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Identification, assessment and proposing mitigation strategies for the risks involved in operations and maintenance activities on highways - crash data analysis and development of integrated risk management model

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Identification, assessment and proposing mitigation strategies for the risks involved in operations and maintenance activities on highways – crash data analysis and development of integrated risk management model

by

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DEDICATION

I dedicate my thesis work to my wonderful family who offered me unconditional love and support throughout my life and the course of my Master of Science program. A special feeling of gratitude is to my loving parents Sandip Kumar Mukhopadhyay and Shovana Mukhopadhyay whose words of encouragement, immense support, selfless sacrifice and push for tenacity always ring in my ears. I give my deepest expression of love and appreciation to my husband Sayantan Bhaduri, for providing me encouragement, inspiration and support during my graduate studies. My sister Sourima Mukhopadhyay has always supported me and is very special to me. I also dedicate this thesis to my loving parents-in-law Sudip Kumar Bhaduri and Bratati Bhaduri whose immense support and love have inspired me in every aspect throughout the process. I would like to thank my uncles Rajib Kairal and Sanjib Kairal for extending their immense support and inspiration to conduct my graduate studies from abroad. I will always appreciate all that they have done for me and I believe that the combined effort of all of them have paved the path for my success.

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ABSTRACT

Mobile operations and highway maintenance work is among the riskiest activities of state highway agencies. Over the past ten years 1,323 fatal-major crashes occurred in Iowa due to the intermittent and moving work zones. Additionally, another 8,234 minor injury crashes, 11,447 possible injury crashes, and 34,038 property damage type of crashes occurred in Iowa in the same time frame (as reported in Iowa DOT crash database). A literature review of research in risk mitigation of mobile operations in other states has indicated that the topic has been addressed, but typically in very narrow areas (e.g. weather or nighttime operations). Few studies have analyzed risk in moving operations and maintenance work using an integrated, system-level analysis. This study provides a broad examination of the different risks that are identified and assessed through expert panel review and analysis of the statewide crash data from 2001 to 2010. A model was developed to identify the significant factors and an analysis of severity and frequency of those factors resulted in the development of the Integrated Risk Management Model. The statistical analysis along with the Integrated Risk Management Model resulted in six factors that bear critical risk potential and catastrophic risk potential for maintenance and mobile operations in highways. They are passenger vehicles, vision not obscured by moving vehicles or frosted windows / wind-shield, region located within or adjacent to the work activity, region located between the advance warning sign and work area, cloudy weather and foggy or misty or partly cloudy weather. Several risk mitigation strategies are recommended in this research study that should be adopted by transportation agencies while planning for a mobile work zone or during the maintenance and operation activities on highway in order to render a safer work zone both for the public and the working crews.

Keywords: Mobile work zone safety, Project risk management, Maintenance and operations in highways, Crash data analysis, Integrated Risk Management model

CHAPTER 1. INTRODUCTION

This chapter explains the needs and objectives for the present research study which mostly explores and quantifies the different types of risks that are associated with operations and maintenance (O/M) activities and recommends mitigation strategies that the different transportation agencies should adopt while planning for mobile maintenance and operation activities on highways. This chapter is divided into three sections:

- Problem statement
- Preliminary background summary
- Research objectives
- Anticipated benefits and contributions

Problem Statement

Previous research on construction work zone safety (Shane, et al. 2009) has found that moving operations represent the highest risk activity when both frequency of occurrence and intensity of loss are considered. The research further determined that using an integrated risk management model that assesses risk over the project life cycle could mitigate the risk of moving operations (among others) during the construction phase.

Although designed specifically to examine risk and safety for work zone applications, the research indicated that construction activities that involve moving operations (e.g. painting, guardrail placement) represented the highest risk. This finding suggests that the risk modeling process could be beneficially applied to operations and maintenance (O/M) functions outside of construction work zone applications. The research described in this thesis will examine how an integrated risk modeling approach could be used to reduce frequency and intensity of loss events (property damage, personal injury, fatality) during highway O/M activities.

Preliminary Background Summary

A brief review of existing literature found little research on the issue of risk management for highway O/M activities. Elrahman and Perry (1998) developed guidelines for nighttime maintenance operations. Manion and Tighe (2007) investigated private sector highway maintenance contracts in Australia and New Zealand that utilize safety performance measures, which may have application to public sector operations as well. Venugopal and Tarko (2000) developed safety models for maintenance work zones on rural freeways based on crash data and traffic volumes.

A Colorado Department of Transportation (DOT) report (Chinowsky and Howell, 2009) indicated that highway maintenance field workers and superintendents had little training in job safety analysis and that job safety analysis needs to be concise and specific to maintenance tasks in order to be effective. Supervisors interviewed in the Colorado DOT maintenance worker safety study suggested that a differentiation between “high risk” and “low risk” activities would allow for improved job safety analysis. In other words, the focus of job safety improvements should be directed towards high-risk activities, instead of treating all maintenance worker activities as equally important in terms of risk mitigation.

Maintenance worker accident rates were lowered after introduction of a comprehensive, integrated risk and safety plan in the Washington DOT. The Oregon DOT has experienced one of the lowest safety incidence rates since it adopted an integrated approach to safety which identifies safety actions at every level of the organization. The Utah DOT Risk Management Office uses an integrated team concept to achieve one of the lowest safety incidence rates in the nation (Chinowsky and Howell, 2009).

The integrated risk model for operations and maintenance activities described in this research proposal is one such technique that will assist transportation agency leaders in creating safer, more efficient maintenance work zones. The Integrated Risk Management Model is a different concept than the Standard Risk Management process. It actually integrates the formal risk management plan into the existing corporate structure so that it can be used throughout the project life-cycle. The following flow-chart (Figure 1) illustrates the difference of the Integrated Risk Management Model to the Standard Risk Management Model.

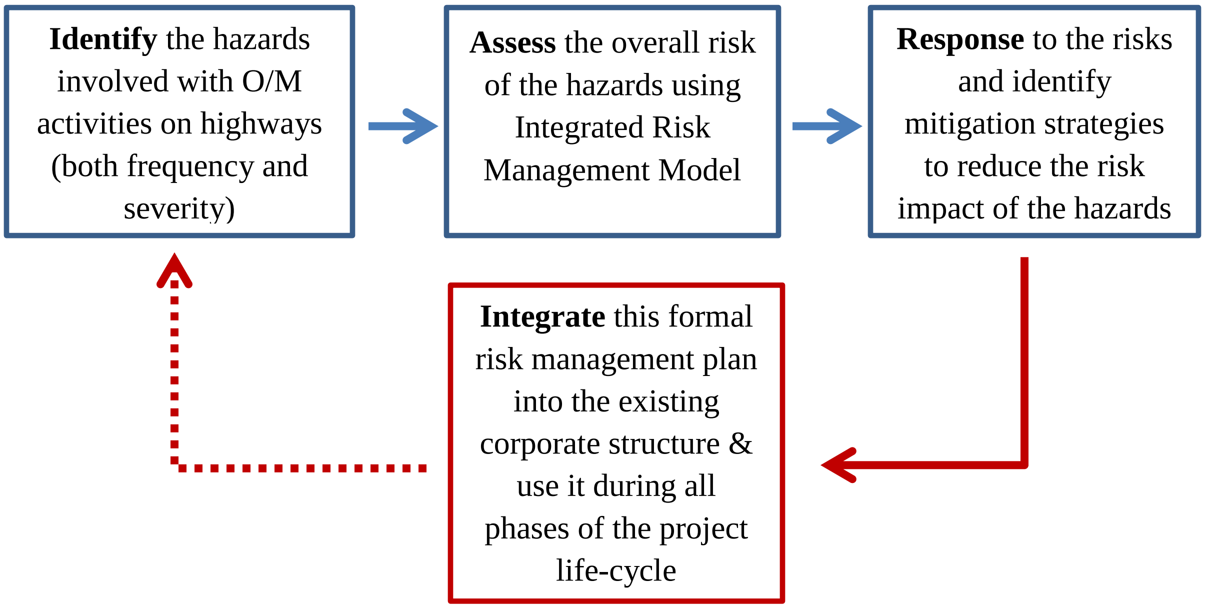

Figure 1. Integrated Risk Management Model

In Figure 1, the activities marked in blue color are a part of the Standard Risk Management Process but when these concepts are integrated into the corporate structure of the organization it is termed as the Integrated Risk management Model (shown by the activity / procedure marked is red). The Integrated Risk Management Model form a kind of loop structure and all the steps that are followed in a standard risk management process has to be followed and repeated throughout the project life-cycle. Basically, it is a concept that integrates the maintenance activities and managing the risks related to those activities properly by imparting proper training to the workers, planning the traffic controls for the work zones to render a safer work zone.

Research Objectives

The objective of this research is to investigate the application of integrated risk modeling to O/M activities, specifically moving operations such as pavement testing, pavement marking, painting, guardrails repairing or replacement, shoulder work, or mowing. The ultimate goal is to reduce frequency and intensity of loss events (property damage, personal injury, and fatality) during operations and maintenance activities. Potential risk factors explored include issues such as:

- Traffic level / Congestion
- Number of roadway lanes
- Posted speed limit
- Inadequate / improper signage
- Inadequate / improper vehicle lighting and marking
- Insufficient worker training
- Proximity of obstructions (equipment) to traveled roadway
- Physical limitations of crash attenuators
- Limitations of equipment due to the specialized nature of the fleet
- Weather (condition of road surface, visibility)
- Work under traffic (inadequate separation or lack of detours / lane shifts)

After potential risk factors had been identified and loss severity has been evaluated, the research team will identify risk mitigation strategies that can be used within integrated teams to reduce the frequency and / or severity of losses during O/M activities.

Anticipated benefits and contributions

Apart from the above mentioned specific research objectives, this research study is extremely important in term its applications both academically and industrially. The present research study has developed the “Mixed Methods of Analysis” which is new and used for the first time in these kinds of research studies involving work zone risks and safety. Most of the studies have focused on either only on the crash data information or on the information obtained from expert interviews and surveys. None of the studies have used all these methodologies together which makes this research study unique in its respect. Thus introduction of the “Mixed Methods of Analysis” methodology takes the researchers a step forward in the field of construction research. Secondly, there is a very few research studies that have focused on the safety of the maintenance and mobile operations work zone, though none of the researches have studied the risks involved in the mobile operations using a system level analysis. The present research study explores this area and takes an attempt to identify the risks involved in the mobile work zones, assesses and compares the various types of risks involved and develops risk response strategies that should be adopted to mitigate the impacts of those risks. Finally, the results of this research study provides a new insight to the transportation industry people about the various types of risks that may be involved in the mobile operations and the new safety techniques that should be adopted to minimize the risks. The research also introduces the new concept of Integrated Risk Management Model (Figure 1) that would help to manage the maintenance and mobile operations risks as explained before.

CHAPTER 2. LITERATURE REVIEW

The literature review is intended to identify the current and common practices that have been adopted by the different state DOTs and also other agencies over the world for safe and efficient maintenance and operations of highways. The review also attempted to find out some of the factors that increase the likelihood of vehicle crashes during any type of mobile operation on highways like testing, painting, repairing and replacement of the guardrails and how the different agencies take precautionary measure to mitigate the chance of crashes due to these factors. However, it has been found that most of the research has been done on the impacts of weather and different climatic changes on highways and other surface transportation systems with a few studies focusing on the identification of traffic control devices and safety for mobile and short duration work zones. Much less focus has been given to a comprehensive examination of risk factors and mitigation strategies for mobile operations, which is the focus of this research project. This chapter is organized into two sections:

- Impact of weather or environment on highways
- Mobile and short duration operations / Maintenance activities and equipment

Impact of Weather / Environment on Highways

The National Research Council estimated that drivers endure over 500 million hours of delay annually on the nation's highways and principal arterial roads because of fog, snow, and ice, excluding delays due to rain and wet pavement (Qin, et al. 2006). Furthermore, 1.5 million vehicular crashes each year, accounting for approximately 800,000 injuries and 7,000 fatalities are related to adverse weather and it has been found that the injuries, loss of lives, and property damage from weather related-crashes cost an average of 42 billion dollars in the U.S. annually (Qin, et al. 2006).

The weather and climate change have a great impact on the surface transportation's safety and operations. In future with the increase in global warming transportation managers would need to modify the advisory, control and treatment strategies to an appropriate level and implement several modern risk mitigation strategies to limit the weather impacts on roadway safety and operations (Pisano, et al. 2002). Moreover, weather also acts through visibility impairments, precipitation, high winds, temperature extremes and lightning to affect driver capabilities, vehicle maneuverability, pavement friction and roadway infrastructure. The combination of adverse weather and poor pavement conditions contributes to 18 percent of fatal crashes and 22 percent of injury crashes annually [National Center for Statistics and Analysis, 2001] (Pisano, et al. 2002).

The crash risk increases during rainfall, especially if rain is followed after a period of dry weather. In fact, the crash risk during rainfall was found to be 70 percent higher than the crash risk under clear and dry conditions *(*Pisano, et al. 2008). In winter however, the drivers adjust their behaviors sufficiently to reduce the crash severity during snowfall but not enough to lower the crash frequency. The traffic volumes during snow events were also found to be 30 percent lower than volumes in clear weather signifying that the drivers themselves become cautious and reluctant to travel during a snow event (Pisano, et al. 2008). Furthermore, on analysis of the ten years of winter crash data on Iowa interstates the crash risk was found to be 3.5 times higher at the start of the winter than it was at the end. The combination of high traffic volumes, relatively high speeds and low traction likely explains why most of the weather related crashes occur during rainfall and on wet pavement. In fact, 47 percent of weather related crashes happen in the rain and the annual cost of these weather related crashes nationally was estimated between $22 billion (includes only those crashes that are reported) and $ 51 billion (including both the reported and un-reported crashes because about 57 percent of the crashes are not reported to police according to the National Highway Traffic Safety Administration [NHTSA] report by Blincoe, et al. (2002). (Pisano et al. 2008). The different strategies recommended in the research to mitigate these kinds of weather related risks are advisory (announcing the road weather information prior to the actual event so that the drivers can take precautionary measures), control (access control, speed management and weather related signal timing are the three different types of control that increase the road safety) and treatment strategy (includes fixed and mobile anti-icing / de-icing systems and chemical sequences).

Several road weather management research programs targeted towards traffic management, emergency management and winter maintenance management would help to increase the safety, mobility and productivity of the nation's roadways and would also benefit national security and environmental quality. Research by Goodwin (2003) on the best practices for road weather management contained 30 case studies of systems in 21 states that improve the roadway operations under inclement weather conditions including fog, high winds, snow, rain, ice, flooding, tornadoes, hurricanes and avalanches. This research also mentioned three types of mitigation strategies in response to the control threats i.e. advisory (provide information on prevailing and predicted conditions to both transportation managers and motorists), control (restrict traffic flow and regulate roadway capacity) and treatment strategies (apply resources to roadways to minimize or eliminate weather impacts). Alabama DOT developed and installed a Low Visibility Warning System integrated with a tunnel management system to reduce the impact of low visibility due to fog. California DOT (Caltrans*)* developed the Motorist Warning System for use during low visibility caused by windblown dust in summer and dense, localized fog in the winter. In Aurora Colorado, a Maintenance Vehicle Management System (MVMS) was implemented to monitor the operation of maintenance vehicles including snow plows and street sweepers. Vehicles were outfitted with MVMS equipment and a GPS system, which tracked the location of the vehicles. This information was controlled centrally, allowing for the transmission of pre-programmed, customized messages to a single vehicle, a selected group of vehicles, or to all the vehicles. The MVMS could also monitor road treatment activities. With the MVMS monitoring system, transportation managers could easily provide information to the citizens about operations and maintenance activities on a particular street or roadway. Also, treatment costs were minimized and productivity increased twelve percent.

Qin, et al. (2006) conducted a research to investigate the impact of snowstorms on traffic safety in Wisconsin. The temporal distribution of the crash occurrence showed that a large percentage of the crashes occurred during the initial stages of the snowstorms indicating it to be the most risky time of travel on the highways during a snowstorm. The factors responsible for the risks were low friction pavement, which makes operating and maneuvering of vehicles difficult, impaired visibility due to blowing snow or fog, which limits drivers' sight distance, accumulating or drifting snow on the roadway, which covers pavement markings and obstructs the vehicles, drivers' inadequate perception and comprehension of the snowstorm event, and also high traffic volumes. Qin, et al. (2006) also found that the highest risk of crashes occurred at traffic flow rate from 1,200 to 1,500 vehicles per hour per lane under snow conditions. In the same study, the researchers also found that higher wind speeds / gusts pose high risks causing more severe crashes than higher snowfall intensity. The mitigation strategies suggested by the researchers to render a "passable roadway" (roadway surface free from drifts, snow ridges, ice and snowpack and can be traveled safely at reasonable speeds without losing traction by the vehicles) were proper winter maintenance operations such as snow plowing and de-icing techniques like salting and sanding.

In United States, the crash frequency was eight times higher on a two-lane highway and 4.5 times higher on a multilane freeway before the de-icing techniques were applied than that after the application; the crash frequency was nine times and seven times higher on two-lane highways and multi-lane freeways respectively before the application of salt than after the application with a crash severity reduction of 30 percent (Qin, et al. 2006). The outcomes of this research by Qin, et al. (2006) were as follows: (a) snow plowing and spreader trucks should be sent out prior to the start of the storm event to reduce the number of crashes, (b) the winter maintenance crews should be deployed earlier to significantly reduce crash occurrence, (c) severity of snow storm and snow fall will increase crash occurrence, and (d) higher wind speed causes more severe crashes. An interesting result from this study was that freezing rain does not cause more crashes than non-freezing rain, which is counter intuitive given the notoriety of the "black ice" phenomenon pavements.

Research by Shi (2010) recommended several best practices for winter road maintenance activities, including the use of a software tool for computer aided design of passive snow control measures to reduce maintenance costs and closure times; use of anti-icing and pre-wetting techniques and; use of improved weather forecasts through several modern technologies such as:

1. Road Weather Information Systems / Environmental Sensor Stations (RWIS-ESS) - Equipment used for aggregation of roadside sensing and processing of data that is used to measure the current weather conditions and road environment such as pavement temperature and pavement conditions in addition to atmospheric conditions and thus aid in winter maintenance decisions;
2. Mesonet - Equipment used as regional networks of weather information integrating the observational data from a variety of sources and thus providing a more comprehensive and accurate picture of the current weather conditions and great potential for improved weather forecasts;
3. Fixed Automated Spray Technology (FAST) - It is used for anti-icing at key locations enabling the winter maintenance personnel to treat potential conditions before the snow and ice problems arise. It is coupled with RWIS and other reliable weather forecasts; it promotes the paradigm shift from being reactive to proactive in fighting the winter storms.
4. Advanced snowplow technologies such as automatic vehicle location (AVL) – It is a vehicle-based sensor, surface temperature measuring devices, freezing point and ice presence detection sensors, salinity measuring devices, visual and multispectral sensors and millimeter wavelength radar sensors have found to be immensely importance in the winter road maintenance procedures
5. Maintenance Decision Support System (MDSS) - A computer-based system that integrates the current weather observations and forecasts to support the response of the maintenance agencies to winter-weather events and provides real time road treatment guidance for each maintenance route.

Mobile and Short Duration Operations / Maintenance Activities and Equipment

As the highway system reaches the end of its serviceable life, it becomes necessary for transportation agencies to focus on the preservation, rehabilitation, and maintenance of these roads. With significant increase in the amount of work zone activities, transportation officials and contractors are challenged with finding ways to reduce the impact of maintenance activities on driver mobility. In addition, agency leaders are sorting out ways to mitigate risks. A study by Sorenson, et al. (1998) on maintaining customer driven highways focused on the efforts by the United States Federal Highway Administration (FHWA) to minimize traffic backups and travel delays caused by highway maintenance, rehabilitation, and reconstruction. The study also investigated traffic management practices and policies intended to cut down on work-zone congestion and minimize crash risks. Lastly, the study identified contracting and maintenance procedures to cut the time from start to finish in pavement rehabilitation projects. Through an extensive interview with 26 state highway agencies, the research formulated the best traffic management practices and policies that most of the states use to cut down on work-zone congestion and to minimize crash risks for drivers and highway workers. Specific examples of state DOT practices identified in the study are discussed below:

Oregon DOT (ODOT) used an innovative contracting technique, awarding contracts based not on the lowest bid, but on a combination of price and qualifications. The innovative contracting introduced a system of awarding incentives if the work is done earlier or a penalty if it is delayed. The use of “lane rental” charged a rental fee to the contractor based on the road user costs for those periods of time when the traffic is obstructed through the lane or shoulder closures. (Sorenson et. al. 1998)

The New Jersey DOT (NJDOT) recommended performing work at night and providing the public with shuttle buses and other transportation alternatives during the construction / rehabilitation of the highways to mitigate the negative impact of the project on traffic flow. They also assigned a state patrol unit full time to state DOT construction projects to assist with traffic control and increase work zone safety. (Sorenson et. al. 1998)

The North Carolina DOT initiated a public information program that informs motorists, businesses, and residents of upcoming road construction and encourages them to use alternate routes. The researchers also interviewed the road users regarding optimizing highway performance and the findings were noteworthy. For example, in addition to reducing traffic congestion caused by work zones, public demanded the following things: (Sorenson et. al. 1998)

- Increased public awareness of the highway construction process
- Longer lasting pavements
- Non-traditional work schedules such as evening and weekend road closures
- Upgraded product performance
- Improved communications with the public – with the help of portable traffic management systems consisting of video detection cameras and a series of variable message signs
- Educating the drivers about how to navigate safely through work zones by using videotapes and other media to describe the construction and rehabilitation process
- High performance hot-mix-asphalt (HMA) to increase the lifetime of the highways and thus minimize disruptions caused by construction and maintenance work.

Moriarty, et al. (2008) examined the impact of preservation, rehabilitation and maintenance activities on traffic. They developed several simulation models to estimate delays, queues, and delay related costs associated with traffic impacts created by work zones. The simulation results provided a low-risk, low-cost environment and helped in improving the planning and design of work zones; however, these simulation results only provided guidance to the users who must have a fundamental understanding of the highway capacity analyses and traffic flow fundamentals.

A study by Paaswell, et al. (2006) entitled “Identification of Traffic Control Devices for Mobile and Short Duration Operations” was conducted to focus on:

- Identification of the state-of-art work zone safety technologies to improve worker safety in mobile work zones;
- Methods for improving the information systems for work zone traffic control to reduce delays and crashes; and
- Introduction of "best practices" for the use of law enforcement to improve work zone safety along with identifying the key issues to be considered from public outreach and information systems.

The study was done for New Jersey DOT (NJDOT) and the team found that most of the NJDOT mobile and short duration work zone crashes were caused by careless driving, speeding and motorist inattention. Hence safety devices should be selected based on their ability to reduce traffic speed through work zones, improve motorists' recognition of work zone hazards, and improve motorists' attention to signs in the work zone. The researchers also noted operational problems with mobile work zone configurations in Texas DOT that included the improper use of arrow-boards, the lack of uniform procedures for freeway entry and exit, large spacing between caravan vehicles, and unnecessary lane blockage by the caravan. The California DOT (Caltrans) conducted the Caltrans Worker Safety program which included construction and maintenance worker safety orientation and a District Driver Training Program to eliminate employee preventable vehicle accidents (Paaswell, et al. 2006).

FHWA recommended the use of automated enforcement and intrusion alarms as well as uniformed police officers to improve traffic safety at highway work zones. Motorist's information about the work zones, education and outreach systems, and proper training of the workers were mentioned as important factors responsible for decreasing the risks of crashes in mobile work zones. The review of work operations found that safety for mobile operations of pothole patching, sweeping, spraying and mobile patching was in accordance with the Manual on Uniform Traffic Control Devices (MUTCD) requirements but workers requested improved devices such as strobe lights and improved reflective materials for signs to get driver's attention (Paaswell, et al. 2006). The

Paaswell studies are very thorough and provide several informative findings, which are summarized in Table 1, Table 2, Table 3, and Table 4.

Table 1. Effective technologies / safety devices for mobile operations: Lights, Signs and Markings

Institution / Agency	Special lights / Signs / Indicators / Markers													
	Fluorescent / Bright lights (Yellow/Green gives best visibility)	Advanced Warning signs	Variable Message signs (VMS)	Flashing lights	Dancing Diamonds (Lights)	Rotating lights / Strobe Lights	Flashing STOP / SLOW Paddle	All-terrain sign & stand	Drone radar / Speed Indicator	Radar triggered Speed Displays	Dynamic Message Signs	Direction Indicator barricade	Lighted raised Pavement Markers	Robotic Highway Safety Markers
New Jersey DOT	**X**								**X**					
Kansas DOT										**X**			**X**	
New York State DOT									**X**		**X**			
Strategic Highway Research Program							**X**	**X**				**X**		**X**
FHWA Research Program	**X**	**X**	**X** (includes flip disk, light emitting diode,fibre-optic, etc.)	**X** (series of synchronous flashing lights)	**X**	**X** (attracts driver's attention)			**X**					

Table 2. Effective technologies / safety devices for mobile operations: Instruments and Technologies

Institution / Agency	Special Instruments / Technologies																	
	Reflectorized/Bright suits & vests	Remotely operated Auto-flagger	Truck mounted Attenuators & Message Boards	CB Wizard Alert System	Rumble Strips	Lane Merger System	White Lane Drop Box	Shadow vehicles	Barrier Vehicles	Advance Warning Vehicles	Cone Shooter	Automated Pavement Crack Sealers	Automated Debris Removal Vehicle	Balsi Beam	Automated enforcement & intrusions alarms	Vehicle Intrusion alarms (both audio & visual)	Salt spreader truck mounted attenuator (TMA)	Queue Detector
New Jersey DOT	X	X	X	X	X	X												
Missouri DOT				X	X (orange)		X											
Kansas DOT				X														
California DOT (Caltrans)								X	X	X				X				
New York State DOT					X													
Strategic Highway Research Program				X	X (Portable)						X	X Longitudinal & Random Crack sealers	X	X		X	X	X
FHWA Research Program			X		X										X	X		

Table 3. Techniques adopted for safer mobile work zones

Institution / Agency	Different techniques adopted				
	Uniformed Police Enforcement in work zone	Reduced Channelization Spacing	Enhanced Flagger Stations	Reduced Speed Limits	Education & outreach systems for training of workers
New York State DOT	X	X	X	X	
FHWA Research Program	X				X

Table 4. Criteria satisfied by selected work zone devices / equipment

Work Zone Device	Criterion				
	1	2	3	4	5
Truck Mounted Attenuator	Partly Satisfy	Fully Satisfy	Partly Satisfy	Partly Satisfy	Fully Satisfy
Vehicle Intrusion Alarm	Does not satisfy	Fully Satisfy	Partly Satisfy	Does not satisfy	Does not satisfy
Rumble Strips	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Does not satisfy
All Terrain Sign and Stand	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Directional Indicator Barricade	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy
Flashing Stop/Slow Paddle	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy
Opposing Traffic Lane Divider	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Queue Detector	Partly Satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Remotely Driven Vehicle	Partly Satisfy	Fully Satisfy	Partly Satisfy	Partly Satisfy	Fully Satisfy
Portable Crash Cushion	Partly Satisfy	Does not satisfy	Fully Satisfy	Partly Satisfy	Does not satisfy
Cone Shooter	Fully Satisfy	Does not satisfy	Partly Satisfy	Does not satisfy	Partly Satisfy
Pavement sealers	Fully Satisfy	Does not satisfy	Partly Satisfy	Partly Satisfy	Partly Satisfy
Debris Removal Vehicle	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy	Partly Satisfy
Balsi Beam	Fully Satisfy	Partly Satisfy	Fully Satisfy	Fully Satisfy	Partly Satisfy
Robotic Highway Safety Marker	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy	Does not satisfy

Does not satisfy   Partly Satisfy   Fully Satisfy

Table 4 shows the evaluation criteria for certain device functionality in mobile operations that would provide assistance in selecting appropriate traffic control devices for worker safety and the safe and efficient movement of traffic through mobile and short duration work zones. The Paaswell study (2006) classified the device functionality into five categories based on the utility and effectiveness of those devices mentioned in the study. The five criteria are:

i. Reduce exposure to the motorists / crew - 1
ii. Warn motorists / crew to minimize the likelihood of crash - 2
iii. Minimize severity of crashes once they occur - 3
iv. Provide separation between work crew and traffic - 4
v. Improve work zone and traffic control devices' visibility - 5

Some Innovative Technologies: Identified by Paaswell, et al. (2006)

1. **Balsi Beam** – Developed by Caltrans, the Balsi Beam (Figure 2), has great potential for protecting exposed workers in short duration work operations. The beam provides a positive protection from errant vehicles and is crash worthy as tested by NCHRP criteria. Unlike portable concrete median barriers which are labor / equipment intensive to set up and require a 42 inch clear zone between the barrier and the worker, the Balsi Beam can be set up in less than ten minutes and requires no clear zone between the beam and workers. The Caltrans is presently implementing the barrier for specialized concrete construction and bridge repair operations on high speed interstate highways. The beam can be used in maintenance operations wherever workers are exposed to traffic in a limited area for several hours. Caltrans uses the beam for median barrier repairs, bridge deck patching and repairs, slab replacement and joint repairs, installation of bridge sealers and guiderail and parapet repairs. The beam is used in conjunction with other safety equipment, such as truck mounted attenuators, trucks, signs and safety set up.

