to any construction which was very frustrating.

R129: I use I95 near Rocky Mount weekly but I use the last exit before the work area.

R136: I no longer am able to drive and am pretty much "housebound" so you need to get answers from someone who uses the highways. Sorry I can't contribute to your survey.

R137: It appears to me, that once a project long or short is completed it takes too long for barriers, etc. to be removed. On paving projects, I travel several miles in single lanes and see no activity at all. Then, see the paving going on in less than a quarter of a mile. At times, I get the idea the paving crews enjoy tying up traffic.

R152: Promote website

R153: If people would merge right or left when they should there would be no need for these signs. Still trying to figure out why all the money spent widening the shoulders around 138-150 MM (I95) when we really need a 6 or 8 lane highway.

R159 Usually I saw the "no delay" message. If there was a delay that info may not be relayed. I would choose an alternate route if fore-warned!

R161 One message would read completely different on time delay than the next one a half mile down the road. (at times)

R166 The signs help us to better understand upcoming traffic conditions. The signs are very informative, should always reflect current situations. Signs (systems) should be used to indicate speed of driver!!!

R176 Based on traffic conditions I think you did a good job.

R179 NC has some of the best highways I have ever driven on.

R183 If you are driving through a work zone, and there is no work going on, do you have to slow down to the work zone speed limit. Example Holidays, after hours, weekends, etc. I would like to know answers to questions I have, and maybe everyone else should know. Thanks. I will check the website. 1-800 number would be nice.

R186 Please continue with the signs as they are a tremendous help!

R189 There should be more signs alerting travelers to traffic conditions at entrances where they can not see the highway until they are on the down ramp.

R198 Thank you for this survey. In some cases, an electronic sign should have been used instead of the orange construction sign to notify of lane closings. Also, this sign should be place further up the road. You know how people are. It seems as if people

weren't paying attention to the orange signs about the lane closings. Also, I think XXXX Construction could have done a better job as for the amount of time it took to complete the project. I think one side should have been closed Mon-Fri, and 2-way traffic on the other side. This was done in the mid-90's for the paving project between exits 160 and 168. Thank You, again.