Figure 2. The Balsi Beam being rotated from side to side

2. **Dancing diamonds (lights)** - These signs use a dancing diamond panel which is a matrix of light elements capable of either flashing and / or sequential displays and acts as an advance caution device.

Figure 3. Dancing diamonds (lights)

3. **Rotating lights / Strobe Lights** - These are effective in getting driver's attention but not as useful in providing speed and closure rate information, especially when the service vehicle has stopped.
4. **Portable Rumble Strips** - These strips are placed temporarily on the road surface at a distance of about 100 meters (250 feet) in advance of the work zone and cause a

vibration in the steering wheel and a rumble as vehicles pass over them, alerting drivers of changing conditions ahead and are best suited for low-speed roads that carry few heavy trucks. These are very easy to use as the device weighs only 34 kg (75 lbs) and one or two workers can deploy it from the back of a pick-up truck.

Figure 4. Portable temporary rumble strips being field tested near Perry, Kansas

5. **Cone Shooter** - This is a machine that can automatically place and retrieve traffic cones and thus can safely and quickly open and close busy lanes without exposing workers to traffic. Typical lane configuration uses 80 traffic cones for each 1.5 miles of lane closure and the cones come in size of 36 inches in general. Manually only three cones can be carried by a worker at a time; thus the cone shooter helps in reducing both the cost and injury involved in mobile work in a busy lane. A picture of the cone shooter in action is shown in Figure 5.

Figure 5. Cone Shooter

6. **Automated Pavement Crack Sealers –** Since one of the most frequent maintenance operations involves crack sealing of the pavements, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center has developed two automated crack sealers – the Longitudinal Crack Sealers and the Random Crack Sealers which perform the same operation with greater efficiency and less time.

Figure 6. Automated Pavement Crack Sealer

7. **Robotic Highway Safety Markers** – In order to use the devices for the mobile work zones efficiently, the Mechanical Engineering Department at University of Nebraska

Lincoln has developed a mobile safety barrel robot. The robotic safety barrels can self-deploy and self-retrieve, removing workers from exposure to moving traffic. The robots move independently so they can be deployed in parallel and can quickly reconfigure as the work zone changes. These devices would be of great advantage in the mobile work zone where the cones or barrels could be programmed to move along with the working crew, saving time and increasing safety to workers.

The Robotic Safety Barrel (RSB) replaces the heavy base of a typical safety barrel with a mobile robot. The mobile robot can transport the safety barrel and robots can work in teams to provide traffic control.

The robotic highway safety markers have been tested in field environments. Each robot moves individually. A single lead robot (general) provides global planning and control and issues commands to each barrel (troops). All robots operate as a team to close the right lane of a highway.

Figure 7. Robotic Highway Safety Marker

8. **CB Wizard Alert System and Program** – CB Wizard is a portable radio that broadcasts real-time work zone information and safety tips through radio channels; the advanced warning will allow drivers the opportunity to moderate their speed and become observant of the need to slow, stop, or maneuver before they reach the work zone or encounter queues of halted vehicles.

Research by Steele and Vavrik (2010) explored the driver behavior and identified some specific challenges that pose a risk for mobile work zones and lane closures such as (a) providing adequate advance warning to motorists; (b) decreasing driver speeds and heightening motorist awareness approaching the work zone; (c) getting drivers to change lanes at a safe distance upstream of the work zone, and (d) maintaining traffic in the open lane until a safe distance beyond the work space. Researchers observed that the return distance of the vehicles in the closed lane on urban expressways (high and low traffic during daytime) was as early as 25 feet in congested and 50 feet under free-flowing traffic while the rural interstate traffic was more relaxed, returning to the closed lane 100 feet beyond the lead traffic control truck. However, in all cases, traffic came back into the closed lane at distances where workers would normally be present. It was also observed that increasing the visibility of the work crew by placing a lead truck downstream is an effective means of extending the buffer space at least by 200 feet and deterring drivers from returning to the closed lane too soon. Observation was also made about the work space length. The analysis of predicted roll-ahead distances for truck mounted attenuators (TMA) impacted by vehicles of different sizes and speeds showed that for typical highway speeds single and multiple-unit trucks were capable of pushing the TMA into the work space creating a dual threat of lateral intrusions. So TMA impacts must be considered when developing traffic control standards. An important conclusion was made regarding nighttime mobile lane closure which created hazardous conditions due to increased traffic speeds, decreased visibility, and increased numbers of impaired drivers. However, the addition of a flashing vehicle on the shoulder of the closed lane and 500 feet upstream reduced the number of vehicles closely approaching the work zone from 18.1 percent to 3.6 percent

The literature review reveals several studies on the impacts of weather on the roadways and hence their effects on work zone along with specific research on the interaction of traffic and operation and maintenance and mobile work zones and related safety. However, these studies did not specifically address risk assessment and mitigation strategies for the operations and maintenance activities on highways. The current research study examines weather (environment), equipment, activities, and related factors to develop a risk severity matrix to indicate the relative severity of each factor on a Likert scale of 1 to 5. An analysis of the Iowa crash database is also performed to generate a model showing the relationships between the various factors and the severity and frequency of crashes in the mobile work zones.

CHAPTER 3. RESEARCH METHODOLOGY

The purpose of this chapter is to describe the research methods used to develop the Integrated Risk Management Model and identify, assess and respond to the risks associated with highway operation and maintenance activities such as pavement testing, pavement marking, painting, shoulder work, mowing, etc. As mentioned earlier, the ultimate goal of this research is to reduce the frequency and severity of loss events (property damage, personal injuries, and fatalities) during operations and maintenance activities. After potential risk factors are identified and loss frequency and severity have been evaluated, the research identifies risk mitigation strategies that can be used within integrated teams to reduce the frequency and/or severity of losses during O/M activities. This chapter is organized into three sections:

- Research planning and organization
- Methodology for crash data analysis
- Methodology for validation survey data analysis

Research Planning and Organization

The research study was planned and organized sequentially to identify the current O/M processes and then analyze the Iowa crash database to develop a statistical model and establish a relationship between the different factors and the severity of the crashes. All these results were validated through a survey and the risk mitigation strategies were identified with the help of a thorough literature review and discussion with the Technical Advisory Committee (TAC) members for the research project. The methodologies that were adopted in this research can be listed as follows:

- Identification of current O/M processes
- Literature review
- Analysis of the crash data
- Validation survey
- Identification of mitigation strategies

Identification of current O/M processes

This research study started with a discussion with the Technical Advisory Committee (TAC) members to identify and map the O/M processes currently utilized by state, county and local agencies. This expert panel session helped in categorizing the activities, environments, tools / equipment and relationships involved with O/M activities.

Literature Review

An extensive literature search was performed and a preliminary list of risk factors and loss events during O/M activities was identified. The search mainly included results from academic journals, trade publications, transportation research technical reports, and state Department of Transportation web sites. The primary websites used to facilitate the search for relevant publications were Google Scholar, Transportation Research Board (TRB), Iowa State University Library and Iowa DOT Library. The literature search also gave an insight to how the identified factors play a role in mobile work zone crashes, specifically work zones that involve O/M activities on highways.

Analysis of the Crash Data

The analysis of the crash database provided by the Iowa DOT played a very important role in the development of the Integrated Risk Management Model. In order to obtain information about the relevant crashes, a query was created to gather data for all severity level of crashes from 2001 to 2010 that involved two types of work zones – "Intermittent or moving work" and "Work on shoulder or median". The methodology adopted for the crash data analysis is described in the next section.

Validation Survey

The loss events identified in the literature review and crash data analysis were validated in a short survey that was administered to state, county, and local O/M personnel, including both "office" and "field" personnel. The survey assisted the research team in prioritizing loss events in order of risk (frequency and severity). The detailed methodology used for developing the survey and utilizing it as one of the validation tools for the research is described in a later section.

Identification of the Risk Mitigation Strategies

After potential risk factors had been identified, and frequency and severity had been estimated, the research identifies risk mitigation strategies that could be used to reduce the frequency and/or severity of losses during O/M activities. Potential mitigation strategies were identified after a meeting with the TAC members which are described in Chapter 6.

Methodology for Crash Data Analysis

The suitable variables in the crash database that were able to explain the effect of the previously identified factors (i.e. activities, environment, tools / equipment and relationships) were queried to analyze their effect on crash severities and the frequencies with which they occur within the database. The entire analysis was performed using the transportation data analysis software LIMDEP. The variables selected from the crash database to analyze the risk posed by each of the factors in O/M activities are shown in Table 5.

Table 5. Variables queried from the Iowa crash database

Data Field (crash data) & Field Description	Categories
CRASH SEVERITIES	
CSEVERITY: The crash severities as measured are	• Fatal • Major Injury • Minor Injury • Possible or Unknown Injury • Property Damage Only (PDO)

Table 5. Variables queried from the Iowa crash database (contd.)

ACTIVITIES	
WZ_Type: Type of the work activities involved)	• Work on shoulder or median • Intermittent or moving work
EQUIPMENT	
FIRSTHARM: When the first harmful event is collision with	Impact Attenuator (fixed object)
SEQEVENTS1: In the sequence of events, when the 1st event is collision with	Impact Attenuator (fixed object)
EmerVeh: What the emergency vehicle type is	Maintenance Vehicle
EmerStatus: It indicates the emergency status of the vehicle considered	• In emergency • Not in emergency
VCONFIG: What the vehicles involved in the crash are	• Passenger car • Four-tire light truck • Van or mini-van • Motor home / recreational vehicle • Motorcycle and sport utility vehicle • Mopeds / Motorcycle • Trucks and tractors (Single-unit truck-2 axle, Single-unit truck >= 3 axles, Truck / trailer, Truck tractor, Tractor / semi-trailer, Tractor / doubles, Tractor / triples and other heavy trucks) • Bus (School bus - > 15 seats, Small school bus – 9 to 15 seats, Other bus - >15 seats and other small bus – 9 – 15 seats) • Maintenance or construction vehicle
ENVIRONMENT	
LIGHTING: Derived Light Conditions	• Daylight • Darkness • Morning Twilight • Evening Twilight

Table 5. Variables queried from the Iowa crash database (contd.)

VISIONOBS: What the vision is obstructed by	• Moving vehicle • Frosted windows / windshield • Blowing snow • Fog / smoke / dust • Sleet / hail / freezing rain • Snow • Blowing sand / soil /dirt
TRAFCONT: The traffic control signs present in the accident zone are	Work zone signs
RAMP: Location of the crash	Mainline or ramp
ROADCLASS: the road classification	• Interstate • US Route • Iowa Route • Secondary Route • Municipal Route • Institutional Road
RCONTCIRC: What the contributing circumstances in the roadway are	• Work zone (Construction / maintenance / utility) • Traffic control device inoperative / missing / obscured
Weather1: Weather Conditions	• Cloudy • Fog / Smoke • Rain • Sleet / Hail / Freezing rain • Snow • Blowing sand or soil or dirt or snow
WZ_LOC: Location of the crash	• Before work zone warning sign • Between advance warning sign and work area • Within transition area for lane shift • Within or adjacent to work activity • Between end of work and work area and End of work zone sign • Others

Table 5. Variables queried from the Iowa crash database (contd.)

DRIVER CHARACTERISTICS	
DAGEBIN1: Age of the driver (in years)	• When driver's age <=18 years • When driver's age > 18 years and <25 years • When driver's age >= 25 years and <45years • When driver's age >= 45 years and <65years • When driver's age >= 65 years
DRIVERGEN: Driver's gender	• Male • Female
DL_STATE: Driver's license state	• Iowa – In state • Others – Out of State

The Integrated Risk Management Model consists of two parts – (a) factors contributing to the severity of the crash and (b) the frequency of the factors involved in the crashes. In this research study the significance of the factors contributing to the severity of the crash is assessed by developing a statistical model (as described in the next section) and the frequency of those factors that are found to be significant in the model is assessed through descriptive statistics of the Iowa crash database.

Assessment of severity

The data collected from the Iowa DOT crash database consists of 55,042 crashes that occurred during the years 2001 to 2010 involving "Intermittent and moving work zones" or "Work on the shoulders or median". The severity of the crashes which are discrete but ordered is the dependent variable for the analysis.

The severities as obtained from the crash database include five categories: Fatal, Major Injury, Minor Injury, Possible or Unknown Injury and Property Damage Only (PDO). The percentage frequency of categories i.e. Fatal, Major Injury, Minor Injury, Possible or Unknown Injury and Property Damage Only (PDO) were 0.88 percent, 1.52 percent, 14.96 percent, 20.80 percent and 61.84 percent respectively and the distribution of these crash severities is shown in Figure 8.

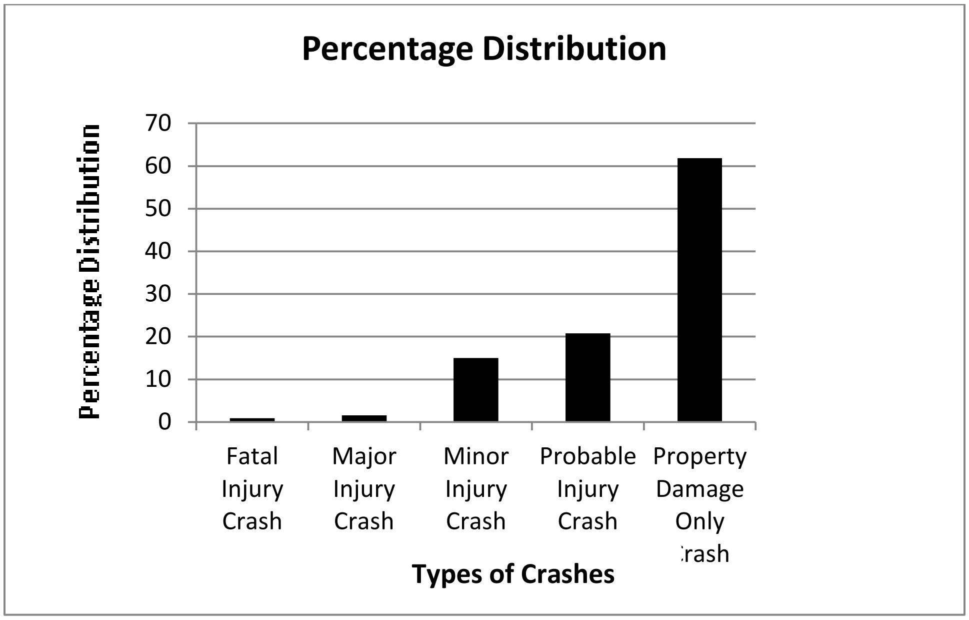

Figure 8. Original percentage distribution of the crashes

It is observed that the categories Fatal and Major Injuries do not have significant numbers of observations and so it was decided to combine these into one category as Fatal-Major Injury while the others are kept the same (Figure 9). The new percentage frequencies for the categories are as follows: Fatal-Major Injury [y=3] = 2.40 percent; Minor Injury [y=2] = 14.96 percent; Possible / Unknown Injury [y=1] = 20.80 percent; and PDO [y=0] = 61.84 percent.

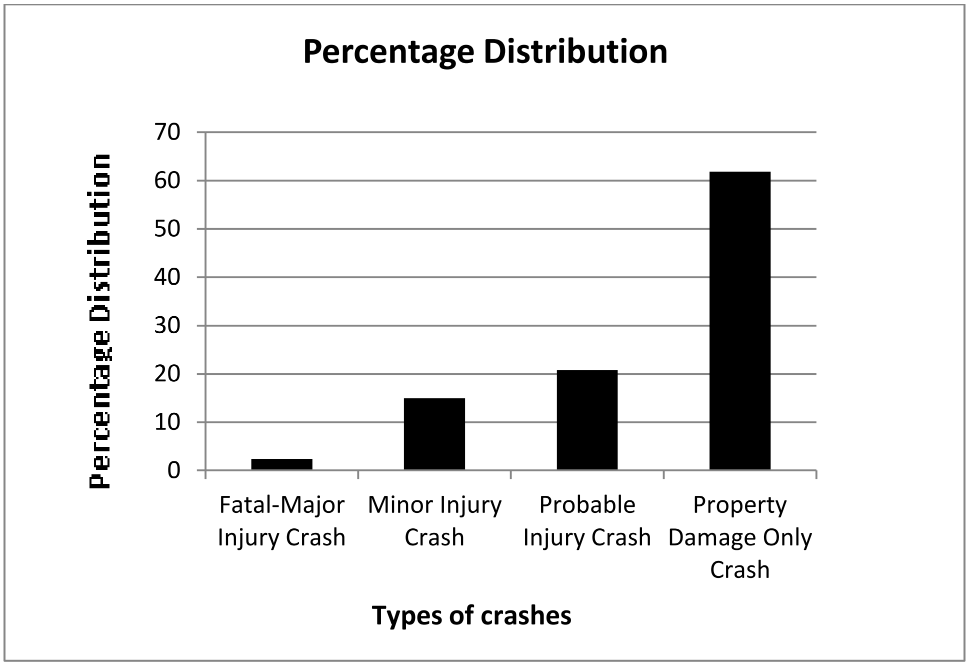

Figure 9. Percentage distribution of the crashes after transformation

To determine the effect of each factor on the severity of the crashes, a statistical approach was needed. Standard multinomial discrete-outcome modeling methods such as the Multinomial Logit Model were a possibility but such models do not take into account the ordered nature of the data (Fatal Injury, Major Injury, Minor Injury, Probable or Unknown Injury and Property Damage Only crash severities) and the comparative analysis of the probability of a factor (hazard) to cause either a Fatal Injury crash or a Major Injury crash or Minor Injury crash or a Probable / Unknown Injury crash or a Property Damage Only Crash could not be determined. This would also result in a loss of parameter efficiency (Choocharukul, et al. 2004 and Shafizadeh, et al. 2006). Thus to account for both the ordered and discrete nature of the data, an ordered probit modeling approach was appropriate (for more details see Washington, et al. 2003).

The desired outcome of the Ordered Probit Model is to obtain an optimized linear function in terms of an unobserved variable z that is used as the basis for modeling the ordinal ranking of data (in this case, the severity ranking of the crashes). This unobserved variable is typically specified as a linear function for each observation, *n* such that –

$$z_n = \boldsymbol{\beta X_n} + \varepsilon_n \quad (1)$$

where, $\boldsymbol{X_n}$ is a vector of variables (such as equipment, environment and driver characteristics) determining the discrete ordering for the crash severities, $\boldsymbol{\beta}$ is a vector of estimable parameters, and ε_n is a random disturbance. Using this equation, observed crash severity, y_n, for each observation is written as (with Property Damage Only Crash, Probable / Unknown Injury Crash, Minor Injury Crash and Fatal-Major Injury Crash corresponding to y = 0, 1, 2 and 3 respectively),

$$\left.\begin{array}{l} y_n = 0 \text{ if } z_n \leq \mu_0 \\ y_n = 1 \text{ if } \mu_0 < z_n \leq \mu_1 \\ y_n = 2 \text{ if } \mu_1 < z_n \leq \mu_2 \\ y_n = 3 \text{ if } z_n \geq \mu_2 \text{ ,} \end{array}\right\} \quad (2)$$

where μ's are estimable parameters (referred to as thresholds) that define y_n. The μ's are parameters that are estimated jointly with the parameter vector $\boldsymbol{\beta}$. The estimation problem then becomes one of determining the probability of a crash involving a fatal-major injury or a minor injury or a probable / unknown injury or just property damage for each observation n, which is done by making an assumption on the distribution of ε_n in Equation (1). It is assumed that the disturbance terms, ε_n be normally distributed across observations with mean = 0 and variance = 1 [$\varepsilon \sim N(0, 1^2)$]. It can be shown that μ_0 can be set to zero without loss of generality (Washington, et al. 2003). With these assumptions, an Ordered Probit Model results (Figure 10) with selection probabilities,

$$P(y_n = 0) = \varphi(- \boldsymbol{\beta X})$$

$$P(y_n = 1) = \varphi(\mu_1 - \boldsymbol{\beta X}) - \varphi(- \boldsymbol{\beta X})$$

$$P(y_n = 2) = \varphi(\mu_2 - \boldsymbol{\beta X}) - \varphi(\mu_1 - \boldsymbol{\beta X})$$

$$P(y_n = 3) = 1 - \varphi(\mu_2 - \boldsymbol{\beta X})$$

where φ (·) is the cumulative normal distribution,

$$\varphi\,(u) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{u} e^{-\frac{1}{2}w^2}\,dw$$

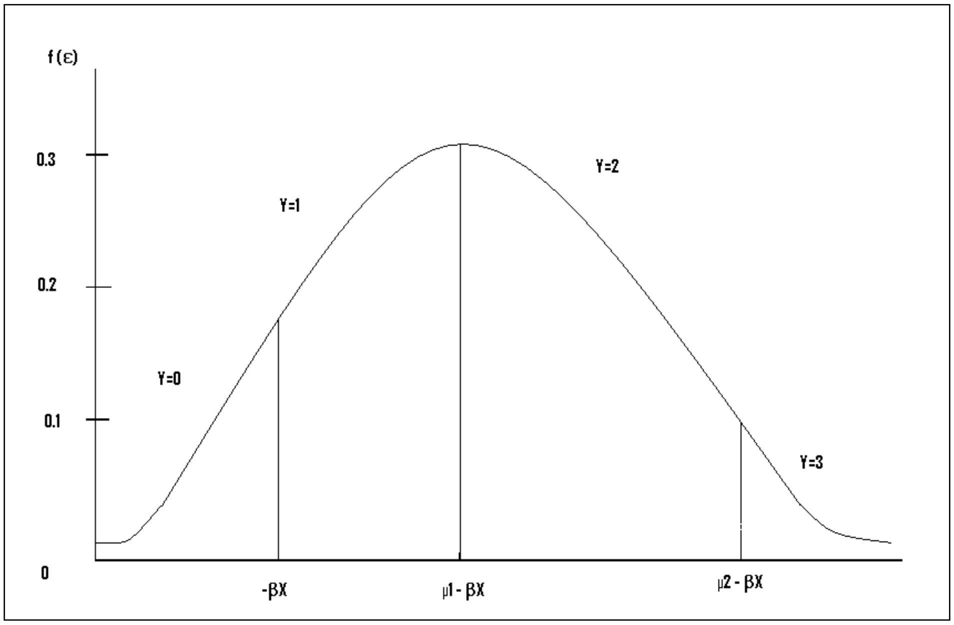

Figure 10. Illustration of an Ordered Probability Model with μ0 = 0

This model can be estimated by standard maximum likelihood procedures of a standard Ordered Probability Model. For a detailed explanation, see Washington, et al. (2003).

The number of threshold parameters for the probit analysis will be two (μ1 and μ2), when the lowest threshold is set at zero. In terms of interpreting the effect of individual coefficients in ordered probability models, a positive value of a coefficient implies that an increase in the variable will unambiguously increase the probability of the highest order discrete category being selected (y=3) and unambiguously decrease the probability of the lowest-ordered discrete category being selected (y=0). The estimated coefficients however do not provide a clear indication of how changes in specific explanatory variables affect the probabilities of intermediate ordered categories (y = 1 or 2). Instead marginal effects (see the definition in Chapter 4) can be computed for each category threshold. For indicator variables created, the effects are computed as the difference in the estimated probabilities with the indicator variable changing from zero to one, while all other variables are equal to their means [Shafizadeh and Mannering (2006), Washington, et al. (2003)].

The statistical significance of the different variables in the model is estimated using a one-tailed t-test and 90 percent confidence ($\alpha = 0.10$). The critical cut-off value for the t-statistic is 1.28 for large sample sizes (e.g. sample size > 100). The 90 percent confidence interval (CI) is chosen instead of a smaller CI such as 95 percent or 99 percent because the data set being very large and consisting of data spanning over ten year contains a lot of variance and a smaller CI would result into elimination of a number of factors from the risk consideration. Moreover since the major objective of the research study was to identify the factors in terms of their risks impacts (considering both the frequency of occurrence and the severity of impact) on the crashes, a smaller CI was not considered.

After the significant factors are identified along with their relationship to the different categories of crashes, they are ranked on a scale of 1-5, 1 being the least severe and 5 being the most severe according to their impact on a crash.

Assessment of frequency

The frequency of the factors involved in the crashes is determined from their descriptive statistics and is expressed as the percentage of the total crashes. This was then evenly categorized on a scale of 1-5, 1 being very rarely occurring and 5 being very frequently occurring. While considering the frequency of the occurrence of the variables, the “exposure” factor was not taken into account.

Methodology for Validation Survey Data Analysis

The surveys were sent out to Traffic and Safety and Operations and Maintenance divisions of Iowa DOT and American Traffic Safety Services Association (ATSSA) and they were asked to distribute it to their counterparts in order to get a better response rate.

The survey questions included the O/M activities identified from the expert panel session. The participants were asked to rank those activities from their experience according to the severity and likelihood of occurrence (frequency), both of which were measured with a likert scale ranging from 0-5. The frequency likert scale was defined as follows:

- 0 – Unable to answer
- 1 – Very unlikely
- 2 – Unlikely
- 3 – Neutral
- 4 – Probable
- 5 – Very Probable.

The severity likert scale was defined as:

- 0 – Unable to answer
- 1 – No loss
- 2 – Potential Property Damage
- 3 – Minor Property Damage and / or Minor Injuries
- 4 – Major Property Damage and / or Major Injury
- 5 – Catastrophic Loss or Fatality.

The number of closed ended responses obtained was 24 and number of closed ended responses along with the open ended responses was 33. “Closed end” responses signify those participant’s responses who answered all the questions that were asked in the survey and “Open end” responses signify those participant’s responses who only answered some of the questions but not all of the questions as asked in the survey. This is quite justified as all of the participants may not have knowledge in all of the safety knowledge areas that were asked for. However, for the quantitative analysis of the responses, 33 responses were considered. Because of the small sample size, no statistical tests could be performed with the survey results. These results were only used to validate the results obtained by the statistical analysis of the Iowa crash database.

The relationship between the crash data variables and the survey data variables are shown in Table 6 and this also clarifies how the variables were selected from the crash data base according to the information obtained from the experts in the TAC meeting.

Table 6. Relationship between the survey factors and the variables of the crash data base

Survey Questions / TAC Factors	Crash Data Variables (Proxy)
ACTIVITIES	
All the activities in the "ACTIVITIES" category such as FWD structural testing on pavements and subgrade; core drilling on pavements; straddling and offset painting; pavement markings; crack filling / patchwork; movement of street sweeper / street cleaner; replacing / repairing signals and signage; repairing and installation of centerline guardrails, cable rails and barrier rails; and shoulder grading.	All the factors included in the "ACTIVITIES" category in the survey data are represented by the work zone type in the crash data base i.e. "Intermittent and moving work" and "Work on the shoulder or median". No particular activity was reported as a cause of the crash. This is however used as the criteria for selection of the crashes from the crash data base – WZ_TYPE
ENVIRONMENT	
Nighttime operations; Pavement markings at intersections (at nighttime); Pavement markings at intersections (at daytime)	No daylight situation – NODAYLIT
Improper signs and signage at ramps and roadway intersections near work zones; Absence of proper signage near the work zone; Absence of fluorescent diamond signs; Not using lights / blinkers in the work zone	Traffic control involved with the work zone crash is a work zone signage – TRAFCONW; Regions of the work zone (e.g. region between the advance warning sign and the work area - BETAWWRK; region within or adjacent to the work activity - WTHWRKZN)

Table 6. Relationship between the survey factors and the variables of the crash data base (contd.)

Work zones on roads in hilly areas	Vision obstructed (However, vision not obstructed is considered in the model) – VISIONOBS
Presence of Small towns or schools nearby ; Peak traffic hours; Work near railway crossings	---No particular variable could be identified from the crash database---
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa); Special events such as parades, races, fairs are carried on in local cities and towns	Drivers' license – In state (Iowa) or Out-of-state drivers – OFSMLDR. If the driver is from a different state they would be more likely to have a lack of knowledge about variable peak traffic time in local regions or different rules in the shared jurisdiction or may not have information about some special events carried on in local cities and towns
Clearing roadway for emergency vehicles	When the vehicle involved in the crash is in emergency or not in emergency – MVEHEM, MVHNOEM.
Fog and mist ; Unforeseen weather conditions	When the weather is cloudy, foggy / misty / partly cloudy, or it is raining – CLOUDY, FOGMIST, RAIN
EQUIPMENT	
Falling Weight Deflectometer; Straddling Painters; Cold Mix Patchwork; Media Trucks; Trucks carrying rock / aggregate; Boom Trucks; Pick-up Trucks; Street Sweepers / Street Cleaners; Jet Vac; Maintainers on Gravel roads; Paint Carts (hauled on trailers)	Four tire light truck / pick-up truck – PCKTRK; Trucks and tractors (Single-unit truck - 2 axle, Single-unit truck >= 3 axles, Truck / trailer, Truck tractor, Tractor / semi-trailer, Tractor doubles / triples) – TRCKTRAC

Table 6. Relationship between the survey factors and the variables of the crash data base (contd.)

Friction Testing	Van or minivan – VAN
OTHERS	
Lack of Co-ordination with Municipalities; Work done under full closure; Lack of Co-ordination between state and the local agencies; Lack of Work safety and training programs; Absence of Train the trainers philosophy; Lack of coordination between DOT and ROW regarding Control of Rights of Way (ROW); Improper Third Party Interaction; Not imposing speed limit fines on public; Different rules in shared jurisdictions;	These are some general problems that are present in the construction work zones, may be static or mobile (in this project these are evaluated in terms of the mobile work zones) and particular variables related to these could not be identified from the crash data base.
NOTE: Some other variables not directly related to the survey factors were queried from the crash database and analyzed such as the passenger vehicles, route types, age of the drivers, location of the crash (in the mainline or in the ramp) and the regions of the work zone (e.g. region between the advance warning sign and the work area; region within or adjacent to the work activity)	

CHAPTER 4. DATA ANALYSIS

This chapter explains the results of the statistical analysis of the Iowa crash database and quantitative analysis of the survey data. It also presents the Integrated Risk Management Model developed from the analyses. This chapter is organized into three sections:

- Crash data analysis
- Validation survey data analysis
- Development of Integrated Risk Management Model

Crash Data Analysis

Data Description

In order to perform a statistical data analysis to get an overall idea about the severities and frequencies of the factors involved in mobile work zone crashes, a query was created to gather data for all the severity levels of crashes from the years 2001 to 2010, as provided in the Iowa DOT Saver Crash Data from the Office of Traffic and Safety. From those data that were collected, crashes pertaining to intermittent and moving work zones and work on the shoulder or median were extracted. The relevant factors affecting the crashes were selected from the crash database based on the information obtained from the expert panel meeting (described in Table 6).

Table 7 shows that 55,042 crashes have occurred in mobile work zones which involve intermittent or moving work and also work on the shoulders or medians. Table 7 also shows the number of crashes according to the severity levels over the 10 years from 2001 to 2010.

Table 7. Iowa statewide work zone crash statistics

Year	No. of Fatal/Major Injury Crash	No. of Minor Injury Crash	No. of Possible Injury Crash	No. of PDO Crash	Total
2001	113	1156	469	982	2720
2002	320	68	3471	1212	5071
2003	65	101	524	9454	10144
2004	54	341	1294	4825	6514
2005	117	683	680	2376	3856
2006	17	4424	957	1923	7321
2007	118	133	358	2123	2732
2008	304	804	521	1972	3601
2009	84	195	2594	1290	4163
2010	131	329	579	7881	8920
TOTAL	1323	8234	11447	34038	55042

The rows in Table 7 show the number of crashes according to the different severity levels in each year as well as the total number of crashes. The total number of crashes of a particular severity level that occurred over the ten years is displayed in the columns. The percentage distribution of the number of crashes according to the crash severity levels is shown in Figure 11 and Figure 12.

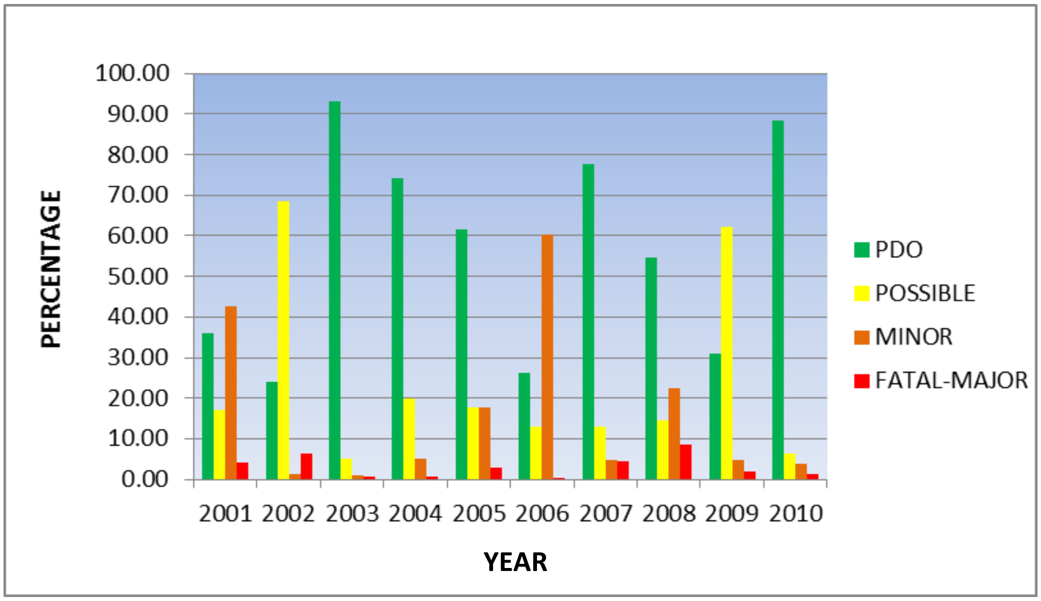

Figure 11. Percentage distribution of statewide work zone crashes according to severities over 10 years (2001 - 2010)

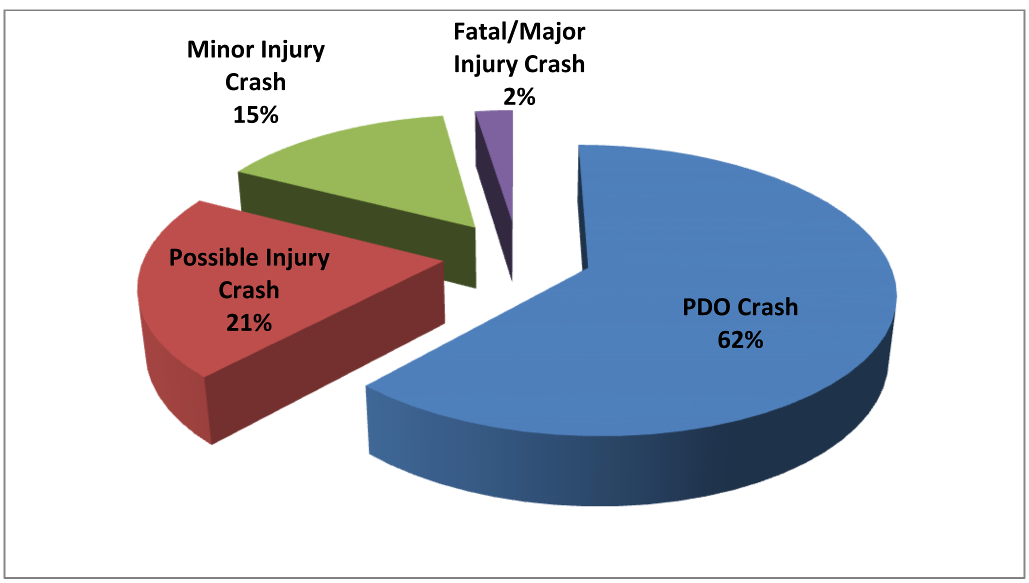

Figure 12. Statewide work zone crash severity distribution—Total crashes (2001 - 2010)

Severity analysis and factor rating according to severity

The crash severity is categorized into five types as defined in the "Investigating Officers Accident Reporting Guide", Iowa DOT, Motor Vehicle Division, Office of Driver Services (January 2001). The categories can be defined as follows:

- **Fatal** – Any injury that results in death within 30 days of the motor vehicle accident
- **Incapacitating / Major Injury** – Any injury, other than a fatal injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred. Inclusions are severe lacerations, broken or distorted limbs, skull, chest, or abdominal injuries, unconsciousness, unable to leave the accident scene without assistance.
- **Non-incapacitating / Minor Injury** – Any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the accident scene, is a minor injury type. Inclusions are lump on head, bruises, abrasions, and minor lacerations.
- **Possible / Unknown Injury** – Any injury reported or claimed which is not a fatal, incapacitating, or a non-incapacitating injury is a possible injury type. Inclusions are momentary unconsciousness, claim of injuries not evident, limping, complaint of pain, nausea, and hysteria.
- **Property Damage Only (PDO)** – Uninjured

It is to be noted that assessment of severity of a particular crash is completely dependent on the reporting officer's assessment and judgment about the degree of severity pertaining to that crash. Moreover, when more than one vehicle is involved in the crash, and one of the vehicles along with its passengers is seriously injured, the degree of severity associated with the most seriously affected vehicle is assigned to all the vehicles in the crash. In one word, the highest severity is assigned to all the vehicles involved in the particular crash. Since the crash narratives were not studied for the crashes occurred due to the intermittent and mobile work zones and works on the shoulders, exact severity category associated with each of the vehicles in a crash could not be determined.

Variables created for analysis along with definitions

The variables that were created to build the model are listed in Table 8. All of the variables created were indicator variables and they were created in such a way that they can portray the effect of the activities, equipment, environment, driver characteristics and some other factors on the crash severities. The variable description along with their frequencies is given in Table 8. Those variables that are marked red were found to be statistically significant at 90 percent confidence level (α=0.10) during the analysis and were used in the model whereas those marked in black were found not to be statistically significant during the analysis and thus were not used in the model.

Table 8. Descriptive statistics and significance of the indicator variables created or used in the model

Variables	**Variable description**	**Frequency**	**Significance indicator**
	EQUIPMENT		
FIRSTHAR	When the 1st harmful event is collision with impact attenuator	0.0004	[black]
SEQEVENT	In the sequence of events, when the 1st event is collision with an impact attenuator	0.0001	[black]
EMRMNTN	When the emergency vehicle type is a maintenance vehicle	0.0068	[black]
MVEHEM	When the maintenance vehicle is in emergency	0.0016	[black]
MVHNOEM	When the maintenance vehicle is not in emergency	0.0052	[black]
PSVEH	Passenger vehicle	0.5429	[red]
PCKTRK	Four tire light truck / pick-up truck	0.1399	[red]
VAN	Van or minivan	0.1026	[red]

Table 8. Descriptive statistics and significance of the indicator variables created or used in the model (contd.)

SUV	Sport utility vehicle	0.1131	
TRCKTRAC	Trucks and tractors (Single-unit truck-2 axle, Single-unit truck>=3 axles, Truck/trailer, Truck tractor, Tractor/semi-trailer, Tractor/doubles, Tractor/triples and other heavy trucks)	0.0772	
BUS	Bus (School bus - > 15 seats, Small school bus with 9 to 15 seats, Other bus - >15 seats and other small bus with 9- 15 seats)	0.0049	
VCNFIGCO	When the vehicle configuration involved in the crash is a maintenance / construction vehicle	0.0077	
ENVIRONMENT			
DAYLIT	If the crash occurs during the daylight	0.8821	
NODAYLIT	If the crash occurs when there is no daylight i.e. during Darkness, Morning Twilight or Evening Twilight	0.1180	
VNOBSCUR	When the driver's vision in not obscured by anything	0.9164	
VOFROSTW	When the driver's vision is obstructed by frosted windows or windshield	0.0002	
VOMOVVEH	When the driver's vision is obstructed by moving vehicle	0.0116	
VOWEATHE	When the driver's vision is obstructed by weather like blowing snow, fog, smoke or dust	0.0068	
NOTFCONT	If no traffic control is present near the work zone where the crash occurs	0.7293	
TRAFCONW	When the traffic control present near the crash work zone involves work zone signs	0.0912	
LOCRAMP	When the location of the crash is near the ramp	0.0545	
LOCMAIN	When the location of the crash is near the Mainline	0.9455	

Table 8. Descriptive statistics and significance of the indicator variables created or used in the model (contd.)

INTERSTA	When the road is classified as an Interstate Route	0.6305	
USROUTE	When the road is classified as a US route	0.1306	
IOWAROUT	When the road is classified as an Iowa Route	0.0680	
SECROAD	When the road is classified as a Secondary Road	0.0545	
MUNIROAD	When the road is classified as a Municipal Road	0.1137	
INSTROAD	When the road is classified as an Institutional Road	0.0009	
RCNTCIRC	When the contributing circumstances of the crash on the roadway involves work zone (construction/maintenance/utility)	0.9509	
CNTNCRCTC	When the contributing circumstances of the crash on the roadway involves Inoperative /Obscured/Missing Traffic Control Device	0.0006	
BLOWSNOW	When the weather condition has blowing snow	0.0027	
CLOUDY	When the weather condition is cloudy	0.1129	
FOGMIST	When the weather condition is foggy or smoky or misty or partly cloudy	0.3121	
RAIN	When the weather condition has rain	0.1633	
SNOW	When the weather condition has snow	0.0024	
BETAWWRK	When the crash location is between the advance warning sign and work area	0.1663	
WTHWRKZN	When the crash location is within or adjacent to the work activity	0.6921	
DRIVER CHARACTERISTICS			
UNDDRI	When driver's age <=18 years	0.0594	
YONDRI	When driver's age > 18 years and <25 years	0.2244	
MDDRI	When driver's age >= 25 years and <45years	0.3499	

Table 8. Descriptive statistics and significance of the indicator variables created or used in the model (contd.)

OLDRI	When driver's age >= 45 years and <65years	0.3304	
VOLDRI	When driver's age >= 65 years	0.0641	
YOGRDRI	When driver's age <25 years	0.2838	
IOWALCNC	When the driver's license is of the state of Iowa	0.7904	
OFSMLDR	Out of state male driver	0.1094	
OFSFMDR	Out of state female driver	0.1002	

Multicollinearity and endogeneity of the variables

Multicollinearity is a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. In this situation the coefficient estimates may change erratically in response to small changes in the model or the data. Multicollinearity does not reduce the predictive power or reliability of the model as a whole but affects calculations regarding individual predictors. That is, a multiple regression model with correlated predictors can indicate how well the entire bundle of predictors predicts the outcome variable, but it may not give valid results about any individual predictor, or about which predictors are redundant with respect to others (information obtained from Wikipedia). Although in context of linear regression, the effects of multicollinearity are well known, these are likely to be the same for the non-linear models such as probit and logit models (Griffiths, et al. 1987). Multicollinearity between two or more independent variables does not actually bias the results but produces large standard errors in the related independent variables which make the parameter estimates inconsistent (Washington, et al. 2003). On the other hand, if the independent variables are correlated to the dependent variables, they are termed to be endogenous variables and the presence of these endogenous variables renders the dataset to be erroneous. When erroneous data are used, the parameter and outcome probabilities are incorrectly estimated which makes the entire model erroneous (Washington, et al.

2003). Thus it is extremely important to ascertain that the independent variables included in the model are neither endogenous nor collinear and the model does not suffer from such specification errors.

Pearson correlation tests were performed to determine the correlation of the variables used in the model. This was also performed using the LIMDEP software. Variables that were correlated with the dependent variable (severity of crashes), i.e. the endogenous variables were excluded from the model. When two or more independent variables were found to be correlated, each of the variables were used in the model separately to check which variable produces a significant effect on the model and the one with the highest effect was selected for the model. Thus, in the final model, neither of the variables were significantly correlated (Table 10).

The Pearson correlation coefficients can range from -1.00 to +1.00. The value of -1.00 signifies a perfect strong negative correlation while the value of +1.00 represents a perfect strong positive correlation. A value 0.00 represents a perfect lack of correlation i.e. the two variables do not vary at all. A negative correlation means that the variables are oppositely related i.e. if one variable increases the respective negatively correlated variable will decrease and vice versa. A positive correlation on the other hand means that if one of the variable increases the other respective positively correlated variable will also increase. With respect to the numerical values, the values closer to 1.00 mean a stronger correlation while those close to 0.00 mean a weaker correlation. A summary for the interpretation of these correlation values are explained in Table 9.

Table 9. Interpretation of Pearson Correlation Coefficient

Pearson Correlation Coefficient (r)	Interpretation
r = 0.00	The two variables do not vary together at all
0.00 < r < 1.00	The two variables tend to increase or decrease together
r = 1.00	Perfect correlation
-1.00 < r < 0.00	One variable increases as the other decreases
r = - 1.00	Perfect negative or inverse correlation

For the present research study, the different range of the coefficient values that were considered for determining the different categories of correlation are:

i. 0.00 to < 0.04 – Weak correlation
ii. 0.04 to < 0.07 – Moderate correlation
iii. 0.07 to ≤ 1.00 – Strong correlation

From Table 10, it is observed that only BETAWWRK and WTHWRKZN have a Pearson correlation value of 0.6697 (highest among all) i.e. they are moderately correlated, but logically they should not be correlated because BETAWWRK means when the crash location is "between the advance warning sign and work area" and WTHWRKZN means "when the crash location is within or adjacent to the work activity", i.e. two are completely different locations. However, in the case of mobile operations, since the traffic control signs are mostly located adjacent to the work activity so these two work zone locations may also bear some common characteristics, as a result of which they are showing a moderate correlation between them.

Table 10. Pearson Correlation Matrix

	PSVEH	PCKTRK	VAN	TRCKTRAC	NODAYLIT	VNOBSCUR	TRAFCONW	LOCRAMP
PSVEH	1	-0.43951	-0.36862	-0.31519	0.09004	0.03374	0.00425	0.06005
PCKTRK	-0.43951	1	-0.13639	-0.11662	-0.04922	-0.00065	-0.01163	-0.0458
VAN	-0.36862	-0.13639	1	-0.09781	-0.03626	0.00915	-0.03683	-0.02844
TRCKTRAC	-0.31519	-0.11662	-0.09781	1	-0.05911	-0.06417	0.07183	-0.01033
NODAYLIT	0.09004	-0.04922	-0.03626	-0.05911	1	-0.0308	-0.00369	0.03729
VNOBSCUR	0.03374	-0.00065	0.00915	-0.06417	-0.0308	1	-0.03137	0.00222
TRAFCONW	0.00425	-0.01163	-0.03683	0.07183	-0.00369	-0.03137	1	0.05828
LOCRAMP	0.06005	-0.0458	-0.02844	-0.01033	0.03729	0.00222	0.05828	1

	PSVEH	PCKTRK	VAN	TRCKTRAC	NODAYLIT	VNOBSCUR	TRAFCONW	LOCRAMP
INTERSTA	-0.00993	-0.04833	0.02512	-0.01022	0.12401	0.11111	-0.13259	0.13252
USROUTE	-0.05873	0.04615	0.05319	0.02554	-0.03203	0.0239	0.06011	-0.03101
SECROAD	-0.0819	0.11153	-0.04613	0.02533	-0.07316	-0.11226	0.06881	-0.05764
CLOUDY	0.10386	-0.04323	-0.06296	-0.02207	0.3446	-0.03828	-0.0368	-0.04011
FOGMIST	-0.09124	-0.03121	0.07902	0.06248	0.10513	-0.00842	0.05628	0.04278
RAIN	0.06901	0.05715	-0.13811	0.02359	-0.14527	0.10646	-0.1058	-0.09546
BETAWWRK	-0.0216	-0.06478	0.03203	-0.00248	0.07642	-0.01194	-0.0318	-0.06058
WTHWRKZN	0.04314	0.07457	-0.04197	-0.0577	-0.04837	0.07175	-0.03134	-0.0733

	INTERSTA	USROUTE	SECROAD	CLOUDY	FOGMIST	RAIN	BETAWWRK	WTHWRKZN
INTERSTA	1	-0.50621	-0.31364	0.03128	0.0051	0.13145	-0.06473	0.156
USROUTE	-0.50621	1	-0.09304	-0.01998	0.06955	-0.12571	0.03849	-0.0842
SECROAD	-0.31364	-0.09304	1	-0.04392	-0.07268	-0.08141	-0.01268	-0.01568
CLOUDY	0.03128	-0.01998	-0.04392	1	-0.17795	-0.15763	-0.13144	0.04851
FOGMIST	0.0051	0.06955	-0.07268	-0.17795	1	-0.22041	0.4005	-0.38347
RAIN	0.13145	-0.12571	-0.08141	-0.15763	-0.22041	1	-0.00244	0.10742
BETAWWRK	-0.06473	0.03849	-0.01268	-0.13144	0.4005	-0.00244	1	**-0.66974**
WTHWRKZN	0.156	-0.0842	-0.01568	0.04851	-0.38347	0.10742	**-0.66974**	1

	PSVEH	PCKTRK	VAN	TRCKTRAC	NODAYLIT	VNOBSCUR	TRAFCONW	LOCRAMP
YOGRDRI	0.09318	-0.00987	-0.0472	-0.07982	0.14974	0.08805	-0.03418	-0.03429
VOLDRI	-0.01958	-0.02176	0.03339	0.01544	-0.07043	0.01502	0.04204	-0.01906
OFSMLDR	-0.04943	0.00412	-0.00638	0.10864	-0.08686	0.05582	0.01575	-0.02312

	INTERSTA	USROUTE	SECROAD	CLOUDY	FOGMIST	RAIN	BETAWWRK	WTHWRKZN
YOGRDRI	0.11819	-0.02062	-0.07445	0.14777	-0.08691	0.10229	-0.05597	0.06469
VOLDRI	-0.143	0.03503	0.06455	-0.03738	0.05953	-0.06251	0.10253	-0.09868
OFSMLDR	0.09976	-0.02355	-0.0457	-0.07889	0.00407	0.24057	0.01754	-0.00817

	YOGRDRI	VOLDRI	OFSMLDR
YOGRDRI	1	-0.16479	0.0543
VOLDRI	-0.16479	1	0.03414
OFSMLDR	0.0543	0.03414	1

The final model of the crash severities was selected after a re-iterative selection of the different independent variables, which are shown in Table 11 and Table 12 with their beta coefficient and statistical significance and the parameter estimates. The final model is represented by the unobserved variable that is created as a linear function of the independent variables and its relation with the severity of crashes (y) and the threshold parameter value (μ).

Z = -1.085 + 0.444 PSVEH + 0.357 PCKTRK + 0.448 VAN + 0.521 TRCKTRAC +0.506 NODAYLIT + 0.292 VNOBSCUR +0.036TRAFCONW + 0.110 LOCRAMP - 0.610 INTERSTA + 0.038 USROUTE + 0.298 SECROAD + 0.785 CLOUDY + 0.079FOGMIST - 0.314 RAIN + 0.854 BETAWWRK + 0.317 WTHWRKZN - 0.222YONGRDRI + 0.154 VOLDRI + 0.148 OFSMLDR (3)

Y=0, when z<=0 (4)

Y=1, when 0 <z <= μ1= 0.762 (5)

Y=2, when μ1 =0.762 < z <= μ2 = 1.915 (6)

Y=3, when z >= μ2 = 1.915 (7)

Table 11. Variable description and results

Variable description	Variable mnemonic	Frequency	Estimated coefficient	t-statistic
Constant			-1.085	-37.71
EQUIPMENT				
Passenger vehicle	PSVEH	0.5429	0.444	25.72
Four tire light truck / pick-up truck	PCKTRK	0.1399	0.357	16.81
Van or minivan	VAN	0.1027	0.448	20.05
Trucks and tractors (Single-unit truck-2 axle, Single-unit truck>=3 axles, Truck/trailer, Truck tractor, Tractor/semi-trailer, Tractor/doubles, Tractor/triples and other heavy trucks)	TRCKTRAC	0.0772	0.521	21.41

Table 11. Variable description and results (contd.)

ENVIRONMENT				
If the crash occurs when there is no daylight i.e. during Darkness, Morning Twilight or Evening Twilight	NODAYLIT	0.1180	0.506	29.67
When the vision in not obscured by anything	VNOBSCUR	0.9164	0.292	15.13
When the traffic control present near the crash work zone involves work zone sign	TRAFCONW	0.0912	0.036	1.97
When the location of the crash is near the ramp	LOCRAMP	0.0545	0.110	4.54
When the road is classified as the Interstate Route	INTERSTA	0.6305	-0.610	-42.62
When the road is classified as the US route	USROUTE	0.1306	0.038	2.09
When the road is classified as the Secondary Road	SECROAD	0.0545	0.298	12.70
When the weather condition is cloudy	CLOUDY	0.1129	0.785	38.67
When the weather condition is foggy or smoky or misty or partly cloudy	FOGMIST	0.3121	0.079	5.24
When the weather condition has rain	RAIN	0.1633	-0.314	-17.24
When the crash location is between the advance warning sign and work area	BETAWWRK	0.1663	0.854	43.23
When the crash location is within or adjacent to the work activity	WTHWRKZN	0.6921	0.317	19.49
DRIVER CHARACTERISTICS				
When driver's age <25 years	YOGRDRI	0.2838	-0.222	-17.43
When driver's age >= 65 years	VOLDRI	0.0641	0.154	7.57
Out of state male driver	OFSMLDR	0.1094	0.148	8.22

Table 12. Goodness of Fit Results

	Threshold Parameter	Estimated coefficient	t-statistic
	μ 1	.762	125.08
	μ 2	1.915	158.26
NO. OF OBSERVATIONS		55042	
Overall fit by ρ – Square	Log likelihood function [LL(β)]	-49278.06	
	Restricted log likelihood [LL(βc)]	-54910.88	
	adjusted ρ - Square = 1-(LL(β)-k) /LL(βc)	0.1021805	
	k= number of parameters in the model	22	
Overall fit by X2estimate	K (No. of parameters in the unrestricted – No. of parameters in the restricted model]	22-3=19	
	-2 [LL(βc) – LL(β)]	11265.64	
	X^2critical [19 d.f.]	50.7955	

Since, -2 [LL(βc) – LL(β)] > $X^2_{critical}$ at α=0.0001, so we can state that the entire model is significant at 99.99% .

The variables that have a larger positive value of estimated β – coefficients are more likely to cause a fatal-major injury than those with a lower positive value of estimated β – coefficients. On the other hand, a larger negative value of the estimated β – coefficients will more likely to cause a property damage type of crash than that having a smaller negative value of the estimated β – coefficients. The adjusted ρ-square value is greater than 0.1. This measure of the goodness of fit result for the model is good for the present research study because of the large sample size. This explains a very little of a large variance rather than a very large of a smaller variance. That is why the ρ-square value is low, but it is accepted for such types of models when the sample size is so large. Moreover, the entire model is highly significant at 99.99 percent confidence level.

Under any given situation of a crash occurring in an intermittent or moving work zone, work on the shoulders or work in the median, the values of the factors generated by the probit model can be analyzed to predict what type of crash (Fatal / Major Injury type, Minor Injury Type, Probable Injury Type or PDO) would result and the graph in Figure 10 portrays the probability of that type of crash.

The marginal effects for each response category (for indicator variables) are computed as the difference in the estimated probabilities with the indicator variable changing from zero to one, while all the other variables are equal to their means (Washington, et al. 2003). These values are relative and they do not carry any specific meaning. There are two ways of estimating how much the event probability changes when a given predictor is changed by one unit. The marginal effect of a predictor is defined as the partial derivative of the event probability with respect to the predictor of interest. A more direct measure is the change in predicted probability for a unit change in the predictor. Being a derivative, the marginal effect is the slope of the line that is drawn tangent to the fitted probability curve at the selected point. Note that the marginal effects depend on the variable settings that correspond to the selected point at which this tangent line is drawn, so the marginal effect of a variable is not constant.

Table 13. Marginal effects of the factors along with their severities

Significant variables affecting severity	Probability of the factors causing PDO [y=0]	Probability of the factors causing possible/ unknown injury crashes [y=1]	Probability of the factors causing minor crashes [y=2]	Probability of the factors causing fatal-major crashes [y=3]	Weighted average of the probabilities of the factors causing several severe crashes
EQUIPMENT VARIABLES					
PSVEH	-0.1644	0.0703	0.0803	0.0139	0.026633**
PCKTRK	-0.1384	0.0501	0.0731	0.0152	0.023762
VAN	-0.1749	0.0588	0.0947	0.0214	0.030771
TRCKTRAC	-0.204	0.064	0.1127	0.0273	0.036662

Table 13. Marginal effects of the factors along with their severities (contd.)

ENVIRONMENT VARIABLES					
NODAYLIT	-0.1973	0.0646	0.1076	0.025	0.034971
VNOBSCUR	-0.1042	0.0493	0.0479	0.0071	0.016195
TRAFCONW	-0.0134	0.0056	0.0067	0.0012	0.002219
LOCRAMP	-0.0418	0.0168	0.0211	0.0039	0.006919
INTERSTA	0.2315	-0.0878	-0.1194	-0.0243	-0.0392
USROUTE	-0.0142	0.006	0.0071	0.0012	0.002333
SECROAD	-0.1158	0.0418	0.0612	0.0127	0.019862
CLOUDY	-0.305	0.0803	0.1745	0.0502	0.057619
FOGMIST	-0.0299	0.0125	0.0148	0.0026	0.004876
RAIN	0.1125	-0.0524	-0.0522	-0.0079	-0.01757
BETAWWRK	-0.3299	0.0894	0.1871	0.0533	0.06191
WTHWRKZN	-0.116	0.0519	0.0552	0.0089	0.018424
DRIVER CHARACTERISTICS VARIABLES					
YOGRDRI	0.0818	-0.0363	-0.0392	-0.0063	-0.01302
VOLDRI	-0.0589	0.0232	0.03	0.0056	0.009781
OFSMLDR	-0.0566	0.0225	0.0288	0.0053	0.009395
Weighting Factors	**1**	**2**	**3**	**4.5**	
Total Weighting		**10.5**			

Calculation of the Weighted Average Of the Probability (example):

0.026633 = (-0.1644* 1 + 0.0703* 2 + 0.0803* 3 - 0.0139* 4.5) / 10.5**

Table 13 depicts the marginal effects of the factors. Marginal effect of any factor can be defined as the effect a positive or a negative coefficient has on the probabilities of the crash severity. For example, if we consider BETAWWRK (the crash location is between the advance warning sign and work area) then the probability of the crash being fatal-major is 0.0533 higher (on average), probability for the crash being a minor injury type would be 0.1871 higher (on average), and probability for the crash being a probable or unknown injury type is 0.0894 higher (on average) whereas the probability of the crash being a PDO type is 0.3299 lower (on average). Thus marginal effects portray the impact each factor has on the potential severity of the crash

In order to rank the factors in terms of their impact on severity, a weighted average technique was adopted. The weighted average of the probabilities of the factors is calculated to give an overall severity value. The different categories of the crashes are assigned ranking factors based on their importance and impact and they are as follows:

i. Fatal Crash – 5
ii. Major Injury Crash – 4
iii. Minor Injury Crash – 3
iv. Probable / Unknown Injury Crash – 2
v. PDO Crash – 1

Since the fatal crashes and the major injury crashes have been combined, the average of the ranking factors 5 and 4 (i.e. 4.5) is assigned to the Fatal-Major Injury Crash. Thus for the present research, the ranking factors are as follows:

i. Fatal / Major Injury Crash – 4.5
ii. Minor Injury Crash – 3
iii. Probable / Unknown Injury Crash – 2
iv. PDO Crash – 1

The calculation of the weighted average for the probabilities is shown in Table 13.

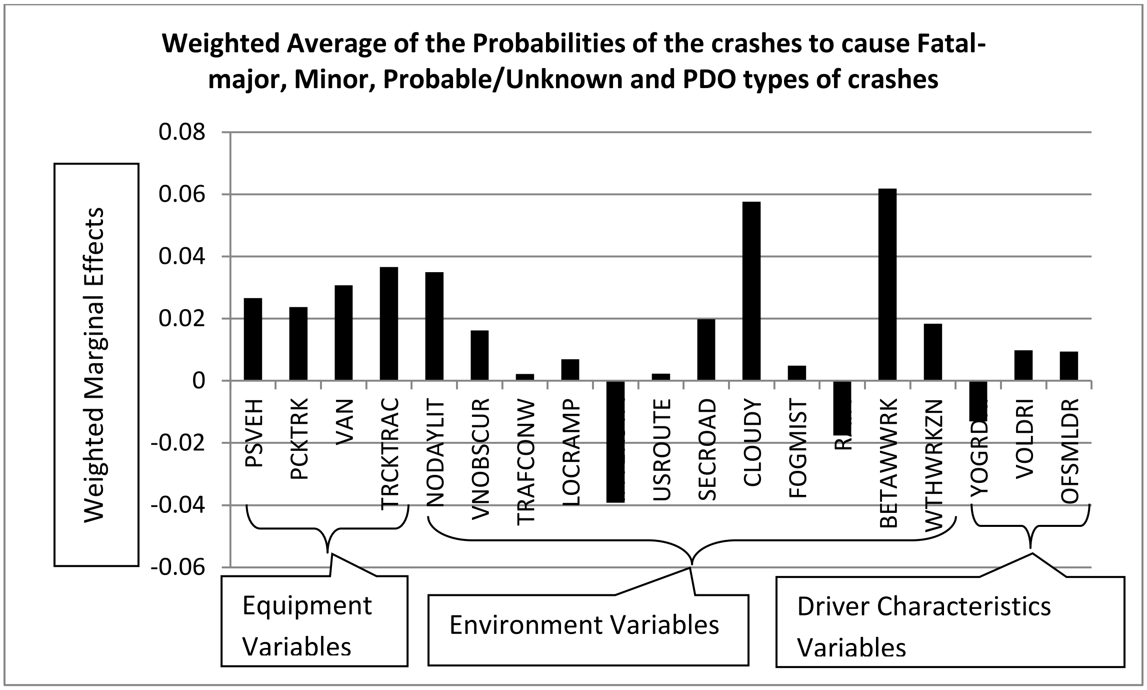

Figure 13. Distribution of the Weighted Average for the Probabilities of the factors for the occurrence of the different types of crashes

Figure 13 shows the distribution of the factors according to the weighted average of the probabilities for the occurrence of the different types of the crashes which is referred to as the severity of the factors in this research paper. The factors showing higher positive probabilities are more likely to cause a Fatal-Major Injury Crash whereas those showing a negative probability indicate that they are more likely to cause a PDO crash. In order to rank the factors on a scale of five on the basis of the severity (5 being the most severe and 1 being the least severe), the probability distribution is categorized in to five distinct levels. The categories are defined as follows:

i. Less than -0.02 = 1
ii. -0.02 – 0.00 = 2
iii. – 0.02 = 3
iv. 0.02 – 0.04 = 4
v. Greater than 0.04 = 5

Following this scale and the distribution graph, the significant factors can be ranked as shown in Table 14.

Table 14. Ranking of the factors according to severity

Variables	Severity Ranking
BETAWWRK	5
CLOUDY	5
TRCKTRAC	4
VAN	4
PSVEH	4
PCKTRK	4
NODAYLIT	4
SECROAD	3
USROUTE	3
VNOBSCUR	3
TRAFCONW	3
FOGMIST	3
WTHWRKZN	3
LOCRAMP	3
VOLDRI	3
OFSMLDR	3
YONGRDRI	2
RAIN	2
INTERSTA	1

Frequency analysis and factor rating according to frequency

Risk is defined as the combined effect of the severity (i.e. the impact) and frequency (i.e. the likelihood of occurrence). Thus the impact the factors have on severity cannot by itself predict the magnitude of risk that those factors possess for operation and maintenance activities on the highways. Frequency of the factors plays a major role in determining the risk value of the factors and develops the Integrated Risk Management

Model. The number of times that the factors are involved in each type of crash is illustrated by Table 15.

Table 15. Frequency distribution of the factors

Significant variables affecting severity	No. of PDO Crash	No. of Possible Injury Crash	No. of Minor Injury Crash	No. of Fatal/Major Injury Crash	Total	Percentage frequency distribution
EQUIPMENT VARIABLES						
PSVEH	17702	5652	6097	433	29884	54.29%
PCKTRK	4928	1721	756	294	7699	13.99%
VAN	3334	1540	587	189	5650	10.27%
TRCKTRAC	2630	910	385	323	4248	7.72%
ENVIRONMENT VARIABLES						
NODAYLIT	2897	562	2916	117	6492	11.80%
VNOBSCUR	30919	10551	7933	1038	50441	91.64%
TRAFCONW	2941	1125	641	311	5018	9.12%
LOCRAMP	1941	877	164	17	2999	5.45%
INTERSTA	24065	6798	3242	600	34705	63.05%
USROUTE	3633	1474	1624	455	7186	13.06%
SECROAD	1035	1513	268	184	3000	5.45%
CLOUDY	2165	1131	2835	83	6214	11.29%
FOGMIST	5526	3914	1375	152	10967	31.21%
RAIN	7154	359	1379	99	8991	16.33%
BETAWWRK	3675	3038	2345	97	9155	16.63%
WTHWRKZN	24995	6857	5189	1056	38097	69.21%
DRIVER CHARACTERISTICS VARIABLES						
YOGRDRI	0.0818	2073	2897	77	15621	28.38%
VOLDRI	10574	1277	582	146	3530	6.41%
OFSMLDR	5956	1529	913	336	8734	10.94%

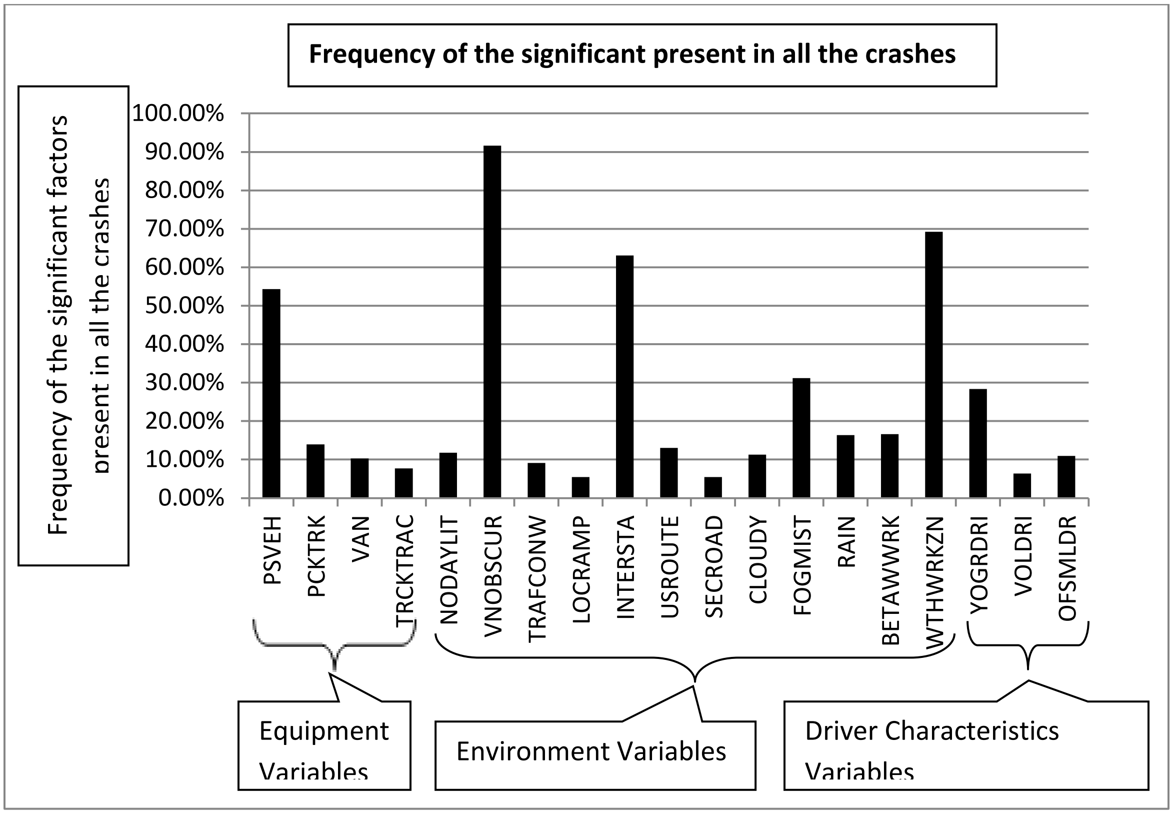

Figure 14. Distribution of the percentage frequency of the factors (crash data base) present in all the crashes involving intermittent and moving work zones and work on the shoulders and median

The frequencies of occurrence of the factors are shown in Table 15 and the frequency distribution is shown in Figure 14. In order to rank these significant factors according to their frequency of occurrence on a scale of one to five (1 being the least frequently occurring factor and 5 being the most frequently occurring factor), the percentage frequency scale is categorized into five levels which are defined as follows:

i. 0 – 9.99 = 1
ii. 10.00 – 19.99 = 2
iii. 20.00 – 39.99 = 3
iv. 40.00 – 59.99 = 4
v. Above 60.00 = 5

Following this category and the frequency distribution graph, the factors can be ranked according to their frequency of occurrence as shown in Table 16.

Table 16. Ranking of significant factors according to their frequency of occurrence

Variables	Frequency Ranking
VNOBSCUR	5
WTHWRKZN	5
INTERSTA	5
PSVEH	4
FOGMIST	3
YONGRDRI	3
BETAWWRK	2
CLOUDY	2
NODAYLIT	2
OFSMLDR	2
RAIN	2
USROUTE	2
PCKTRK	2
VAN	2
VOLDRI	1
SECROAD	1
TRCKTRAC	1
TRAFCONW	1
LOCRAMP	1

Risk rating of the factors

Risk can be mathematically defined as the product of the severity or impact of the factors and the frequency of occurrence of the factors. This combined estimate of the severity and frequency of occurrence gives an assessment of risk posed by the hazard and helps decision makers to prioritize which hazards should be addressed, assists in safety planning, and facilitates the development of risk mitigation strategies. Risk values are assigned to the significant factors in Table 17.

Table 17. Risk values of significant factors

Variables	Severity Ranking	Frequency	Risk Value
PSVEH	4	4	16
VNOBSCUR	3	5	15
WTHWRKZN	3	5	15
BETAWWRK	5	2	10
CLOUDY	5	2	10
FOGMIST	3	3	9
VAN	4	2	8
PCKTRK	4	2	8
NODAYLIT	4	2	8
USROUTE	3	2	6
OFSMLDR	3	2	6
YONGRDRI	2	3	6
INTERSTA	1	5	5
TRCKTRAC	4	1	4
RAIN	2	2	4
TRAFCONW	3	1	3
LOCRAMP	3	1	3
VOLDRI	3	1	3
SECROAD	3	1	3

Validation Survey Data Analysis

In the validation survey, a total of 33 responses were obtained of which 24 were complete responses and 9 were partial responses but without open-ended responses. The responses were obtained in the form of percentages of participants selecting that particular category of a particular question (see Appendix C). The severity analysis, frequency analysis and risk value assessment of the variables from the survey database is discussed in the following sections.

Severity analysis and factor rating according to the severity

Table 18 illustrates the levels of probable severities and it is followed by Figure 15 that shows the distribution of the different factors (i.e. hazards) under activities, environment, equipment and others that the participants had anticipated from their experience. The different weights assigned to the different categories of severities are as follows:

i. No loss -1
ii. Potential Property Damage – 2
iii. Minor Property Damage and / or Minor Injuries – 3
iv. Major Property Damage and / or Major Injuries - 4
v. Catastrophic Loss / Fatality - 5

Weighted average of the severity is calculated in the following way:

Weighted average of severity (FWD Structural Testing on Pavement & Subgrade)
= (0.06 x 1 + 0.16 x 2 + 0.22 x 3 + 0.22 x 4 + 0.0 x 5) / 15 = 0.1280

Table 18. Severity levels of the factors

	SEVERITY					
	No Loss	Potential Property Damage	Minor Property Damage and/or Minor Injuries	Major Property Damage and/or Major Injuries	Catastrophic Loss/Fatality	Weighted average of the severity
ACTIVITIES	**1**	**2**	**3**	**4**	**5**	
FWD structural testing on pavement and subgrade	0.06	0.16	0.22	0.22	0	0.1280
Ride quality testing on pavement or bridge surface	0.16	0.16	0.16	0.06	0	0.0800
Core drilling on pavements	0.03	0.16	0.16	0.26	0.03	0.1347
Manual condition surveys for pavement section	0.12	0.09	0.06	0.22	0.06	0.1107
Bridges and culvert repair and inspection	0.06	0.12	0.16	0.28	0.06	0.1467
Mowing	0.12	0.16	0.34	0.16	0.03	0.1500
Movement of street sweeper / street cleaner	0.16	0.22	0.16	0.19	0.03	0.1327
Straddling painting (centerline painting)	0.06	0.26	0.26	0.26	0.06	0.1800
Offset painting (edge-line painting) in 4 lane divided highway	0.09	0.28	0.25	0.19	0.03	0.1540
Offset painting (edge-line painting) in 2-lane 2-way traffic roadway	0.06	0.32	0.23	0.19	0.06	0.1633
Pavement markings	0.03	0.25	0.28	0.22	0.06	0.1700
Crack filling / Patch work	0.09	0.12	0.25	0.31	0.06	0.1747
Curb and surface repairs	0.06	0.19	0.32	0.16	0.03	0.1460
Flagger operations	0.16	0.06	0.25	0.34	0.16	0.2127
Replacing / repairing the signals and signage	0.15	0.22	0.33	0.11	0.07	0.1580

Table 18. Severity levels of the factors (contd.)

Loading / unloading material for maintenance operations (in a 4 lane divided highway)	0.15	0.22	0.19	0.26	0.07	0.1700
Loading / unloading material for maintenance operations (in a 2-lane 2-way road)	0.12	0.23	0.19	0.27	0.08	0.1753
Shoulder grading	0.12	0.31	0.27	0.15	0	0.1433
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 4-lane divided highway)	0.04	0.22	0.19	0.33	0.07	0.1813
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 2-way 2-lane road)	0.04	0.31	0.12	0.27	0.12	0.1800
Repair, maintenance and installation of centerline guardrails, cable rails and barrier rails (on a 4-lane divided traffic roadway)	0.11	0.22	0.19	0.26	0.07	0.1673
Maintenance of sanitary and storm sewer and water main	0.07	0.41	0.04	0.19	0.04	0.1313
Ditch cleaning	0.23	0.35	0.04	0.15	0	0.1100
Cleaning storm sewer intakes and structures	0.24	0.28	0.08	0.08	0.04	0.1040
Survey work	0.3	0.19	0	0.19	0.11	0.1327
Ingress and egress from construction site	0.15	0.04	0.33	0.37	0	0.1800
Electric / power system maintenance and street lighting	0.04	0.35	0.12	0.23	0.04	0.1480
Snow removal	0	0.22	0.3	0.22	0	0.1480
ENVIRONMENT	**1**	**2**	**3**	**4**	**5**	
Night time operations	0.04	0.08	0.16	0.4	0.24	0.2320
Presence of small towns or schools nearby	0.2	0.24	0.24	0.08	0.04	0.1280
Improper signs and signage at ramps and roadway intersections near work zones	0.08	0.08	0.28	0.28	0.2	0.2133
Pavement markings at intersections (at nighttime)	0.12	0.08	0.24	0.36	0.08	0.1893
Pavement markings at intersections (at daytime)	0.12	0.2	0.4	0.16	0	0.1573
Work zones on roads in hilly areas	0.08	0.04	0.36	0.32	0.16	0.2213
Peak traffic hours	0.08	0.04	0.2	0.6	0.08	0.2373

Table 18. Severity levels of the factors (contd.)

Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	0.08	0.04	0.33	0.33	0.08	0.1913
Work near railway crossings	0.12	0.16	0.08	0.36	0.12	0.1813
Clearing roadway for emergency vehicles	0.16	0.12	0.32	0.2	0.04	0.1573
Unforeseen weather conditions	0.12	0.28	0.16	0.28	0.12	0.1920
Fog and mist	0.08	0.08	0.32	0.4	0.12	0.2267
Different rules in shared jurisdictions	0.16	0.24	0.08	0.2	0	0.1120
Special events such as parades, races, fairs, etc. are carried on in local cities and towns	0.16	0.24	0.36	0.08	0	0.1360
EQUIPMENT	**1**	**2**	**3**	**4**	**5**	
Falling Weight Deflectometer	0.17	0.13	0.13	0.13	0	0.0893
Straddling Painters	0.05	0.23	0.32	0.18	0.05	0.1627
Maintainers on Gravel roads	0.04	0.35	0.13	0.09	0	0.0993
Cold Mix Patchwork	0.09	0.26	0.22	0.22	0.09	0.1733
Friction Testing	0.22	0.13	0.13	0.09	0	0.0820
Media Trucks	0.3	0.3	0	0.17	0	0.1053
Trucks carrying rock / aggregate	0.04	0.22	0.3	0.26	0	0.1613
Boom Trucks	0.13	0.22	0.17	0.26	0.04	0.1547
Pick-up Trucks	0.22	0.22	0.17	0.22	0	0.1367
Street Sweepers / Street Cleaners	0.13	0.22	0.26	0.17	0	0.1353
Jet Vac	0.17	0.22	0.17	0.13	0	0.1093
Paint Carts (hauled on trailers)	0.13	0.3	0.04	0.22	0	0.1153
Absence of proper signage near the work zone	0.09	0	0.23	0.36	0.27	0.2380
Absence of fluorescent diamond signs	0.13	0.09	0.26	0.3	0.13	0.1960
Not using morning lights in the work zone	0.09	0.17	0.17	0.26	0.22	0.2053

Table 18. Severity levels of the factors (contd.)

OTHERS	1	2	3	4	5	
Lack of co-ordination with municipalities	0.26	0.13	0.26	0.17	0.04	0.1453
Work done under full closure	0.57	0.13	0.13	0.04	0.13	0.1353
Lack of co-ordination between state and the local agencies	0.26	0.09	0.26	0.17	0.04	0.1400
Lack of work safety and training programs	0.09	0.04	0.26	0.22	0.35	0.2387
Absence of "train the trainers" philosophy	0.17	0.04	0.22	0.22	0.22	0.1927
Lack of coordination between DOT and ROW regarding control of Rights of Way (ROW)	0.35	0.09	0.17	0.13	0.04	0.1173
Improper third party interaction	0.18	0.14	0.27	0.14	0	0.1220
Not imposing speed limit fines on public	0.09	0.09	0.26	0.3	0.22	0.2233

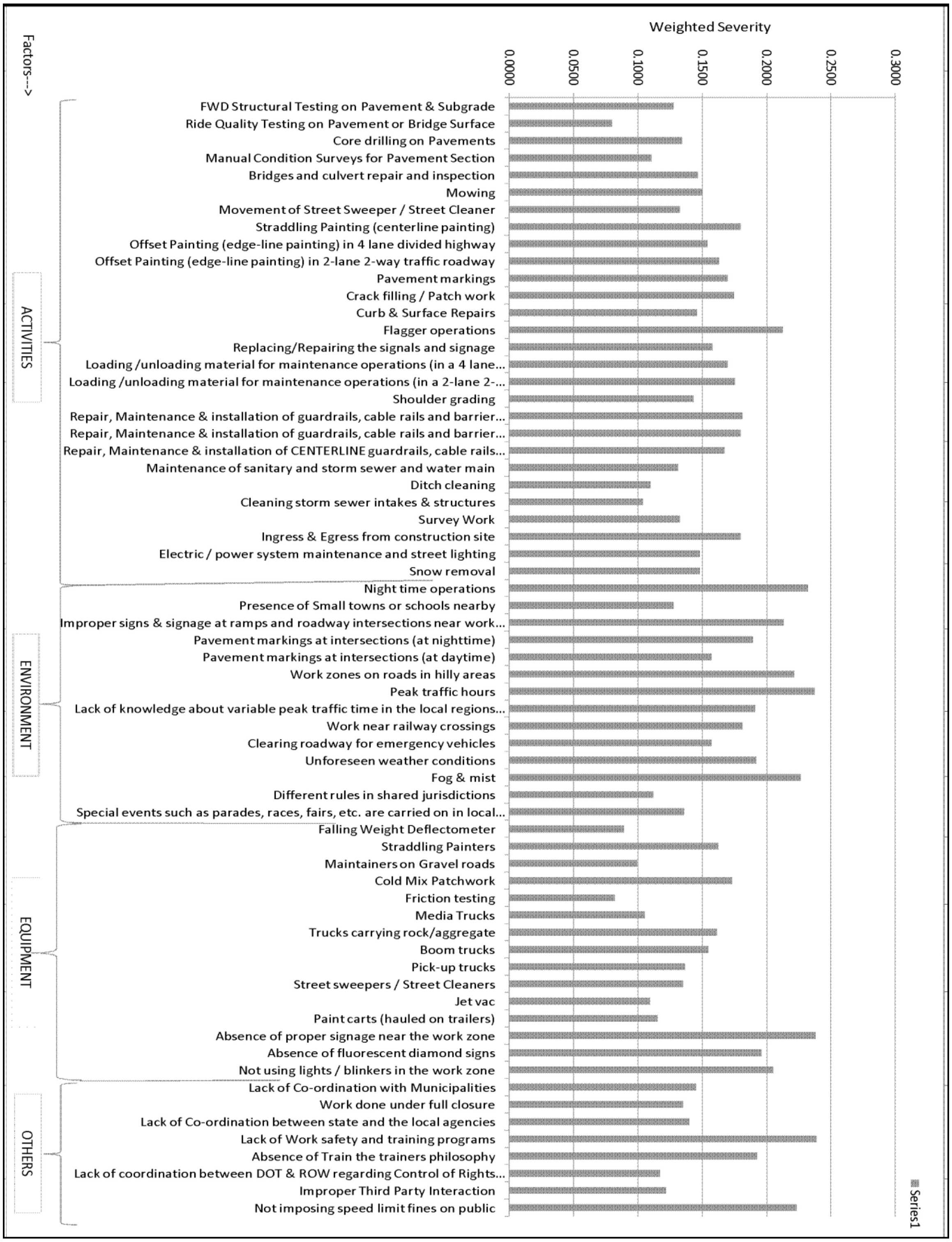

Figure 15. Distribution of the severity levels of the factors (survey data) present in all the crashes involving intermittent and moving work zones and work on the shoulders and median

According to the distribution the factors are ranked on a Likert scale from 1 to 5 (1 being the least and 5 being the most). The ranking for the severity is done based on the following category:

i. Below 0.1 = 1
ii. 0.10 - 0.15 = 2
iii. 0.15 - 0.20 = 3
iv. 0.20 - 0.25 = 4
v. 0.25 - 0.30 = 5

Based on the distribution of the factors according to the severity levels as shown and the categories as defined above, the factors can be ranked according to severity as shown in Table 19.

Table 19. Ranking of the factors according to severity

ACTIVITIES	SEVERITY
Flagger operations	4
Mowing	3
Straddling painting (centerline painting)	3
Offset painting (edge-line painting) in 4 lane divided highway	3
Offset painting (edge-line painting) in 2-lane 2-way traffic roadway	3
Pavement markings	3
Crack filling / Patch work	3
Replacing / repairing signals and signage	3
Loading / unloading material for maintenance operations (in a 4 lane divided highway)	3
Loading / unloading material for maintenance operations (in a 2 lane 2-way road)	3
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 2-way 2-lane road)	3
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 4-lane divided highway)	3
Repair, maintenance and installation of centerline guardrails, cable rails and barrier rails (on a 4-lane divided traffic roadway)	3

Table 19. Ranking of the factors according to severity (contd.)

Ingress and egress from construction site	3
FWD structural testing on pavement and subgrade	2
Movement of street sweeper / street cleaner	2
Core drilling on pavements	2
Manual condition surveys for pavement section	2
Bridges and culvert repair and inspection	2
Curb and surface repairs	2
Shoulder grading	2
Maintenance of sanitary and storm sewer and water main	2
Ditch cleaning	2
Cleaning storm sewer intakes and structures	2
Survey work	2
Electric / power system maintenance and street lighting	2
Snow removal	2
Ride quality testing on pavement or bridge surface	1
ENVIRONMENT	**SEVERITY**
Night time operations	4
Improper signs and signage at ramps and roadway intersections near work zones	4
Work zones on roads in hilly areas	4
Peak traffic hours	4
Fog and mist	4
Pavement markings at intersections (at nighttime)	3
Pavement markings at intersections (at daytime)	3
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	3
Work near railway crossings	3
Clearing roadway for emergency vehicles	3
Unforeseen weather conditions	3
Presence of small towns or schools nearby	2

Table 19. Ranking of the factors according to severity (contd.)

Different rules in shared jurisdictions	2
Special events such as parades, races and fairs are carried on in local cities and towns	2
EQUIPMENT	**SEVERITY**
Absence of proper signage near the work zone	4
Not using morning lights in the work zone	4
Absence of fluorescent diamond signs	3
Straddling Painters	3
Trucks carrying rock / aggregate	3
Cold Mix Patchwork	3
Boom Trucks	3
Media Trucks	2
Pick-up Trucks	2
Street Sweepers / Street Cleaners	2
Jet Vac	2
Paint Carts (hauled on trailers)	2
Falling Weight Deflectometer	1
Maintainers on Gravel roads	1
Friction Testing	1
OTHERS	**SEVERITY**
Lack of worker safety and training programs	4
Not imposing speed limit fines on public	4
Absence of “train the trainers” philosophy	3
Lack of co-ordination with municipalities	2
Work done under full closure	2
Lack of co-ordination between state and the local agencies	2
Lack of coordination between DOT and ROW regarding control of Rights of Way (ROW)	2
Improper third party interaction	2

Frequency analysis and factor rating according to severity

Table 20 illustrates the probable frequency of occurrence of the different factors (hazards) under activities, environment, equipment and others that the participants had anticipated from their experience. It is followed by Figure 16 which shows the distribution of the factors according to their weighted average likelihood of occurrence. The weights are assigned to the different levels of likelihood of the factors being present according to their importance. The different weights assigned to the different categories of their likelihood of presence are as follows:

i. Very Unlikely -1
ii. Unlikely – 2
iii. Neutral – 3
iv. Probable- 4
v. Very Probable – 5

Weighted average of the frequency of occurrence of the different factors is calculated in order to rank the factors on the same scale. The weighted average is calculated in the following way:

Weighted average of frequency (FWD Structural Testing on Pavement & Subgrade)
= (0.12 x 1 + 0.12 x 2 + 0.28 x 3 + 0.12 x 4 + 0.0 x 5) / 15 = 0.1120

Table 20. Frequency distribution of the factors

	FREQUENCY					
	Very Unlikely	Unlikely	Neutral	Probable	Very Probable	Weighted average of likelihood of occurrence
ACTIVITIES	**1**	**2**	**3**	**4**	**5**	
FWD structural testing on pavement and subgrade	0.12	0.12	0.28	0.12	0	0.1120
Ride quality testing on pavement or bridge surface	0.12	0.19	0.16	0.16	0	0.1080
Core drilling on pavements	0.09	0.25	0.16	0.22	0	0.1300
Manual condition surveys for pavement section	0.1	0.19	0.06	0.23	0	0.1053
Bridges and culvert repair and inspection	0.07	0.23	0.13	0.3	0	0.1413
Mowing	0.19	0.29	0.19	0.13	0	0.1240
Movement of street sweeper / street cleaner	0.12	0.19	0.19	0.25	0	0.1380
Straddling painting (centerline painting)	0.03	0.26	0.1	0.45	0.06	0.1967
Offset painting (edge-line painting) in 4 lane divided highway	0.1	0.19	0.23	0.32	0.03	0.1733
Offset painting (edge-line painting) in 2-lane 2-way traffic roadway	0.06	0.25	0.25	0.25	0.03	0.1640
Pavement markings	0.06	0.16	0.31	0.28	0.03	0.1720
Crack filling / Patch work	0.12	0.09	0.22	0.41	0	0.1733
Curb and surface repairs	0.03	0.23	0.3	0.23	0	0.1540
Flagger operations	0.12	0.12	0.34	0.31	0.06	0.1947
Replacing / repairing the signals and signage	0.11	0.3	0.33	0.11	0.04	0.1560
Loading / unloading material for maintenance operations (in a 4 lane divided highway)	0.07	0.3	0.22	0.19	0.11	0.1760
Loading / unloading material for maintenance operations (in a 2-lane 2-way road)	0.08	0.23	0.23	0.31	0.08	0.1913

Table 20. Frequency distribution of the factors (contd.)

Shoulder grading	0.07	0.37	0.33	0.04	0	0.1307
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 4-lane divided highway)	0.07	0.22	0.37	0.19	0	0.1587
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 2-way 2-lane road)	0.07	0.22	0.3	0.26	0	0.1633
Repair, maintenance and installation of centerline guardrails, cable rails and barrier rails (on a 4-lane divided traffic roadway)	0.11	0.11	0.48	0.15	0	0.1580
Maintenance of sanitary and storm sewer and water main	0.11	0.33	0.19	0.11	0	0.1187
Ditch cleaning	0.22	0.33	0.11	0.07	0	0.0993
Cleaning storm sewer intakes and structures	0.15	0.35	0.19	0.08	0	0.1160
Survey work	0.22	0.15	0.26	0.11	0.04	0.1293
Ingress and egress from construction site	0.04	0.15	0.19	0.48	0.04	0.2020
Electric / power system maintenance and street lighting	0.12	0.19	0.23	0.19	0	0.1300
Snow removal	0	0.11	0.15	0.48	0	0.1727
ENVIRONMENT	**1**	**2**	**3**	**4**	**5**	
Night time operations	0	0.04	0.17	0.58	0.17	0.2507
Presence of small towns or schools nearby	0	0.32	0.28	0.16	0.04	0.1547
Improper signs and signage at ramps and roadway intersections near work zones	0.12	0	0.08	0.56	0.16	0.2267
Pavement markings at intersections (at nighttime)	0	0.08	0.16	0.48	0.16	0.2240
Pavement markings at intersections (at daytime)	0.04	0.04	0.52	0.24	0.04	0.1893
Work zones on roads in hilly areas	0	0	0.29	0.54	0.12	0.2420
Peak traffic hours	0	0	0.08	0.68	0.24	0.2773
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	0.08	0.04	0.21	0.46	0.12	0.2153
Work near railway crossings	0.12	0.16	0.28	0.24	0.04	0.1627

Table 20. Frequency distribution of the factors (contd.)

Clearing roadway for emergency vehicles	0	0.17	0.17	0.33	0.17	0.2013
Unforeseen weather conditions	0.04	0.08	0.28	0.4	0.16	0.2293
Fog and mist	0.04	0.08	0.16	0.48	0.24	0.2533
Different rules in shared jurisdictions	0.12	0.08	0.16	0.24	0.12	0.1547
Special events such as parades, races, and fairs are carried on in local cities and towns	0.08	0	0.48	0.2	0.12	0.1947
EQUIPMENT	**1**	**2**	**3**	**4**	**5**	
Falling Weight Deflectometer	0.04	0.13	0.17	0.17	0	0.0993
Straddling Painters	0.04	0.13	0.26	0.39	0	0.1760
Maintainers on Gravel roads	0	0.26	0.3	0.04	0	0.1053
Cold Mix Patchwork	0.09	0.22	0.39	0.17	0	0.1587
Friction Testing	0.17	0.09	0.26	0.04	0	0.0860
Media Trucks	0.3	0.09	0.22	0.17	0	0.1213
Trucks carrying rock / aggregate	0.13	0.13	0.26	0.26	0.04	0.1607
Boom Trucks	0.13	0.17	0.35	0.17	0	0.1467
Pick-up Trucks	0.17	0.39	0.17	0.13	0	0.1320
Street Sweepers / Street Cleaners	0.13	0.22	0.17	0.26	0	0.1413
Jet Vac	0.14	0.14	0.36	0.09	0	0.1240
Paint Carts (hauled on trailers)	0.13	0.13	0.3	0.17	0.04	0.1447
Absence of proper signage near the work zone	0.04	0	0.04	0.61	0.26	0.2600
Absence of fluorescent diamond signs	0.09	0.05	0.27	0.36	0.14	0.2093
Not using morning lights in the work zone	0.04	0.04	0.26	0.43	0.17	0.2313

Table 20. Frequency distribution of the factors (contd.)

OTHERS	1	2	3	4	5	
Lack of co-ordination with Municipalities	0.04	0.13	0.39	0.3	0.04	0.1913
Work done under full closure	0.39	0.48	0	0.04	0.09	0.1307
Lack of co-ordination between state and the local agencies	0.04	0.17	0.35	0.22	0.09	0.1840
Lack of worker safety and training programs	0.09	0	0.26	0.17	0.43	0.2467
Absence of “train the trainers” philosophy	0.05	0.14	0.14	0.32	0.23	0.2120
Lack of coordination between DOT & ROW regarding control of Rights of Way (ROW)	0.13	0.13	0.35	0.22	0.04	0.1680
Improper third party interaction	0	0.14	0.23	0.41	0.05	0.1907
Not imposing speed limit fines on public	0	0.05	0.23	0.45	0.23	0.2493

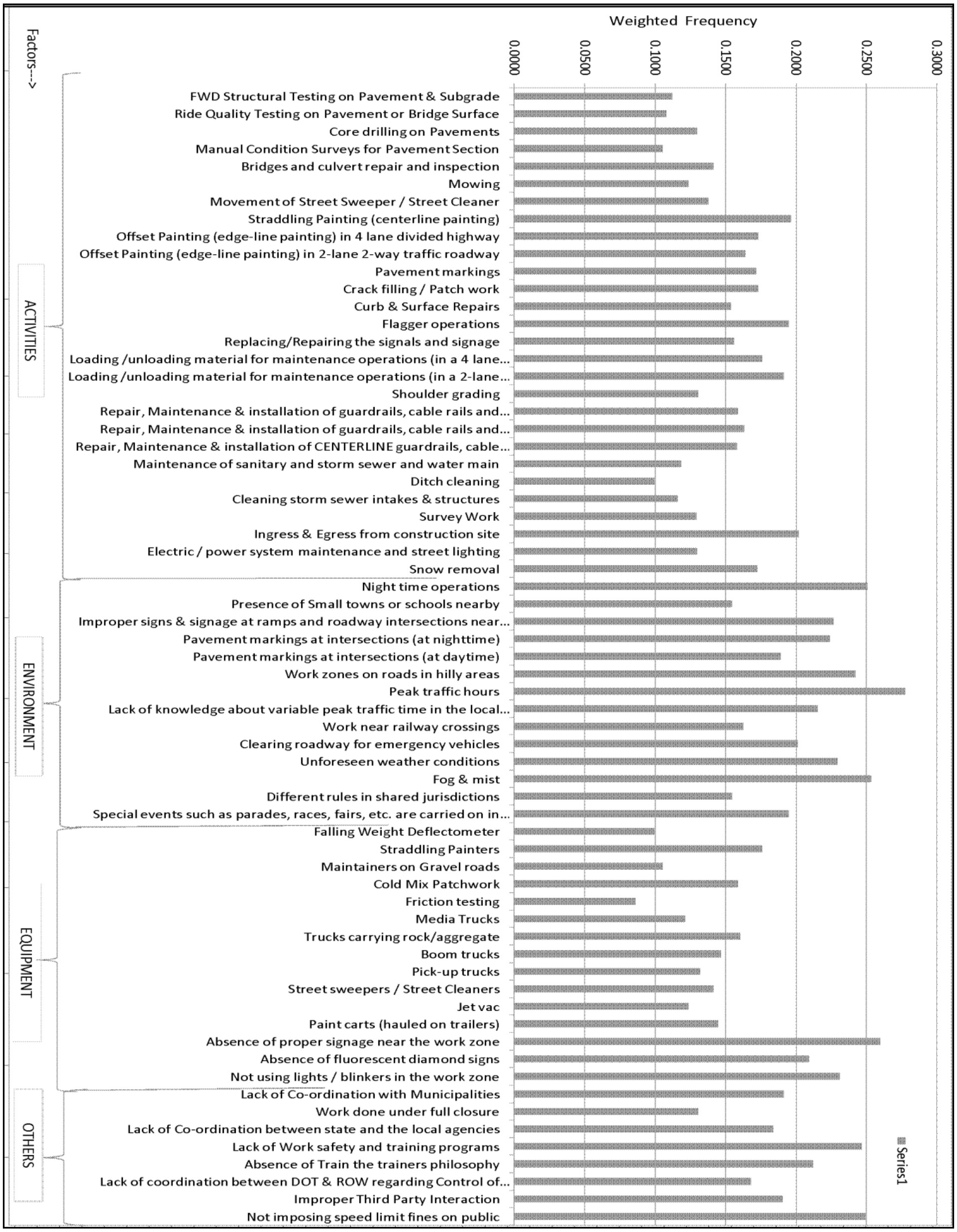

Figure 16. Distribution of the percentage frequency of the factors (survey data) present in all the crashes involving intermittent and moving work zones and work on the shoulders and median

According to the distribution the factors are ranked on a Likert scale from 1 to 5 (1 being the least and 5 being the most). The ranking for both the severity and frequency is done based on the following category:

i. Below 0.1 = 1
ii. 0.10 - 0.15 = 2
iii. 0.15 - 0.20 = 3
iv. 0.20 - 0.25 = 4
v. 0.25 - 0.30 = 5

Based on the distribution of the factors according to the frequencies as shown above and the categories as defined, the factors can be ranked according to frequency as shown in Table 21.

Table 21. Ranking of the factors according to frequency

ACTIVITIES	FREQUENCY
Ingress and egress from construction site	4
Straddling painting (centerline painting)	3
Offset painting (edge-line painting) in 4 lane divided highway	3
Offset painting (edge-line painting) in 2-lane 2-way traffic roadway	3
Pavement markings	3
Crack filling / Patch work	3
Curb and surface repairs	3
Flagger operations	3
Replacing / repairing the signals and signage	3
Loading / unloading material for maintenance operations (in a 4 lane divided highway)	3
Loading / unloading material for maintenance operations (in a 2-lane 2-way road)	3
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 4-lane divided highway)	3
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 2-way 2-lane road)	3

Table 21. Ranking of the factors according to frequency (contd.)

Repair, maintenance and installation of centerline guardrails, cable rails and barrier rails (on a 4-lane divided traffic roadway)	3
Snow removal	3
FWD structural testing on pavement and subgrade	2
Ride quality testing on pavement or bridge surface	2
Core drilling on pavements	2
Manual condition surveys for pavement section	2
Bridges and culvert repair and inspection	2
Mowing	2
Movement of Street Sweeper / Street Cleaner	2
Shoulder grading	2
Cleaning storm sewer intakes and structures	2
Survey work	2
Electric / power system maintenance and street lighting	2
Maintenance of sanitary and storm sewer and water main	2
Ditch cleaning	1
ENVIRONMENT	**FREQUENCY**
Night time operations	5
Peak traffic hours	5
Improper signs and signage at ramps and roadway intersections near work zones	4
Pavement markings at intersections (at nighttime)	4
Work zones on roads in hilly areas	4
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	4
Clearing roadway for emergency vehicles	4
Unforeseen weather conditions	4
Fog and mist	4
Presence of small towns or schools nearby	3
Pavement markings at intersections (at daytime)	3
Work near railway crossings	3

Table 21. Ranking of the factors according to frequency (contd.)

Different rules in shared jurisdictions	3
Special events such as parades, races, and fairs are carried on in local cities and towns	3
EQUIPMENT	**FREQUENCY**
Absence of proper signage near the work zone	5
Absence of fluorescent diamond signs	4
Not using morning lights in the work zone	4
Straddling Painters	3
Cold Mix Patchwork	3
Trucks carrying rock/aggregate	3
Maintainers on Gravel roads	2
Media Trucks	2
Boom Trucks	2
Pick-up Trucks	2
Street Sweepers / Street Cleaners	2
Jet Vac	2
Paint Carts (hauled on trailers)	2
Falling Weight Deflectometer	1
Friction Testing	1
OTHERS	**FREQUENCY**
Lack of worker safety and training programs	4
Absence of “train the trainers” philosophy	4
Not imposing speed limit fines on public	4
Lack of co-ordination with Municipalities	3
Lack of co-ordination between state and the local agencies	3
Lack of coordination between DOT and ROW regarding Control of Rights of Way (ROW)	3
Improper third party interaction	3
Work done under full closure	2

Risk Assessment of the Factors

The risk of the factors is assessed by multiplying the values in the severity ranking and the frequency ranking and it is depicted in Table 22.

Table 22. Ranking of the factors according to risk assessment value

	Frequency	Severity	Risk Value
ACTIVITIES	**1**	**2**	**(1x2)**
Flagger operations	3	4	12
Ingress and egress from construction site	4	3	12
Straddling painting (centerline painting)	3	3	9
Offset painting (edge-line painting) in 4 lane divided highway	3	3	9
Offset painting (edge-line painting) in 2-lane 2-way traffic roadway	3	3	9
Pavement markings	3	3	9
Crack filling / Patch work	3	3	9
Replacing / repairing signals and signage	3	3	9
Loading / unloading material for maintenance operations (in a 4 lane divided highway)	3	3	9
Loading / unloading material for maintenance operations (in a 2-lane 2-way road)	3	3	9
Repair, maintenance and installation of guardrails, cable rails and barrier rails (on a 4-lane divided highway)	3	3	9
Repair, maintenance and installation of guardrails, cable rails and barrier rails(on a 2-way 2-lane road)	3	3	9
Repair, maintenance and installation of centerline guardrails, cable rails and barrier rails(on a 4-lane divided traffic roadway)	3	3	9
Mowing	2	3	6
Curb and surface repairs	3	2	6
Snow removal	3	2	6
FWD structural testing on pavement and subgrade	2	2	4
Shoulder grading	2	2	4
Core drilling on pavements	2	2	4
Manual condition surveys for pavement section	2	2	4
Bridges and culvert repair and inspection	2	2	4

Table 22. Ranking of the factors according to risk assessment value (contd.)

Maintenance of sanitary and storm sewer and water main	2	2	4
Movement of Street Sweeper / Street Cleaner	2	2	4
Cleaning storm sewer intakes and structures	2	2	4
Survey work	2	2	4
Electric / power system maintenance and street lighting	2	2	4
Ride quality testing on pavement or bridge surface	2	1	2
Ditch cleaning	1	2	2
ENVIRONMENT	**Frequency**	**Severity**	**Risk Value**
Night time operations	5	4	20
Peak traffic hours	5	4	20
Improper signs and signage at ramps and roadway intersections near work zones	4	4	16
Work zones on roads in hilly areas	4	4	16
Fog and mist	4	4	16
Pavement markings at intersections (at nighttime)	4	3	12
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	4	3	12
Clearing roadway for emergency vehicles	4	3	12
Unforeseen weather conditions	4	3	12
Pavement markings at intersections (at daytime)	3	3	9
Work near railway crossings	3	3	9
Presence of small towns or schools nearby	3	2	6
Different rules in shared jurisdictions	3	2	6
Special events such as parades, races, or fairs are carried on in local cities and towns	3	2	6
EQUIPMENT	**Frequency**	**Severity**	**Risk Value**
Absence of proper signage near the work zone	5	4	20

Table 22. Ranking of the factors according to risk assessment value (contd.)

Not using lights / blinkers in the work zone	4	4	16
Absence of fluorescent diamond signs	4	3	12
Straddling Painters	3	3	9
Cold Mix Patchwork	3	3	9
Trucks carrying rock / aggregate	3	3	9
Boom Trucks	2	3	6
Media Trucks	2	2	4
Pick-up Trucks	2	2	4
Street Sweepers / Street Cleaners	2	2	4
Jet Vac	2	2	4
Paint Carts (hauled on trailers)	2	2	4
Maintainers on gravel roads	2	1	2
Friction testing	1	1	1
Falling Weight Deflectometer	1	1	1
OTHERS	**Frequency**	**Severity**	**Risk Value**
Not imposing speed limit fines on public	4	4	16
Lack of worker safety and training programs	4	4	16
Absence of "train the trainers" philosophy	4	3	12
Lack of co-ordination with municipalities	3	2	6
Lack of co-ordination between state and the local agencies	3	2	6
Lack of coordination between DOT and ROW regarding control of Rights of Way (ROW)	3	2	6
Improper third party interaction	3	2	6
Work done under full closure	2	2	4

The results are analyzed and explained in the next section, "Discussion and Implications of the Results".

Development of Integrated Risk Management Model

A **Risk Matrix** was developed as part of the risk assessment process as a metric representing the association of significant factors to severity of the crash In the development of the Integrated Risk Management Model, the significant factors were termed "hazards" to be consistent with prior research on risk. A hazard is a condition (e.g. blowing snow or excessive speed) that contributes to a loss event, either as the proximate cause of the loss or as a contributing factor. A risk of loss can be represented as the total of each of the hazards (factor) that contribute to it. The risk associated with any particular hazard, H, can be defined as its probability or likelihood of occurrence (i.e. the frequency), p, multiplied by its severity, c. Stated simply, the risk associated with any single hazard is the product of how likely it is to happen and how bad it would be if it did happen, as represented in the following equation.

$$\textbf{\textit{Hazard}} = P_H * C_H$$

The total risk, R, of a loss event, e, is the sum of the *n* potential hazards that would result in that event:

$$R_c = \sum_{i=0}^{n} Hi$$

The severity of the factors is obtained from the weighted average of the marginal effects of the statistical model and the frequency or likelihood of occurrence of the factors is obtained from the descriptive statistics (refer to Table 13 and Table 15).

The best tool to assess the risk of the hazards in such a scenario is to develop a risk assessment matrix. A risk assessment matrix is a two-dimensional representation of the frequency or likelihood of occurrence of the hazards on one scale (Frequency Scale) and the severity or consequence of those hazards on the other scale (Severity Scale). The frequency scale is on the vertical axis and the severity scale is on the horizontal axis. Both the scales are marked from 1 to 5. Thus, the risk assessment matrix (Figure 17) measures the risk of the hazards on a scale of 1 (1x1) to 25 (5x5). This scale is further categorized into five levels depending on the magnitude or overall effect of the risk. The four different categories can be defined as follows:

- Negligible Risk Potential (Risk value ranging from 1 to 3)
- Marginal Risk Potential (Risk value ranging from 4 to 5)
- Moderate Risk Potential (Risk value ranging from 6 to 9)
- Critical Risk Potential (Risk value ranging from 10 to 12)
- Catastrophic Risk Potential (Risk value ranging from 15 to 25)

FREQUENCY						
	5	**5**	**10**	**15**	**20**	**25**
	4	**4**	**8**	**12**	**16**	**20**
	3	**3**	**6**	**9**	**12**	**15**
	2	**2**	**4**	**6**	**8**	**10**
	1	**1**	**2**	**3**	**4**	**5**
		1	**2**	**3**	**4**	**5**
		SEVERITY				

12 to 25	**Catastrophic Risk Potential**
10 to 12	**Critical Risk Potential**
6 to 9	**Moderate Risk Potential**
4 to 5	**Marginal Risk Potential**
1 to 3	**Low Risk Potential**

Figure 17. Risk Assessment Matrix

The color coded risk assessment matrix is a very useful technique to determine the potential risk of the hazards already identified from the Iowa crash database analysis This matrix should be used in conjunction with Table 17 and Table 22 which contains the identified significant factors generated from the Iowa DOT statewide crash data analysis along with the combined hazard value and also the factors identified from the survey data analysis respectively. The colors and their respective codes are explained in Figure 17. Any hazard present in a risk event can be assessed in the following way: say, for example, the factor WTHWRKZN, from the crash database, has a hazard value of 15 which means the region located within or adjacent to the work activity bears a **catastrophic**

risk potential and a crash occurring within this region would likely be an extremely severe crash. On the other hand, the factor BETAWWRK has a hazard value of 10 that means the region between the advance warning sign and work area bears **critical risk potential** and the crashes occurring within this zone is more likely to be less severe than the region within or adjacent to the work activity. Hence this location needs to be closely monitored and proper traffic control measures need to be taken to avoid crashes within this location. Hence the risk assessment matrix helps in prioritizing the different hazards and thus helps in planning risk mitigation strategies.

Since a “typical” crash is assumed to have both the frequency and severity ranked as 3, the combined value of 9 (3x3) marked the boundary for the moderate risk potential. Anything above this value was considered as a critical or catastrophic risk potential.

CHAPTER 5. DISCUSSION AND IMPLICATIONS OF THE RESULTS

The results obtained in the previous chapter both from the crash data analysis and the survey data analysis are discussed and analyzed here in this chapter. The most interesting result that emerged from the entire statistical analysis and the survey data analysis is that both from a detailed and an overall perspective the survey data validates the crash data analysis. This chapter is organized into four sections:

- Crash data analysis results
- Validation survey data analysis results
- Results compared from an overall perspective
- Results compared from a detailed perspective

Crash Data Analysis Results

Six factors were assessed with a **hazard value greater than 9** and they are described as follows:

- Passenger vehicle
- Vision not obscured by moving vehicles or frosted windows / wind-shield
- Region located within or adjacent to the work activity
- Region located between the advance warning sign and work area
- Cloudy weather
- Foggy / misty / partly cloudy weather

It is quite interesting that the vehicle configuration also plays an important role as it is observed that the passenger vehicles bear catastrophic risk potential for the maintenance and mobile work zone related crashes. This may be due to the light weight of the passenger vehicles along with the speed limit in highways for which they are more likely to lose control near a work zone on highways and cause severe accidents frequently.

Moreover when the vision of the driver is not obstructed by any hindrance such as moving vehicles, frosted windows or wind shields, it indirectly creates a catastrophic risk situation. The drivers are more likely to drive at a higher speed in this unobstructed situation and if a mobile work zone like lane painting or mowing the side of the roads or guardrail repairs or shoulder repairs come on the way, then it may happen that the drivers are unable control their speed and move into the work zone very frequently causing a crash of moderate severity.

The analysis shows interesting results in terms of location of the crash also. It describes that both the regions located within or adjacent to the work activity or the region located between the advance warning sign and work area bears critical or catastrophic risk potential and severe crashes are more likely to occur within this zone. This indicates that proper traffic control measures are not adopted near or within the mobile work zones and proper safety rules need to be followed in those regions.

The weather condition is also very critical with respect to the overall risk potential. A cloudy or partially cloudy or foggy or misty weather event should be avoided if planning for a mobile maintenance operation on highways. The reason may be due to reduced daylight and reduced sight of vision. However, it is interesting to note that there are not many mobile work zone related crashes during the rains because people become more cautious when it is raining as they are aware of the fact that during rain the crash risk increases (confirmed in a study by Pisano, et al. 2008) mainly due to decrease in the pavement friction and vehicle maneuverability.

Out of the above factors, the three factors which are in the **red zone** (i.e. bearing catastrophic risk potential) are as follows:

- Passenger vehicle
- Vision not obscured by moving vehicles or frosted windows / wind-shield
- Region located within or adjacent to the work activity

The reasons behind these factors bearing high risk potential is same as above, but they warrant further attention while planning for a mobile work zone

However, not only the above mentioned factors are important and need attention, but also those hazards that have a value of 5 either in the severity scale or in the frequency scale warrant attention.

Two factors assessed with a value of **5 in the severity scale** are described as follows:

- Region located between the advance warning sign and work area
- Cloudy weather

The severity analysis resulted in two factors that have the highest ranking of severity, i.e. 5. They are the region located between the advance warning sign and the work area and cloudy weather. Extreme caution needs to be taken regarding the traffic control systems that are being used in the region between the advance warning sign and the mobile work zone area. Cloudy weather is also very dangerous in terms of a crash being a severe.

Three factors assessed with a value of **5 in the frequency scale** are described as follows:

- Vision not obscured by moving vehicles or frosted windows / wind-shield
- Region located within or adjacent to the work activity
- Interstate route

The frequency analysis resulted in three factors that show the highest ranking of 5. Most of the crashes related to the maintenance and mobile operations work zone occur when vision of the driver is not obscured by moving vehicles or frosted windows / wind-shield. The reason is same as mentioned before because with respect to overall risk potential.

The region located within or adjacent to the mobile work activity is also critical in terms of the frequency of the crashes. Most of the crashes are likely to occur within or adjacent to the work activity indicating that proper traffic control systems and safety rules may not be obeyed in these types of work zones.

The Interstate route is also another important factor in terms of frequency of the crashes taking place. About 63 percent of the crashes take place on the interstates. It may signify that since most of the roadway section with the highest ratio of vehicle volume to capacity of the roadway is the interstates, the frequency of crashes is more there. Thus more traffic is exposed to the work zones on Interstate routes than on the other routes. This is quite interesting that the frequency of crashes occurring on the Interstate routes is highest, but the severity of the crashes taking place was the lowest. The model developed in the present research study explains that a crash on an interstate is actually more likely to be a PDO type crash rather than a fatal – major or a minor injury crash. This result is quite striking as people mostly assume that with higher speeds on these types of highways, more severe crashes would occur but in reality this is likely not the case based on the results of this research.

An alternative explanation for this result is that since the study focused on work zone crashes only, where speeds are reduced, and variation in travel speeds are likely to be minimized, Interstates are actually safer due to their superior design parameters compared to other routes and are also better maintained, generally speaking. Moreover, Interstates almost always maintain a minimum of two divided lanes in each direction whereas other routes are frequently head-to-head traffic. In other words, the Interstates provide more space (in terms of number of lanes) for the vehicles to pass by even if there is a mobile work zone than compared to other types of routes.

On an overall scenario, it is thus observed that the environmental factors are most critical both with respect to severity and frequency and also the overall risk potential. Thus proper measures need to be taken in such events as recommended in Chapter 6.

Validation Survey Data Analysis Results

In the validation survey, factors (or hazards) were categorized into four different categories as explained before. These are:

- Activities
- Environment
- Equipment

- Others

The factors within each category are ranked in the descending order of magnitude of their severity, frequency and risk assessment value in Table 20, Table 21 and Table 22 respectively. The Integrated Risk Management Model helps in prioritizing the different identified factors (or hazards) when it is used in conjunction with the risk assessment values of the factors (as shown in Table 22).

The hazards with a **risk assessment value** (i.e. the combined value of severity and frequency) **greater than 9** (i.e. hazards bearing critical or catastrophic risk potential) are as follows:

Activities

- Flagger operations
- Ingress and egress from construction site

Environment

- Night time operations
- Peak traffic hours
- Improper signs and signage at ramps and roadway intersections near work zones
- Work zones on roads in hilly areas
- Fog and mist
- Pavement markings at intersections (at nighttime)
- Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)
- Clearing roadway for emergency vehicles
- Unforeseen weather conditions

Equipment

- Absence of proper signage near the work zone
- Not using morning lights in the work zone
- Absence of fluorescent diamond signs

Others

- Not imposing speed limit fines on public
- Lack of worker safety and training programs
- Absence of “train the trainers” philosophy

The nine hazards which are in the **red zone** (among all the factors and under all the categories) and require immediate attention are as follows:

- Night time operations
- Peak traffic hours
- Absence of proper signage near the work zone
- Improper signs and signage at ramps and roadway intersections near work zones
- Work zones on roads in hilly areas
- Fog and mist
- Not using morning lights in the work zone
- Not imposing speed limit fines on public
- Lack of worker safety and training programs

All these above mentioned hazards should be managed with extreme precaution as they are most likely to cause very serious (or catastrophic) crashes. However, of the 65 hazards that were identified from the expert panel discussion, only three hazards have been assessed with a **frequency score of 5** (although none of the hazards scored 5 for severity). They are listed as follows:

- Night time operations
- Peak traffic hours
- Absence of proper signage near the work zone

Thus it appears that most of the crashes due to operations and maintenance activities occur when the operations are carried out during the night time and during the peak office hours. Absence of proper signage near the work zone is another major cause of such type of crashes.

Thus all the potential hazards related to the operations and maintenance activities were identified, assessed and analyzed in the above two sections and the relevant mitigation strategies that should be adopted in such cases are described in the Chapter 6.

Results compared from an overall perspective

To get an idea about how the results from the crash data analysis matched with the survey data analysis, the percentage of factors that were found to be significant under each of the five risk categories (low risk potential, marginal risk potential, moderate risk potential, critical risk potential and catastrophic risk potential as defined before) were compared. Table 23 and Table 24 illustrate the percentage of the significant factors present in each category of the risk potentials defined earlier and their comparison is shown in Figure 18 and Figure 19. This comparison helps in understanding how the overall result from the crash data analysis was similar to the survey data analysis.

Table 23. Percentage of the significant factors (from crash data analysis) present in each risk category

Risk Categories	No. of Factors	% of the factors from crash data analysis (actual risk)
Negligible Risk Potential (1-3)	4	21.05
Marginal Risk Potential (4-5)	3	15.79
Moderate Risk Potential (6-9)	7	36.84
Critical Risk Potential (10-12)	2	10.53
Catastrophic Risk Potential (15-25)	3	15.79
Total factors	19	

Table 24. Percentage of the significant factors (from survey data analysis) present in each risk category

Risk Categories	No. of Factors	% of the factors from survey data (perspective of people)
Negligible Risk Potential (1-3)	5	7.69
Marginal Risk Potential (4-5)	16	24.62
Moderate Risk Potential (6-9)	27	41.54
Critical Risk Potential (10-12)	8	12.31
Catastrophic Risk Potential (15-25)	9	13.85
Total no of factors	65	

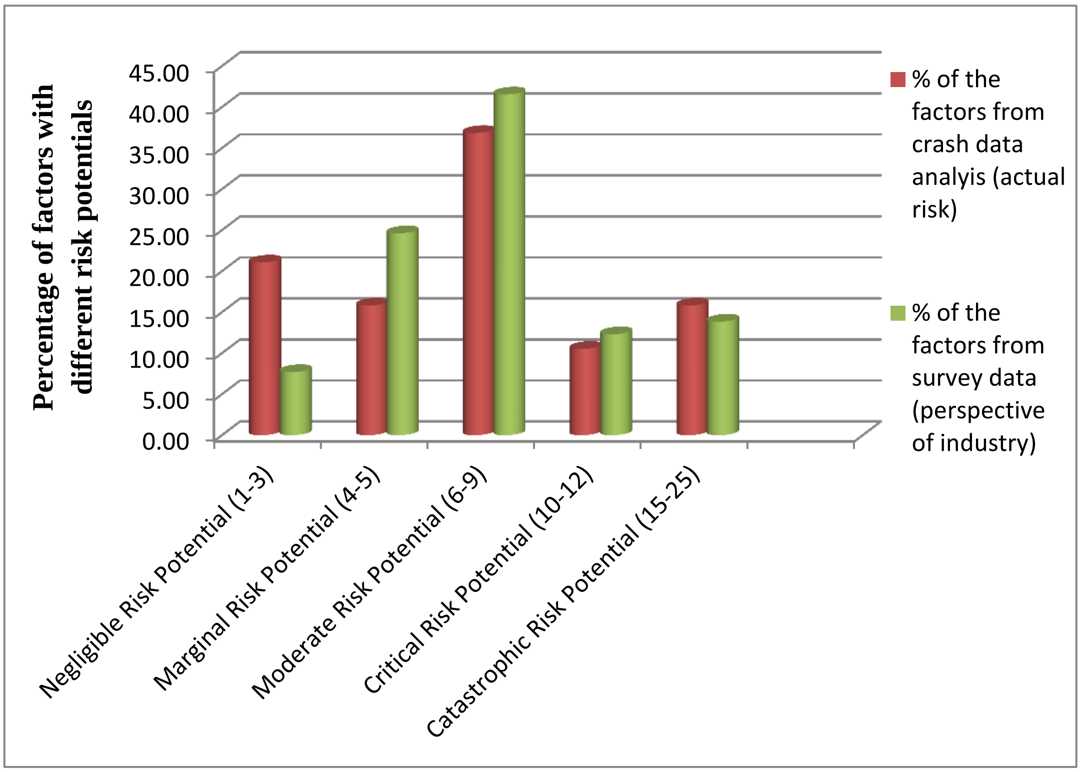

Figure 18. Percentage of factors present in risk potential category

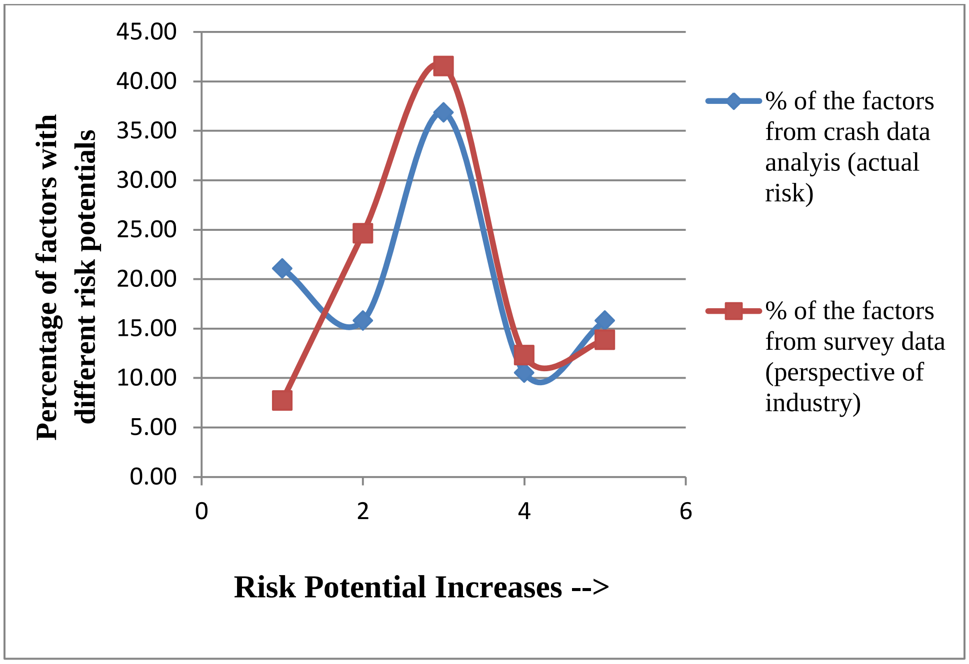

Figure 19. Validation of the results

The comparison of the data analysis from the Iowa crash database and the survey data is shown in Figure 19. The two graphs, the blue one being the percentage of factors from the crash data analysis and the red one being the percentage of the factors from the survey data analysis, show a very similar pattern. If we consider significant factors from the crash data analysis to be “actual risk” and that from the survey data analysis to be the “perspective of industry”, then it is clarified from the graph above (Figure 19) that the experts or safety professionals estimate the potential risk of a situation correctly. It also suggests that the data from the crash data base analysis is validated by the survey data analysis. The only difference is that the experts take into account a larger number of factors to bear a significant risk potential than in reality (depicted by the model in this research) and thus this research result would help them to narrow down their selection of factors in terms of risk potential and provide guidelines while planning for a maintenance and operation activity on highways.

Results compared from a detailed perspective

To validate the results from a detailed perspective, each of the factors found significant from the Iowa crash data analysis were compared with those found to be significant from the survey data analysis and the commonalities between them were identified. It was observed that results from both types of data and analysis yielded some common factors which were found to bear a high risk potential and need to be addressed by the transportation agencies.

Both from the crash data analysis and the validation survey data analysis it is observed that the environment such as cloudy weather is one of the major causes behind the crashes during maintenance and operation activities. Also the region located between the advance warning sign and work area is critical and it is more likely that severe crashes would occur within this region. Again from the frequency standpoint, the three factors belonging to the environment category are the most significant ones with their frequency of occurrence being ranked as five. The factors are the situation when the vision of the drivers are not obstructed by any obstacle such as trees, crops, buildings, parked vehicles, moving vehicles, frosted windows or windshield, blowing snow and fog / smoke / dust, is the region within or adjacent to the work activity and the Interstate routes. Improper work zone signage may is the major reason for the first and the third factor being so significant in terms of their frequency of occurrence. The second factor regarding the crash location within or adjacent to the work activity also pints to the improper work zone signage. All these factors could be taken care of by installing speed limit signs starting from reasonable distances away from the mobile work zone, imposing very high speed limit fines near the work zones and also by improving the visibility of the work zone signage.

The validation survey analysis also indicates that environmental factors such as performing maintenance and operation activities during nighttime and peak office hours, improper signage and signage at ramps and roadway intersections near the work zones, executing maintenance and operation activities on roads in hilly areas and also in foggy and misty weather bear the highest risk potential. Care should be taken to handle these situations and mitigate the risk potential. The other factors which also bear very high risk potential are absence of proper signage near the work zone (which has been also found to be significant from the crash data analysis), not using morning lights in the work zone which is also a kind of signage inadequacy, not imposing speed limit fines on public and lack of worker safety and training programs. It should be also noted that among the factors mentioned above, maintenance work during the nighttime and peak traffic hours and absence of proper signage near the work zone occur most frequently and hence proper mitigation techniques should be adopted in these situations.

CHAPTER 6. CONCLUSION

This chapter concludes the research findings and provides a recommendation for the probable risk mitigation strategies that could be adopted by transportation agencies while planning or performing maintenance and operation activities on highways. This chapter also explains the limitations of this research study and suggests future research needs which would mainly focus on the practical applications of the present research findings. This chapter is organized into four sections:

- Summary
- Recommended risk mitigation strategies
- Limitations
- Future research

Summary

The primary benefits of this research are reduced risk of injury, fatality, and property damage for O/M employees and the traveling public. The research results can be implemented by the Iowa DOT staff, county engineers, municipal transportation directors, and any other transportation professionals responsible for operations and maintenance activities, including field personnel. The results can be also used as a standard process for identifying highest risk O/M activities and developing mitigation strategies to reduce those risks. However, it should be noted that the envisioned risk mitigation processes developed in this research are highly inclusive, involving state, local, and regional professionals from both field and office positions. Thus, before adopting these results in other states, proper judgment should be applied. Intuitively, any process that decreases risk should improve worker safety, lower agency costs, improve service to the traveling public, and lead to more efficient procedures over the long-term, although these specific performance benefits are not directly assessed as part of this research. Table 25 shows the summary of the findings and the list of the factors identified both from the crash data base and by the experts.

Table 25. Summary of the results

CRASH DATA RESULTS	SURVEY DATA RESULTS
Red-Zone Hazards (Catastrophic Risk Potential)	
Passenger vehicle	Night time operations and peak traffic hours
Vision not obscured by moving vehicles or frosted windows / wind-shied	Not imposing speed limit fines on public
Region located within or adjacent to the work activity	Absence of proper signage near the work zone; Improper signs and signage at ramps and roadway intersections near work zones; Not using morning lights in the work zone; Work zones on roads in hilly areas
	Fog and mist
	Lack of work safety and training programs
Hazards With Risk Value Greater Than 9 (Critical And Catastrophic Risk Potential)	
Passenger vehicle	Flagger operations; Ingress and egress from construction site; Clearing roadway for emergency vehicles
Vision not obscured by moving vehicles or frosted windows / wind-shield	Not imposing speed limit fines on public
Region located within or adjacent to the work activity; Region located between the advance warning sign and work area	Improper signs and signage at ramps and roadway intersections near work zones; Absence of proper signage near the work zone; Not using morning lights in the work zone; Work zones on roads in hilly areas
Cloudy weather; Foggy / misty / partly cloudy weather	Fog and mist; unforeseen weather conditions
	Night time operations and peak traffic hours; Pavement markings at intersections (at nighttime)

Table 25. Summary of the results (contd.)

	Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like Department of Transportation (DOT), the University, the Animal Disease lab in Ames, Iowa)
Hazards With Highest Severity Score (5)	
Region located between the advance warning sign and work area	No such variables were ranked 5on the severity scale from the survey data
Cloudy weather	
Hazards With Highest Frequency Score (5)	
Vision not obscured by moving vehicles or frosted windows / wind-shield	Night time operations and Peak traffic hours
Region located within or adjacent to the work activity	Absence of proper signage near the work zone
Interstate Route	

Recommended Risk Mitigation Strategies

Some of the mitigation strategies that could be considered by transportation agencies while planning or conducting maintenance and operational activities on highways are enlisted below:

Planning for Temporary Traffic Controls (TTC)

- Consider expanding traffic control options to include proven technologies such as Balsi Beams, portable rumble strips, blue strobe lights, and other innovations.
- Two lane, two way highways, work at railroads and other utility sites, overhead work, and work on bridges are likely high-risk environments where additional vehicles and workers increase the risk of crashes. The value of impact attenuators should be

researched to determine the safety benefits of such equipment. The analysis of the crash database did not find any reports of impact attenuators associated with mobile work zone crashes.

- Certain environments should be reviewed to ensure that the minimum number of workers and vehicles are used in the traffic control system.

Training

- Investigate new delivery technologies (Skype, webinars, and remote conferencing) to allow for improved training within the flattened structure of the Iowa DOT.
- Policies and safety training programs should stress the need for locating the traffic controls at the appropriate distance from the work site, and the traffic controls should be moved at the same pace as the mobile operations whenever possible.
- The training should include both formal programs for centralized functions and informal, weekly programs for supervisory personnel to discuss issues with field crews. The Local Technical Assistance Program (LTAP) at the Institute for Transportation may be of assistance in developing such a safety training program. The safety training program will be particularly helpful for new and temporary employees working in mobile operations.

Manual and guidelines

- Written manuals and training programs should focus on the importance of worker and equipment visibility and advance warning systems, especially in high-speed environments (Interstates, U.S. Highways) and those where drivers may be more easily distracted by pedestrians, traffic signals, bicyclists, etc., such as municipal streets.
- Provide clear guidance on placement of traffic control measures for mobile work zones.

Limitations

The limitations of this research study are as follows:

- All of the factors/hazards that were studied in this research could not be described by the crash database variables queried. Representative variables were selected and analyzed from the crash database which indirectly explained the effect of the required variables / factors / hazards.
- The “exposure” factor was not considered while analyzing the frequency of occurrence of the factors from the crash data base.
- The crash narratives were not studied. In a particular crash, a number of variables may be involved and thus the exact reason for which the crash occurred or what was the outcome of the crash could not be identified.
- In order to get a good sample size, last ten year’s data (2001-2010) was analyzed. This may have included information about several crashes that had occurred even after work zone signage and infrastructure development. However, this effect had been minimized when the results were also supported by the validation survey.
- The validation survey sample size was small - only 23 completed responses along with nine partial responses were obtained. The sample size being very small, no statistical analysis could be performed.
- The results were only applicable to the state of Iowa and other similar states and transferability test was not performed to see whether it is valid for the other states or not.

Future Research

The possible mitigation techniques strategies that are developed through the rigorous research study are not field-tested as it is out of the scope of this research. However, if further research on the implementation ideas is needed, a separate research study can be conducted focusing on the implementation of the risk mitigation techniques identified as a result of this current research study. This may also include testing of the risk mitigation strategies in simulators or actual field situations to determine effectiveness.

Moreover, the crash data provided information of the crashes that had taken place only in the state of Iowa. None of the other states' crash information was included. Thus transferability test may be performed to see whether the results may be applicable in other states (other than Iowa or similar states) or not. As a future research effort, this study may be expanded to see its applicability in other different states with respect to their population, political environment, traffic volume, infrastructural facilities and modify the results and the mitigation strategies such that it could be adopted by all the transportation agencies nationally throughout United States.

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APPENDIX A: EXPERT PANEL SUMMARY REPORT

Risk Mitigation Strategies for Operations and Maintenance Activities

IHRB Project Report: TAC Kick off Meeting

Moving operations is a common term used for construction activities that involve mobile work zones, such painting and pavement marking, guardrail replacement, repair of the signage, pavement inspection, structural testing, etc. These activities fall under the general heading of operations and maintenance (O/M). The basic objective of the research is to develop an integrated risk modeling approach which could be used to reduce the frequency and intensity of loss events (property damage, personal injury or fatality) during highway O/M activities.

The first task of the research plan was to identify the current O/M processes used by state, county and local agencies. To begin this task, a meeting was held with the expert Technical Advisory Committee (TAC) on 10th December, 2010 at Institute for Transportation, Iowa State University to identify the current O/M processes.

During the panel discussion, identified O/M activities were classified into four (4) broad categories viz. the activities, environments, tools / equipment used and the different relationships involved with O/M functions. The potential risk factors involved in the above mentioned categories that were identified during this meeting include the following:

- Traffic level/Congestion
- Number of roadway lanes
- Posted speed limit
- Inadequate /Improper signage
- Inadequate / Improper vehicle lighting and marking
- Insufficient worker training

- Proximity of obstructions (equipment) to traveled roadway
- Weather (condition of road surface or visibility)
- Work under traffic (inadequate separation or lack of detours/ lane shifts)

Moving operations involve mainly the following four types of work zones:

- Short term work zones
- Intermediate work zones
- Overnight work zone
- Work zones within 15 feet of the moving traffic

A detailed report of current O/M processes and practices is as follows:

ACTIVITIES

1. **Material testing**: The methods generally used for roadway and pavement testing are **FWD (Falling Weight Deflectometer) Structural testing** - a non-destructive test performed to evaluate the strength properties of the pavement and subgrade layers. Information is used in the pavement management system as well as in the pavement design process. The equipment stops in the lane and the loading instrument in lowered to contact the pavement. **Ride Quality Testing** – a non-destructive test conducted with either a 25' Profilograph or a light-weight inertial profiler to measure the ride quality of a pavement or bridge surface. The profilograph is pushed at about 3 mph. A light-weight profiler operates at 10 to 20 mph; **Core drilling** – a destructive process used to drill & cut out a pavement core for laboratory analysis. The drill is truck mounted. The truck stops in the lane and the drill is lowered to contact the pavement; and **Manual Condition Surveys** – a non-destructive process to obtain condition data for a pavement section. The FWD and core drilling operations involve stopping in the lane of travel. Depending on the distance between stops or the length of time stopped, these operations will be either a moving operation or a temporary lane closure. Once the test is taken or the core is drilled, the equipment

can move to the shoulder to allow traffic to proceed. The ride quality testing involves a machine / equipment mounted on a moving vehicle and thus belongs to the moving operations work zone. The testing is continuous and the equipment must stay in the lane and at test speed for the duration of the test section. The condition survey process is done from the shoulder when there is a wide enough shoulder. Staff may have to enter the lane to take measurements, normally done at traffic gaps. These testing operations can often block the main roadway and disrupt / slow down the normal flow of the traffic. The risks posed by these types of operations include, but are not limited to: a) distract the drivers' attention, b) force the vehicles to move towards the roadway edge, c) loss of control d) infringe on sidewalk or bike path.

2. **Bridges and culvert repair and inspection**: This type of operation is also a moving work zone operation as most of the inspection activities are of short duration. This activity also poses risks including, but not limited to, a) blocks the main roadway, b) slows down the traffic, c) distracts the drivers' attention towards the work zone, d) forces vehicles to move adjacent to the testing equipment, e) forces vehicles to move towards the roadway edge, f) loss of control g) collision with guardrails of the bridges or the culverts. Thus these types of inspection activities also pose risk.
3. **Mowing**: This activity typically doesn't affect the traffic but would be considered a work zone when it occurs within 15 ft of the roadway. However, while mowing a sloped embankment on the side of a pavement or a roadway, the equipment may block the traffic to some extent and the same risks as mentioned above may occur.
4. **Movement of Street Sweeper**: A **street sweeper** or **street cleaner** refers to a variety of mobile equipment that cleans streets, usually in an urban area. This type of activity slows down traffic to less than the normal traffic speed and may distract the drivers' attention.
5. **Painting**: It constitutes the major portion of the moving O/M activities. About 90 % of the painting activities belong to the moving operation category. It has a big impact on the traffic. It is extremely dynamic and depends on several factors. Roadway / Pavement painting is of 2 types – Straddling (for centerline painting) and Offset to centerline (for edge-line painting). The Straddling type doesn't affect the traffic much

compared to the second type. However the riskiest situation is the edge-line painting on 2-lane 2-way traffic roads because the traffic is moving in the opposite direction of the operation. The most difficult situation arises when the traffic has to be maintained in both lanes. In some situations, the traffic coming from one direction may have to temporarily let the traffic from the other direction pass by when the painting operation blocks a roadway (especially during edge-line painting).

6. **Pavement markings**: It is very important as a guide to the drivers and it is also included as a moving operation as it involves marking the pavement by blocking the traffic in that zone for a short duration. However this also blocks and slows down the traffic and creates similar problems as that of painting. However in this case, care should be taken about the safety of the unprotected (not inside a vehicle) workers working on the roadways as sometimes vehicles coming at high speed may lose control.
7. **Crack filling / Patch work**: This is a really "hectic" maintenance operation of the roadways and the roadway may be blocked for up to half a day in case of a high volume road. This type of work involves flagger operations which act as a signal for the moving work zone. Also, high strength materials are used here so that the road track becomes usable after a short while. However, there are people responsible for guiding the public to stop and move off to the shoulder and also make the vehicles stop until the work is done. In other situations, O/M workers may simply wait for a break in traffic and walk out into the travelled path to fill a crack.
8. **Curb and Surface Repairs**: This is usually done by smaller trucks and equipment (e.g pick-up trucks and even golf-cart type buggies), which do not have as much protection or visibility when positioned next to moving vehicles. This can become a risky operation in a busy roadway. However, this type of repair work also blocks the traffic road for a while and thus makes the normal traffic flow slower and may distract the drivers.
9. **Flagger operations:** This type of operation takes place generally in a 2-way, 2-lane highway where the roadway is partially blocked for a moving O/M activity. The portion which is blocked is being guarded by two flaggers or signals on its either side

which stops the flow of traffic on the lane where work is going on, letting the traffic move on the other lane and then after a particular amount of time, the flow is reversed (opposite lane traffic is halted and the disrupted lane traffic is allowed to pass). This is a timed activity and attention is given to the fact that traffic is affected by the O/M activity.

10. **Replacing / Repairing the signals and signage:** Many sign-replacement and repair tasks occur at the side of the road and thus in most of the times it does not disrupt the traffic flow. If it is on the shoulder then it is safer than in the travelled lane, but workers are very close to the track (within 15 feet) that are at risk. Special precaution needs to be taken so that workers mistakenly do not enter the travelled roadway / street. In some instances, barricades need to be put up to keep the traffic flow from the work-zone. In case of repairing or removal of the signage over the roadway, boom trucks are generally used which also block the roadway and disrupt the traffic to a great extent.
11. **Loading / unloading material for maintenance operations**: This is an activity where the trucks may block traffic while unloading / loading material for maintenance of signals and signage, for instance. If it is a low volume road, then the problem is not as significant compared to a high volume road. However the risk events associated are quite dangerous. In a 2-lane, 2-way road, it can block the vision of the vehicle operators. Moreover, the vehicles trying to pass the obstructing truck may move on to the side lane and cross the centerline where vehicles are coming from the opposite direction. Pedestrians, on finding that the sidewalk is blocked, may also try to pass the truck by coming on to the roadway.
12. **Shoulder grading**: Shoulder grading involves the shaping and stabilizing of unpaved roadway shoulder areas. This maintenance activity can be completed year-round, but is usually programmed between April and November. A shoulder grading crew utilizes about ten workers on the road, in addition to graders, dump trucks, a belt loader, a roller and usually a street sweeper. Thus this activity has a large impact on the traffic as it involves several types of equipment which block the roadway and slows down the traffic.

13. **Repair, maintenance and installation of guardrails, cable rails and barrier rails:** Guardrails and cable rails may be very close to the traveling lanes just at the edge of the shoulder and these rails frequently need repair or replacement when they are hit by a vehicle. Many times, if their damage is projected outside the roadway, they may be replaced or repaired without blocking the traffic. But if the shoulder width is not enough or the damage is projected towards the traveling lane then it becomes a mobile work zone condition. In these cases a portion of the road needs to be closed temporarily. Also, drivers tend to move towards the centerline of the road while passing the short length of the temporary work zone, which can pose risks if it is a 2-lane 2-way roadway.
14. On the other hand, the repair and maintenance of barrier rails (mainly at the center of the road) and some guardrails and cable rails that are at the center of the road (such as for many bridges) present different work zone conditions. Here the risk is more for the safety of the workers rather than the traveling public. If a vehicle loses control and crosses the centerline, then the bridge deck crews will have limited time or routes to escape from that situation as there would be vehicles coming from the opposite direction.
15. **Maintenance of sanitary and storm sewer and water main**: In this case also the equipment is kept on the shoulder but if there is not enough space, some parts of the roadway need to be blocked which again becomes a moving work zone.
16. **Ditch cleaning**: Similar to the activity above, and in most cases it is not a high- risk event except for potential driver distraction and the traffic may become a little slower if a part of the roadway is blocked.
17. **Cleaning storm sewer intakes & structures**: Similar to that of activities 14 and 15 above.
18. **Survey work**: This is a moving operation that often has to block the roadway for a short while. One of the main problems is that survey work uses minimum work zone signage which creates several problems mainly on 2-way highways. In many cases, drivers do not understand what the survey crew is doing. Moreover, vehicles moving

at high speed need time to lower their speed for which proper signage should be installed at a certain distance from the work zone.

19. **Ingress and egress from construction site**: This is a risk event created when trucks load and unload the materials needed for the repair and maintenance job of signals and signage, among others. The trucks need to slow down their speed when they ingress the work zone site and have to separate themselves from the moving traffic. This often creates a problem on high volume roads as the traffic behind the truck also needs to slow down. Again, the same problem arises at the time of the egress from the work zone site. The trucks need to come back to the normal traffic flow by entering the right lane and gaining the required speed. This activity also blocks the moving traffic to some extent and proper signals need to be given so that accidents and head-on collisions can be avoided.
20. **Electric / power system maintenance and street lighting**: In many states, the electric / power system is overhead, above the traveled lane, so repair or maintenance of such overhead lines requires the use of boom trucks which may block the roadway and disrupt the normal traffic flow. They also can distract the drivers' attention and force the vehicles to move towards the centerline of the road. Proper attention should also be given to the safety of the crews working in these kinds of work-zones as workers in the buckets have little mobility or protection.
21. **Snow removal**: Generally snow plows are used to move the snow from the roads and streets, but they may be unobserved by the moving vehicles which lead to accidents. Also, removing snow frequently requires end-loaders to back into traveled lanes, especially in urban area (streets). Because of the unique characteristics of snow removal, it will be excluded from this study.

ENVIRONMENT

1. **Night time operations**: To avoid the high volume of traffic in rush hours, some operations are done at night. But night operations on bridges are risky both for materials testing and maintenance operations. Coring, painting, some patching work,

debris pick-up, and different barrier rail repairs are done at night rather than in the daylight. In all these cases, the major issue is the lighting of the work zone. If the work zone is properly illuminated, then the problems are minimized. But most of the mobile work zones require portable lights as many of the working regions may not have proper street lighting.

2. **Rutted roadways**: Due to the weathering effect, the roadway tracks in the traveled lanes can become deteriorated and there may also be potholes in the middle of the tracks. This often affects driver behavior as in order to avoid the potholes, they try to move towards the edge of the road and thus may hit signs or guardrails. Sometimes, they are forced to move towards the centerline and thus shift lanes to where vehicles are moving in a different speed (divided 4-lane) or vehicles are coming from the opposite direction (2-lane 2-way highways). Unanticipated movements such as these can create risks in mobile work zones.
3. **Small towns or schools nearby**: If the work zone is near a small town or a school, the work in that area needs to be scheduled according to the timing of the local peak traffic flows. For instance, in the case of a school, the work needs to be stopped near the time when school starts or when it ends. Roadways cannot be blocked at those peak hours as that would cause real inconvenience to the public and also increase the risk factor to a higher degree.
4. **Ramps and roadway intersections**: If work is going on at the intersection of the roads or at the ramps, proper signals and signage is often not installed for the vehicles coming from the other lanes where no work is being performed. Proper attention should be given to the movement of these vehicles (on the intersecting or merging roads/streets) so that they may know that there is a work zone ahead. Without such configurations, entrance to the work zone can't be controlled. Signage and warnings needs to be installed on both sides of the ramps. Again, all signage should be pertaining to the current work situation and thus needs to be updated according to the progress of the work.
5. **Pavement markings**: This type of work is generally done in the morning hours to avoid disruption of the traffic, especially at the intersections.

6. **Roads in hilly areas**: In these conditions, the sight distance is problematic. In any work zone in hilly areas, flaggers may be employed ahead of the stoplights to make sure that the information about the work zone is communicated to the public at appropriate time and distance, and to make sure that the convoys stay together.
7. **Peak traffic hours**: Work should be scheduled in the moving work zones according to the traffic hours. Generally in peak traffic hours on high volume roads, the work is stopped for a while and is again resumed after the peak hours.
8. **Variable travel pattern**: In some areas (like Ames) different institutions like the DOT, the University, the Animal Disease lab, etc. create different and variable peak travel times. Therefore, some decisions on moving operations require local knowledge or input.
9. **Work near railway crossings**: Work near the railway crossings should be done very carefully and also it needs to be stopped when a train will be approaching. Thus this type of work should be coordinated as much as possible with train schedules.
10. **Responding to emergency vehicles**: In these cases, the work is brought to a temporary halt and the emergency vehicle is allowed to pass by.
11. **Unforeseen weather conditions**: The weather conditions in Iowa can be quite variable and hard to predict, especially in the last 3 years. There should be flexibility to move to another site for O/M work if the weather is bad in the region where work was originally planned. For instance, if a large area is experiencing heavy rain or dense fog, the scheduled operation needs to be shifted to a different area.
12. **Fog and mist**: This is a temporary weather situation which affects the visibility for a short time (usually early mornings) or in a small area (river valleys). In this situation, either special signals are used to warn the vehicles of a mobile work zone nearby or if the situation worsens the work is brought to a temporary halt.
13. **Different rules in shared jurisdictions**: Different rules can apply when work moves “across the street” in a shared jurisdiction which mainly includes city streets, DOT routes and institutional routes (such as within ISU). This sometimes may create confusion among drivers, contractors, utility companies, etc. This may cause

inconvenience (permits, notifications, coordination, etc.) to the working crews in the different mobile work zones.

14. **Special events**: Different local special events such as parades, races, fairs, etc. are carried on in local cities and towns which may block the road for a while. These also stop the work in the O/M work zone for a while to give space for the events to take place.

EQUIPMENT

1. **Falling Weight Deflectometer**: This type of equipment is used to test the strength properties of the pavement and subgrade. This equipment is mounted on a moving vehicle which stops in the lane to test at different locations. Since it is stop-and-go, they hinder the normal traffic flow to some extent.
2. **Straddling painters**: These are mobile painting machines used to paint the center line of roads. Usually they do not block traffic but will slow down traffic flow in both directions.
3. **Maintainers on gravel roads**: No signage is used during this operation. Most of these are used on low volume roads with local traffic only that is knowledgeable of the operation.
4. **Cold mix patchwork**: Generally when cold mix is put in a hole on the roadway, traffic is not affected and hence no signage is used for this activity.
5. **Friction testing**: This machine can disrupt the traffic because of the water that is applied to the roadway surface during the 3 second test at 40 mph.
6. **Media trucks**: Although the work is for a short duration, these vehicles and their operators frequently lack safety protocols while working. They may block the road for more than 2 hours and often do not use any proper signage which can disrupt the movement of traffic.
7. **Trucks carrying rock / aggregate**: Many times, rocks and other aggregate may fall on the roadway while being hauled, sometimes cracking the windshields of the following vehicles. Proper signage should be used and precaution should be taken.

8. **Boom trucks**: These trucks are mounted with long booms which are used to maintain & repair signage and signboards across the road lanes and also help to repair the electric overhead lines at times.
9. **Pick-up trucks**: This is a light weight motor vehicle used to carry light material, tools, and equipment from one place to the other or during inspections.
10. **Street sweepers**: A street sweeper or street cleaner refers to a machine that cleans streets, usually in an urban area.
11. **Jet vac**: This equipment is used for cleaning the leaves out of storm or sanitary intakes and structures.
12. **Paint carts (hauled on trailers)**: These are usually used for painting roads and pavements in urban areas (e.g. turn arrows and crosswalks).
13. **Proper signage**: Proper signage at different types of moving work zones is a necessity in order to prevent accidents and warn drivers in advance about the work zone. The signage should be changed as the work progresses so that current information can be conveyed to the public.
14. **Fluorescent diamond signs**: These types of signs should be used at the back of the vehicles and the equipment in order to notify the vehicles coming from behind that there is a moving work zone ahead.
15. **Use of lights / blinkers**: Several types of lights and blinkers are used in the mobile O/M work zone with little standardization.
16. **Fluorescent borders**: In some mobile work zones where work is mainly conducted at night or equipment is stored overnight, fluorescent colored indicators form borders on signs to signal that a mobile work zone is ahead.
17. **Speed limit fines**: Fines for mobile operations generally do not exist as they do for other construction activities and so people may not be as aware or as careful in these types of operations.

RELATIONSHIPS

1. **Co-ordination with municipalities**: Many times due to lack of communication, local events impact O/M activities. This is probably a bigger problem for centralized state activities than for local (e.g. county) activities.
2. **Advantage of the closed roads**: For many types of O/M activities, preference of work should be given to those roads which are temporarily closed. However, due to lack of co-ordination and information, static and mobile operations often run into each other.
3. **Co-ordination between state and the local agencies**: Sometimes due to lack of information, the state and local agencies may come to work at the same place at the same time, which may create a problem.
4. **Worker safety and training programs**: Younger and temporary O/M workers are not given enough training which may lead to inefficient work and an unsafe work zone.
5. **Train the trainers**: This philosophy is used to train all the employees of the organization to the extent which is required only for performing their particular work. Training is given by the individuals where only the basics are taught. If any additional problems occur it is generally escalated to the supervisor.
6. **Control of Rights of Way (ROW):** Frequently ROW managers are not aware of O/M activities occurring in the ROW. DOT tries to coordinate ROW permits, but they don't always get a copy of the final permit. In some local and institutional situations (such as ISU/Ames), there is no communication or coordination when control of the ROW changes. Private utility and contractors making taps or upgrades in streets or ROW should get a new ROW permit form, which contains a requirement for traffic control planning, but this doesn't always happen.
7. **Third party interaction**: There is subcontracted maintenance and repair work on some major utility repairs, especially directional drilling for electrical conduit. There are also O/M activities on shared jurisdiction roads. Neighborhood groups often do not communicate upcoming activities. O/M also tries to coordinate with law

enforcement on issues such as missing signs or placement of stop signs. O/M also has to coordinate with railroads and utilities on maintenance of rail crossings and utilities under the railroad.

APPENDIX B: SURVEY QUESTIONNAIRE

Events	Likelihood					Impact				
ACTIVITIES	Very unlikely	Unlikely	Neutral	Probable	Very Probable	Very Rarely	Rarely	Neutral	Frequently	Very Frequently
	1	2	3	4	5	1	2	3	4	5
FWD Structural Testing on Pavement & Subgrade	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ride Quality Testing on Pavement or Bridge Surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Core drilling on Pavements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manual Condition Surveys for Pavement Section	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bridges and culvert repair and inspection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mowing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Movement of Street Sweeper / Street Cleaner	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Straddling Painting (centerline painting)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Offset to Centerline Painting (edge-line painting)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2-lane 2-way traffic roads edge-line painting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pavement markings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Crack filling / Patch work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Curb & Surface Repairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flagger operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Replacing/Repairing the signals and signage	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Loading /unloading material for maintenance operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Loading /unloading material for maintenance operations (in a 2-lane 2-way road)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Shoulder grading	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Repair, Maintenance & installation of guardrails, cable rails and barrier rails(at the edge of the shoulder)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Repair, Maintenance & installation of guardrails, cable rails and barrier rails(at the edge of the shoulder in a 2-way 2-lane road)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Repair, Maintenance & installation of guardrails, cable rails and barrier rails(at center of the road)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Maintenance of sanitary and storm sewer and water main	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ditch cleaning	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cleaning storm sewer intakes & structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Survey Work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ingress & Egress from construction site	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Electric / power system maintenance and street lighting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Snow removal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Events	Likelihood					Impact				
ENVIRONMENT	Very unlikely	Unlikely	Neutral	Probable	Very Probable	Very Rarely	Rarely	Neutral	Frequently	Very Frequently
	1	2	3	4	5	1	2	3	4	5
Night time operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rutted roadways (Track change of vehicles)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Presence of Small towns or schools nearby	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improper signs & signage at ramps and roadway intersections near work zones	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pavement markings at intersections (at nighttime)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pavement markings at intersections (at daytime)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Work zones on roads in hilly areas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Peak traffic hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. Variable travel patterns near institutions like DOT, the University, the Animal Disease lab in Ames, Iowa)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Work near railway crossings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Responding to the Emergency Vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Unforeseen weather conditions	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fog & mist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Different rules in shared jurisdictions	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Special events such as parades, races, fairs, etc. are carried on in local cities and towns	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Events	Likelihood					Impact				
EQUIPMENT	Very unlikely	Unlikely	Neutral	Probable	Very Probable	Very Rarely	Rarely	Neutral	Frequently	Very Frequently
	1	2	3	4	5	1	2	3	4	5
Falling Weight Deflectometer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Straddling Painters	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Maintainers on Gravel roads	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cold Mix Patchwork	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Friction testing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Media Trucks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Trucks carrying rock/aggregate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Boom trucks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pick-up trucks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Street sweepers / Street Cleaners	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jet vac	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Paint carts (hauled on trailers)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Absence of proper signage near the work zone	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Absence of fluorescent diamond signs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Not using lights / blinkers in the work zone	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Not using fluorescent borders / indicators for mobile work zones at night	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Not imposing speed limit fines on public	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Events	Likelihood					Impact				
OTHERS	Very unlikely	Unlikely	Neutral	Probable	Very Probable	Very Rarely	Rarely	Neutral	Frequently	Very Frequently
	1	2	3	4	5	1	2	3	4	5
Lack of Co-ordination with Municipalities	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Advantage of the closed roads	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lack of Co-ordination between state and the local agencies	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lack of Work safety and training programs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Absence of Train the trainers philosophy	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lack of coordination between DOT & ROW regarding Control of Rights of Way (ROW)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improper Third Party Interaction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

APPENDIX C. SURVEY RAW DATA

You are being asked to rate the likelihood and severity of incidents involving the work activity identified in each of the questions below. The incident could involve injury or property damage to maintenance equipment, maintenance workers, or the traveling public. As you are going through this page, please keep the following two questions in mind: How likely is it to have an incident with the identified work activity (odd numbered questions)? If an incident does occur with this work activity, what is the most likely severity of the incident (even numbered questions)? Please rate on a 0-5 scale as identified below:

1. FWD structural testing on pavement & subgrade		
Unable to Answer	11	34%
Very Unlikely	4	12%
Unlikely	4	12%
Neutral	9	28%
Probable	4	12%
Very Probable	0	0%
Total	32	100%
2. FWD structural testing on pavement & subgrade		
Unable to Answer	11	34%
No Loss	2	6%
Potential Property Damage	5	16%
Minor Property Damage and/or Minor Injuries	7	22%
Major Property Damage and/or Major Injuries	7	22%
Catastrophic Loss/Fatality	0	0%
Total	32	100%
3. Ride quality testing on pavement or bridge surface		
Unable to Answer	12	38%
Very Unlikely	4	12%
Unlikely	6	19%
Neutral	5	16%

Probable	5	16%
Very Probable	0	0%
Total	32	100%
4. Ride quality testing on pavement or bridge surface		
Unable to Answer	15	47%
No Loss	5	16%
Potential Property Damage	5	16%
Minor Property Damage and/or Minor Injuries	5	16%
Major Property Damage and/or Major Injuries	2	6%
Catastrophic Loss/Fatality	0	0%
Total	32	100%
5. Core drilling on pavements		
Unable to Answer	9	28%
Very Unlikely	3	9%
Unlikely	8	25%
Neutral	5	16%
Probable	7	22%
Very Probable	0	0%
Total	32	100%
6. Core drilling on pavements		
Unable to Answer	11	35%
No Loss	1	3%
Potential Property Damage	5	16%
Minor Property Damage and/or Minor Injuries	5	16%
Major Property Damage and/or Major Injuries	8	26%
Catastrophic Loss/Fatality	1	3%
Total	31	100%
7. Manual condition surveys for pavement section		
Unable to Answer	13	42%
Very Unlikely	3	10%

Unlikely	6	19%
Neutral	2	6%
Probable	7	23%
Very Probable	0	0%
Total	31	100%
8. Manual condition surveys for pavement section		
Unable to Answer	14	44%
No Loss	4	12%
Potential Property Damage	3	9%
Minor Property Damage and/or Minor Injuries	2	6%
Major Property Damage and/or Major Injuries	7	22%
Catastrophic Loss/Fatality	2	6%
Total	32	100%
9. Bridges and culvert repair and inspection		
Unable to Answer	8	27%
Very Unlikely	2	7%
Unlikely	7	23%
Neutral	4	13%
Probable	9	30%
Very Probable	0	0%
Total	30	100%
10. Bridges and culvert repair and inspection		
Unable to Answer	10	31%
No Loss	2	6%
Potential Property Damage	4	12%
Minor Property Damage and/or Minor Injuries	5	16%
Major Property Damage and/or Major Injuries	9	28%
Catastrophic Loss/Fatality	2	6%
Total	32	100%
11. Mowing		

Unable to Answer	6	19%
Very Unlikely	6	19%
Unlikely	9	29%
Neutral	6	19%
Probable	4	13%
Very Probable	0	0%
Total	31	100%
12. Mowing		
Unable to Answer	6	19%
No Loss	4	12%
Potential Property Damage	5	16%
Minor Property Damage and/or Minor Injuries	11	34%
Major Property Damage and/or Major Injuries	5	16%
Catastrophic Loss/Fatality	1	3%
Total	32	100%
13. Movement of street sweeper / street cleaner		
Unable to Answer	8	25%
Very Unlikely	4	12%
Unlikely	6	19%
Neutral	6	19%
Probable	8	25%
Very Probable	0	0%
Total	32	100%
14. Movement of street sweeper / street cleaner		
Unable to Answer	8	25%
No Loss	5	16%
Potential Property Damage	7	22%
Minor Property Damage and/or Minor Injuries	5	16%
Major Property Damage and/or Major Injuries	6	19%
Catastrophic Loss/Fatality	1	3%
Total	32	100%

15. Straddle painting (centerline painting) on 2-lane 2-way traffic roadway		
Unable to Answer	3	10%
Very Unlikely	1	3%
Unlikely	8	26%
Neutral	3	10%
Probable	14	45%
Very Probable	2	6%
Total	31	100%
16. Straddle painting (centerline painting) on 2-lane 2-way traffic roadway		
Unable to Answer	3	10%
No Loss	2	6%
Potential Property Damage	8	26%
Minor Property Damage and/or Minor Injuries	8	26%
Major Property Damage and/or Major Injuries	8	26%
Catastrophic Loss/Fatality	2	6%
Total	31	100%
17. Offset painting (edge-line painting) on 4-lane divided highway		
Unable to Answer	4	13%
Very Unlikely	3	10%
Unlikely	6	19%
Neutral	7	23%
Probable	10	32%
Very Probable	1	3%
Total	31	100%
18. Offset painting (edge-line painting) on 4-lane divided highway		
Unable to Answer	5	16%
No Loss	3	9%
Potential Property Damage	9	28%
Minor Property Damage and/or Minor Injuries	8	25%
Major Property Damage and/or Major Injuries	6	19%

Catastrophic Loss/Fatality	1	3%
Total	32	100%
19. Offset painting (edgeline painting) on 2-lane 2-way traffic roadway		
Unable to Answer	5	16%
Very Unlikely	2	6%
Unlikely	8	25%
Neutral	8	25%
Probable	8	25%
Very Probable	1	3%
Total	32	100%
20. Offset painting (edgeline painting) on 2-lane 2-way traffic roadway		
Unable to Answer	4	13%
No Loss	2	6%
Potential Property Damage	10	32%
Minor Property Damage and/or Minor Injuries	7	23%
Major Property Damage and/or Major Injuries	6	19%
Catastrophic Loss/Fatality	2	6%
Total	31	100%
21. Pavement markings		
Unable to Answer	5	16%
Very Unlikely	2	6%
Unlikely	5	16%
Neutral	10	31%
Probable	9	28%
Very Probable	1	3%
Total	32	100%
22. Pavement markings		
Unable to Answer	5	16%
No Loss	1	3%
Potential Property Damage	8	25%

Minor Property Damage and/or Minor Injuries	9	28%
Major Property Damage and/or Major Injuries	7	22%
Catastrophic Loss/Fatality	2	6%
Total	32	100%
23. Crack filling / patch work		
Unable to Answer	5	16%
Very Unlikely	4	12%
Unlikely	3	9%
Neutral	7	22%
Probable	13	41%
Very Probable	0	0%
Total	32	100%
24. Crack filling / patch work		
Unable to Answer	5	16%
No Loss	3	9%
Potential Property Damage	4	12%
Minor Property Damage and/or Minor Injuries	8	25%
Major Property Damage and/or Major Injuries	10	31%
Catastrophic Loss/Fatality	2	6%
Total	32	100%
25. Curb & surface repairs		
Unable to Answer	6	20%
Very Unlikely	1	3%
Unlikely	7	23%
Neutral	9	30%
Probable	7	23%
Very Probable	0	0%
Total	30	100%
26. Curb & surface repairs		
Unable to Answer	7	23%

No Loss	2	6%
Potential Property Damage	6	19%
Minor Property Damage and/or Minor Injuries	10	32%
Major Property Damage and/or Major Injuries	5	16%
Catastrophic Loss/Fatality	1	3%
Total	31	100%
27. Flagger operations		
Unable to Answer	1	3%
Very Unlikely	4	12%
Unlikely	4	12%
Neutral	11	34%
Probable	10	31%
Very Probable	2	6%
Total	32	100%
28. Flagger operations		
Unable to Answer	1	3%
No Loss	5	16%
Potential Property Damage	2	6%
Minor Property Damage and/or Minor Injuries	8	25%
Major Property Damage and/or Major Injuries	11	34%
Catastrophic Loss/Fatality	5	16%
Total	32	100%
29. Replacing/Repairing signals and signage		
Unable to Answer	3	11%
Very Unlikely	3	11%
Unlikely	8	30%
Neutral	9	33%
Probable	3	11%
Very Probable	1	4%
Total	27	100%

30. Replacing/Repairing signals and signage		
Unable to Answer	3	11%
No Loss	4	15%
Potential Property Damage	6	22%
Minor Property Damage and/or Minor Injuries	9	33%
Major Property Damage and/or Major Injuries	3	11%
Catastrophic Loss/Fatality	2	7%
Total	27	100%
31. Loading /unloading material for maintenance operations on a 4-lane divided highway		
Unable to Answer	3	11%
Very Unlikely	2	7%
Unlikely	8	30%
Neutral	6	22%
Probable	5	19%
Very Probable	3	11%
Total	27	100%
32. Loading /unloading material for maintenance operations on a 4-lane divided highway		
Unable to Answer	3	11%
No Loss	4	15%
Potential Property Damage	6	22%
Minor Property Damage and/or Minor Injuries	5	19%
Major Property Damage and/or Major Injuries	7	26%
Catastrophic Loss/Fatality	2	7%
Total	27	100%
33. Loading /unloading material for maintenance operations on a 2-lane 2-way traffic roadway		
Unable to Answer	2	8%
Very Unlikely	2	8%
Unlikely	6	23%
Neutral	6	23%
Probable	8	31%
Very Probable	2	8%

Total	26	100%
34. Loading /unloading material for maintenance operations on a 2-lane 2-way traffic roadway		
Unable to Answer	3	12%
No Loss	3	12%
Potential Property Damage	6	23%
Minor Property Damage and/or Minor Injuries	5	19%
Major Property Damage and/or Major Injuries	7	27%
Catastrophic Loss/Fatality	2	8%
Total	26	100%
35. Shoulder grading		
Unable to Answer	5	19%
Very Unlikely	2	7%
Unlikely	10	37%
Neutral	9	33%
Probable	1	4%
Very Probable	0	0%
Total	27	100%
36. Shoulder grading		
Unable to Answer	4	15%
No Loss	3	12%
Potential Property Damage	8	31%
Minor Property Damage and/or Minor Injuries	7	27%
Major Property Damage and/or Major Injuries	4	15%
Catastrophic Loss/Fatality	0	0%
Total	26	100%
37. Repair, maintenance & installation of guardrails, cable rails and barrier rails on a 4-lane divided highway		
Unable to Answer	4	15%
Very Unlikely	2	7%
Unlikely	6	22%

Neutral	10	37%
Probable	5	19%
Very Probable	0	0%
Total	27	100%
38. Repair, maintenance & installation of guardrails, cable rails and barrier rails on a 4-lane divided highway		
Unable to Answer	4	15%
No Loss	1	4%
Potential Property Damage	6	22%
Minor Property Damage and/or Minor Injuries	5	19%
Major Property Damage and/or Major Injuries	9	33%
Catastrophic Loss/Fatality	2	7%
Total	27	100%
39. Repair, maintenance & installation of guardrails, cable rails and barrier rails on a 2-lane 2-way traffic roadway		
Unable to Answer	4	15%
Very Unlikely	2	7%
Unlikely	6	22%
Neutral	8	30%
Probable	7	26%
Very Probable	0	0%
Total	27	100%
40. Repair, maintenance & installation of guardrails, cable rails and barrier rails on a 2-lane 2-way traffic roadway		
Unable to Answer	4	15%
No Loss	1	4%
Potential Property Damage	8	31%
Minor Property Damage and/or Minor Injuries	3	12%
Major Property Damage and/or Major Injuries	7	27%
Catastrophic Loss/Fatality	3	12%
Total	26	100%

41. Repair, maintenance & installation of centerline guardrails, cable rails and barrier rails on a 4-lane divided highway		
Unable to Answer	4	15%
Very Unlikely	3	11%
Unlikely	3	11%
Neutral	13	48%
Probable	4	15%
Very Probable	0	0%
Total	27	100%
42. Repair, maintenance & installation of centerline guardrails, cable rails and barrier rails on a 4-lane divided highway		
Unable to Answer	4	15%
No Loss	3	11%
Potential Property Damage	6	22%
Minor Property Damage and/or Minor Injuries	5	19%
Major Property Damage and/or Major Injuries	7	26%
Catastrophic Loss/Fatality	2	7%
Total	27	100%
43. Maintenance of sanitary and storm sewer and water main		
Unable to Answer	7	26%
Very Unlikely	3	11%
Unlikely	9	33%
Neutral	5	19%
Probable	3	11%
Very Probable	0	0%
Total	27	100%
44. Maintenance of sanitary and storm sewer and water main		
Unable to Answer	7	26%
No Loss	2	7%
Potential Property Damage	11	41%
Minor Property Damage and/or Minor Injuries	1	4%
Major Property Damage and/or Major Injuries	5	19%

Catastrophic Loss/Fatality	1	4%
Total	27	100%
45. Ditch cleaning		
Unable to Answer	7	26%
Very Unlikely	6	22%
Unlikely	9	33%
Neutral	3	11%
Probable	2	7%
Very Probable	0	0%
Total	27	100%
46. Ditch cleaning		
Unable to Answer	6	23%
No Loss	6	23%
Potential Property Damage	9	35%
Minor Property Damage and/or Minor Injuries	1	4%
Major Property Damage and/or Major Injuries	4	15%
Catastrophic Loss/Fatality	0	0%
Total	26	100%
47. Cleaning storm sewer intakes & structures		
Unable to Answer	6	23%
Very Unlikely	4	15%
Unlikely	9	35%
Neutral	5	19%
Probable	2	8%
Very Probable	0	0%
Total	26	100%
48. Cleaning storm sewer intakes & structures		
Unable to Answer	7	28%
No Loss	6	24%
Potential Property Damage	7	28%

Minor Property Damage and/or Minor Injuries	2	8%
Major Property Damage and/or Major Injuries	2	8%
Catastrophic Loss/Fatality	1	4%
Total	25	100%
49. Survey work		
Unable to Answer	6	22%
Very Unlikely	6	22%
Unlikely	4	15%
Neutral	7	26%
Probable	3	11%
Very Probable	1	4%
Total	27	100%
50. Survey work		
Unable to Answer	6	22%
No Loss	8	30%
Potential Property Damage	5	19%
Minor Property Damage and/or Minor Injuries	0	0%
Major Property Damage and/or Major Injuries	5	19%
Catastrophic Loss/Fatality	3	11%
Total	27	100%
51. Ingress & egress from construction site		
Unable to Answer	3	11%
Very Unlikely	1	4%
Unlikely	4	15%
Neutral	5	19%
Probable	13	48%
Very Probable	1	4%
Total	27	100%
52. Ingress & egress from construction site		

Unable to Answer	3	11%
No Loss	4	15%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	9	33%
Major Property Damage and/or Major Injuries	10	37%
Catastrophic Loss/Fatality	0	0%
Total	27	100%
53. Electric / power system maintenance and street lighting		
Unable to Answer	7	27%
Very Unlikely	3	12%
Unlikely	5	19%
Neutral	6	23%
Probable	5	19%
Very Probable	0	0%
Total	26	100%
54. Electric / power system maintenance and street lighting		
Unable to Answer	6	23%
No Loss	1	4%
Potential Property Damage	9	35%
Minor Property Damage and/or Minor Injuries	3	12%
Major Property Damage and/or Major Injuries	6	23%
Catastrophic Loss/Fatality	1	4%
Total	26	100%
55. Snow removal		
Unable to Answer	7	26%
Very Unlikely	0	0%
Unlikely	3	11%
Neutral	4	15%
Probable	13	48%
Very Probable	0	0%
Total	27	100%

56. Snow removal		
Unable to Answer	7	26%
No Loss	0	0%
Potential Property Damage	6	22%
Minor Property Damage and/or Minor Injuries	8	30%
Major Property Damage and/or Major Injuries	6	22%
Catastrophic Loss/Fatality	0	0%
Total	27	100%
57. Night time operations		
Unable to Answer	1	4%
Very Unlikely	0	0%
Unlikely	1	4%
Neutral	4	17%
Probable	14	58%
Very Probable	4	17%
Total	24	100%
58. Night time operations		
Unable to Answer	2	8%
No Loss	1	4%
Potential Property Damage	2	8%
Minor Property Damage and/or Minor Injuries	4	16%
Major Property Damage and/or Major Injuries	10	40%
Catastrophic Loss/Fatality	6	24%
Total	25	100%
59. Presence of small towns or schools nearby		
Unable to Answer	5	20%
Very Unlikely	0	0%
Unlikely	8	32%
Neutral	7	28%
Probable	4	16%
Very Probable	1	4%

Total	25	100%
60. Presence of small towns or schools nearby		
Unable to Answer	5	20%
No Loss	5	20%
Potential Property Damage	6	24%
Minor Property Damage and/or Minor Injuries	6	24%
Major Property Damage and/or Major Injuries	2	8%
Catastrophic Loss/Fatality	1	4%
Total	25	100%
61. Improper signs & signage at ramps and roadway intersections near work zones		
Unable to Answer	2	8%
Very Unlikely	3	12%
Unlikely	0	0%
Neutral	2	8%
Probable	14	56%
Very Probable	4	16%
Total	25	100%
62. Improper signs & signage at ramps and roadway intersections near work zones		
Unable to Answer	2	8%
No Loss	2	8%
Potential Property Damage	2	8%
Minor Property Damage and/or Minor Injuries	7	28%
Major Property Damage and/or Major Injuries	7	28%
Catastrophic Loss/Fatality	5	20%
Total	25	100%
63. Pavement markings at intersections at nighttime		
Unable to Answer	3	12%
Very Unlikely	0	0%
Unlikely	2	8%
Neutral	4	16%

Probable	12	48%
Very Probable	4	16%
Total	25	100%
64. Pavement markings at intersections at nighttime		
Unable to Answer	3	12%
No Loss	3	12%
Potential Property Damage	2	8%
Minor Property Damage and/or Minor Injuries	6	24%
Major Property Damage and/or Major Injuries	9	36%
Catastrophic Loss/Fatality	2	8%
Total	25	100%
65. Pavement markings at intersections at daytime		
Unable to Answer	3	12%
Very Unlikely	1	4%
Unlikely	1	4%
Neutral	13	52%
Probable	6	24%
Very Probable	1	4%
Total	25	100%
66. Pavement markings at intersections at daytime		
Unable to Answer	3	12%
No Loss	3	12%
Potential Property Damage	5	20%
Minor Property Damage and/or Minor Injuries	10	40%
Major Property Damage and/or Major Injuries	4	16%
Catastrophic Loss/Fatality	0	0%
Total	25	100%
67. Work zones on roads in hilly areas		
Unable to Answer	1	4%

Very Unlikely	0	0%
Unlikely	0	0%
Neutral	7	29%
Probable	13	54%
Very Probable	3	12%
Total	24	100%
68. Work zones on roads in hilly areas		
Unable to Answer	1	4%
No Loss	2	8%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	9	36%
Major Property Damage and/or Major Injuries	8	32%
Catastrophic Loss/Fatality	4	16%
Total	25	100%
69. Peak traffic hours		
Unable to Answer	0	0%
Very Unlikely	0	0%
Unlikely	0	0%
Neutral	2	8%
Probable	17	68%
Very Probable	6	24%
Total	25	100%
70. Peak traffic hours		
Unable to Answer	0	0%
No Loss	2	8%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	5	20%
Major Property Damage and/or Major Injuries	15	60%
Catastrophic Loss/Fatality	2	8%
Total	25	100%

71. Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. variable travel patterns near schools, hospitals, campuses, etc)		
Unable to Answer	2	8%
Very Unlikely	2	8%
Unlikely	1	4%
Neutral	5	21%
Probable	11	46%
Very Probable	3	12%
Total	24	100%
72. Lack of knowledge about variable peak traffic time in the local regions near work zone (e.g. variable travel patterns near schools, hospitals, campuses, etc)		
Unable to Answer	3	12%
No Loss	2	8%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	8	33%
Major Property Damage and/or Major Injuries	8	33%
Catastrophic Loss/Fatality	2	8%
Total	24	100%
73. Work near railway crossings		
Unable to Answer	4	16%
Very Unlikely	3	12%
Unlikely	4	16%
Neutral	7	28%
Probable	6	24%
Very Probable	1	4%
Total	25	100%
74. Work near railway crossings		
Unable to Answer	4	16%
No Loss	3	12%
Potential Property Damage	4	16%
Minor Property Damage and/or Minor Injuries	2	8%
Major Property Damage and/or Major Injuries	9	36%

Catastrophic Loss/Fatality	3	12%
Total	25	100%
75. Clearing roadway for emergency vehicles		
Unable to Answer	4	17%
Very Unlikely	0	0%
Unlikely	4	17%
Neutral	4	17%
Probable	8	33%
Very Probable	4	17%
Total	24	100%
76. Clearing roadway for emergency vehicles		
Unable to Answer	4	16%
No Loss	4	16%
Potential Property Damage	3	12%
Minor Property Damage and/or Minor Injuries	8	32%
Major Property Damage and/or Major Injuries	5	20%
Catastrophic Loss/Fatality	1	4%
Total	25	100%
77. Unforeseen weather conditions		
Unable to Answer	1	4%
Very Unlikely	1	4%
Unlikely	2	8%
Neutral	7	28%
Probable	10	40%
Very Probable	4	16%
Total	25	100%
78. Unforeseen weather conditions		
Unable to Answer	1	4%
No Loss	3	12%

Potential Property Damage	7	28%
Minor Property Damage and/or Minor Injuries	4	16%
Major Property Damage and/or Major Injuries	7	28%
Catastrophic Loss/Fatality	3	12%
Total	25	100%
79. Fog & mist		
Unable to Answer	0	0%
Very Unlikely	1	4%
Unlikely	2	8%
Neutral	4	16%
Probable	12	48%
Very Probable	6	24%
Total	25	100%
80. Fog & mist		
Unable to Answer	0	0%
No Loss	2	8%
Potential Property Damage	2	8%
Minor Property Damage and/or Minor Injuries	8	32%
Major Property Damage and/or Major Injuries	10	40%
Catastrophic Loss/Fatality	3	12%
Total	25	100%
81. Different rules in shared jurisdictions		
Unable to Answer	7	28%
Very Unlikely	3	12%
Unlikely	2	8%
Neutral	4	16%
Probable	6	24%
Very Probable	3	12%
Total	25	100%
82. Different rules in shared jurisdictions		

Unable to Answer	8	32%
No Loss	4	16%
Potential Property Damage	6	24%
Minor Property Damage and/or Minor Injuries	2	8%
Major Property Damage and/or Major Injuries	5	20%
Catastrophic Loss/Fatality	0	0%
Total	25	100%
83. Special events such as parades, races, fairs, etc. in local cities and towns near the work zone		
Unable to Answer	3	12%
Very Unlikely	2	8%
Unlikely	0	0%
Neutral	12	48%
Probable	5	20%
Very Probable	3	12%
Total	25	100%
84. Special events such as parades, races, fairs, etc. in local cities and towns near the work zone		
Unable to Answer	4	16%
No Loss	4	16%
Potential Property Damage	6	24%
Minor Property Damage and/or Minor Injuries	9	36%
Major Property Damage and/or Major Injuries	2	8%
Catastrophic Loss/Fatality	0	0%
Total	25	100%
85. Falling weight deflectometer		
Unable to Answer	11	48%
Very Unlikely	1	4%
Unlikely	3	13%
Neutral	4	17%
Probable	4	17%
Very Probable	0	0%
Total	23	100%

86. Falling weight deflectometer		
Unable to Answer	10	43%
No Loss	4	17%
Potential Property Damage	3	13%
Minor Property Damage and/or Minor Injuries	3	13%
Major Property Damage and/or Major Injuries	3	13%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
87. Straddling painters		
Unable to Answer	4	17%
Very Unlikely	1	4%
Unlikely	3	13%
Neutral	6	26%
Probable	9	39%
Very Probable	0	0%
Total	23	100%
88. Straddling painters		
Unable to Answer	4	18%
No Loss	1	5%
Potential Property Damage	5	23%
Minor Property Damage and/or Minor Injuries	7	32%
Major Property Damage and/or Major Injuries	4	18%
Catastrophic Loss/Fatality	1	5%
Total	22	100%
89. Maintainers on gravel roads		
Unable to Answer	9	39%
Very Unlikely	0	0%
Unlikely	6	26%
Neutral	7	30%

Probable	1	4%
Very Probable	0	0%
Total	23	100%
90. Maintainers on gravel roads		
Unable to Answer	9	39%
No Loss	1	4%
Potential Property Damage	8	35%
Minor Property Damage and/or Minor Injuries	3	13%
Major Property Damage and/or Major Injuries	2	9%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
91. Cold mix patchwork		
Unable to Answer	3	13%
Very Unlikely	2	9%
Unlikely	5	22%
Neutral	9	39%
Probable	4	17%
Very Probable	0	0%
Total	23	100%
92. Cold mix patchwork		
Unable to Answer	3	13%
No Loss	2	9%
Potential Property Damage	6	26%
Minor Property Damage and/or Minor Injuries	5	22%
Major Property Damage and/or Major Injuries	5	22%
Catastrophic Loss/Fatality	2	9%
Total	23	100%
93. Friction testing		
Unable to Answer	10	43%
Very Unlikely	4	17%

Unlikely	2	9%
Neutral	6	26%
Probable	1	4%
Very Probable	0	0%
Total	23	100%
94. Friction testing		
Unable to Answer	10	43%
No Loss	5	22%
Potential Property Damage	3	13%
Minor Property Damage and/or Minor Injuries	3	13%
Major Property Damage and/or Major Injuries	2	9%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
95. Media trucks		
Unable to Answer	5	22%
Very Unlikely	7	30%
Unlikely	2	9%
Neutral	5	22%
Probable	4	17%
Very Probable	0	0%
Total	23	100%
96. Media trucks		
Unable to Answer	5	22%
No Loss	7	30%
Potential Property Damage	7	30%
Minor Property Damage and/or Minor Injuries	0	0%
Major Property Damage and/or Major Injuries	4	17%
Catastrophic Loss/Fatality	0	0%
Total	23	100%

97. Trucks carrying rock/aggregate		
Unable to Answer	4	17%
Very Unlikely	3	13%
Unlikely	3	13%
Neutral	6	26%
Probable	6	26%
Very Probable	1	4%
Total	23	100%
98. Trucks carrying rock/aggregate		
Unable to Answer	4	17%
No Loss	1	4%
Potential Property Damage	5	22%
Minor Property Damage and/or Minor Injuries	7	30%
Major Property Damage and/or Major Injuries	6	26%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
99. Boom trucks		
Unable to Answer	4	17%
Very Unlikely	3	13%
Unlikely	4	17%
Neutral	8	35%
Probable	4	17%
Very Probable	0	0%
Total	23	100%
100. Boom trucks		
Unable to Answer	4	17%
No Loss	3	13%
Potential Property Damage	5	22%
Minor Property Damage and/or Minor Injuries	4	17%
Major Property Damage and/or Major Injuries	6	26%
Catastrophic Loss/Fatality	1	4%
Total	23	100%

101. Pick-up trucks		
Unable to Answer	3	13%
Very Unlikely	4	17%
Unlikely	9	39%
Neutral	4	17%
Probable	3	13%
Very Probable	0	0%
Total	23	100%
102. Pick-up trucks		
Unable to Answer	4	17%
No Loss	5	22%
Potential Property Damage	5	22%
Minor Property Damage and/or Minor Injuries	4	17%
Major Property Damage and/or Major Injuries	5	22%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
103. Street sweepers / street cleaners		
Unable to Answer	5	22%
Very Unlikely	3	13%
Unlikely	5	22%
Neutral	4	17%
Probable	6	26%
Very Probable	0	0%
Total	23	100%
104. Street sweepers / street cleaners		
Unable to Answer	5	22%
No Loss	3	13%
Potential Property Damage	5	22%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	4	17%

Catastrophic Loss/Fatality	0	0%
Total	23	100%
105. Jet vac		
Unable to Answer	6	27%
Very Unlikely	3	14%
Unlikely	3	14%
Neutral	8	36%
Probable	2	9%
Very Probable	0	0%
Total	22	100%
106. Jet vac		
Unable to Answer	7	30%
No Loss	4	17%
Potential Property Damage	5	22%
Minor Property Damage and/or Minor Injuries	4	17%
Major Property Damage and/or Major Injuries	3	13%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
107. Paint carts (hauled on trailers)		
Unable to Answer	6	26%
Very Unlikely	3	13%
Unlikely	3	13%
Neutral	7	30%
Probable	4	17%
Very Probable	0	0%
Total	23	100%
108. Paint carts (hauled on trailers)		
Unable to Answer	7	30%
No Loss	3	13%
Potential Property Damage	7	30%

Minor Property Damage and/or Minor Injuries	1	4%
Major Property Damage and/or Major Injuries	5	22%
Catastrophic Loss/Fatality	0	0%
Total	23	100%
109. Absence of proper signage near the work zone		
Unable to Answer	1	4%
Very Unlikely	1	4%
Unlikely	0	0%
Neutral	1	4%
Probable	14	61%
Very Probable	6	26%
Total	23	100%
110. Absence of proper signage near the work zone		
Unable to Answer	1	5%
No Loss	2	9%
Potential Property Damage	0	0%
Minor Property Damage and/or Minor Injuries	5	23%
Major Property Damage and/or Major Injuries	8	36%
Catastrophic Loss/Fatality	6	27%
Total	22	100%
111. Absence of fluorescent diamond signs		
Unable to Answer	2	9%
Very Unlikely	2	9%
Unlikely	1	5%
Neutral	6	27%
Probable	8	36%
Very Probable	3	14%
Total	22	100%
112. Absence of fluorescent diamond signs		

Unable to Answer	2	9%
No Loss	3	13%
Potential Property Damage	2	9%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	7	30%
Catastrophic Loss/Fatality	3	13%
Total	23	100%
113. Not using lights / blinkers in the work zone		
Unable to Answer	1	4%
Very Unlikely	1	4%
Unlikely	1	4%
Neutral	6	26%
Probable	10	43%
Very Probable	4	17%
Total	23	100%
114. Not using lights / blinkers in the work zone		
Unable to Answer	2	9%
No Loss	2	9%
Potential Property Damage	4	17%
Minor Property Damage and/or Minor Injuries	4	17%
Major Property Damage and/or Major Injuries	6	26%
Catastrophic Loss/Fatality	5	22%
Total	23	100%
115. Lack of co-ordination with municipalities		
Unable to Answer	2	9%
Very Unlikely	1	4%
Unlikely	3	13%
Neutral	9	39%
Probable	7	30%
Very Probable	1	4%
Total	23	100%

116. Lack of co-ordination with municipalities		
Unable to Answer	3	13%
No Loss	6	26%
Potential Property Damage	3	13%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	4	17%
Catastrophic Loss/Fatality	1	4%
Total	23	100%
117. Work done under full closure		
Unable to Answer	0	0%
Very Unlikely	9	39%
Unlikely	11	48%
Neutral	0	0%
Probable	1	4%
Very Probable	2	9%
Total	23	100%
118. Work done under full closure		
Unable to Answer	0	0%
No Loss	13	57%
Potential Property Damage	3	13%
Minor Property Damage and/or Minor Injuries	3	13%
Major Property Damage and/or Major Injuries	1	4%
Catastrophic Loss/Fatality	3	13%
Total	23	100%
119. Lack of co-ordination between state and the local agencies		
Unable to Answer	3	13%
Very Unlikely	1	4%
Unlikely	4	17%
Neutral	8	35%
Probable	5	22%
Very Probable	2	9%

Total	23	100%
120. Lack of co-ordination between state and the local agencies		
Unable to Answer	4	17%
No Loss	6	26%
Potential Property Damage	2	9%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	4	17%
Catastrophic Loss/Fatality	1	4%
Total	23	100%
121. Lack of work safety and training programs		
Unable to Answer	1	4%
Very Unlikely	2	9%
Unlikely	0	0%
Neutral	6	26%
Probable	4	17%
Very Probable	10	43%
Total	23	100%
122. Lack of work safety and training programs		
Unable to Answer	1	4%
No Loss	2	9%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	5	22%
Catastrophic Loss/Fatality	8	35%
Total	23	100%
123. Absence of "train the trainers" philosophy		
Unable to Answer	3	14%
Very Unlikely	1	5%
Unlikely	3	14%

Neutral	3	14%
Probable	7	32%
Very Probable	5	23%
Total	22	100%
124. Absence of "train the trainers" philosophy		
Unable to Answer	3	13%
No Loss	4	17%
Potential Property Damage	1	4%
Minor Property Damage and/or Minor Injuries	5	22%
Major Property Damage and/or Major Injuries	5	22%
Catastrophic Loss/Fatality	5	22%
Total	23	100%
125. Lack of coordination between DOT & others regarding control of Rights of Way (ROW)		
Unable to Answer	3	13%
Very Unlikely	3	13%
Unlikely	3	13%
Neutral	8	35%
Probable	5	22%
Very Probable	1	4%
Total	23	100%
126. Lack of coordination between DOT & others regarding control of Rights of Way (ROW)		
Unable to Answer	5	22%
No Loss	8	35%
Potential Property Damage	2	9%
Minor Property Damage and/or Minor Injuries	4	17%
Major Property Damage and/or Major Injuries	3	13%
Catastrophic Loss/Fatality	1	4%
Total	23	100%
127. Improper third party interaction		
Unable to Answer	4	18%

Very Unlikely	0	0%
Unlikely	3	14%
Neutral	5	23%
Probable	9	41%
Very Probable	1	5%
Total	22	100%
128. Improper third party interaction		
Unable to Answer	6	27%
No Loss	4	18%
Potential Property Damage	3	14%
Minor Property Damage and/or Minor Injuries	6	27%
Major Property Damage and/or Major Injuries	3	14%
Catastrophic Loss/Fatality	0	0%
Total	22	100%
129. Not imposing speed limit fines on public		
Unable to Answer	1	5%
Very Unlikely	0	0%
Unlikely	1	5%
Neutral	5	23%
Probable	10	45%
Very Probable	5	23%
Total	22	100%
130. Not imposing speed limit fines on public		
Unable to Answer	1	4%
No Loss	2	9%
Potential Property Damage	2	9%
Minor Property Damage and/or Minor Injuries	6	26%
Major Property Damage and/or Major Injuries	7	30%
Catastrophic Loss/Fatality	5	22%
Total	23	100%