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EVALUATING AND ENHANCING THE SAFETY OF NIGHTTIME CONSTRUCTION PROJECTS

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EVALUATING AND ENSURING SAFETY OF NIGHTTIME CONSTRUCTION AND MAINTENANCE ACTIVITIES

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16. Abstract

The increased demand on the current highway system has caused transportation agencies to increase scheduling for nighttime work in order to alleviate daytime work zone congestion, especially during peak traffic hours. Although traffic congestion is reduced, safety in nighttime workzones remains a concern among both transportation agencies and contractors. According to the Federal Highway Administration (FHWA), approximately one-half of the fatalities that occurred in workzones nationwide occurred at night. These work zone statistics have received increased attention among agencies to evaluate planning and safety issues concerning the workers and the general public on nighttime workzones.

Four separate, but interrelated research studies were conducted between September 2005 - May 2007 to address safety issues in nighttime construction and maintenance projects on highways in Indiana. The first study investigated owner and contractor safety management planning for nighttime construction and maintenance operations, while the second study investigated traffic control planning and implementation procedures for nighttime construction and maintenance operations. The third study investigated the effectiveness of speed control measures on nighttime construction and maintenance projects and the fourth study evaluated the effectiveness of high-visibility personal protective equipment practices.

The safety management practices of the general contractor heavily influence the perception of safety of nighttime construction workers. Workers and general contractors have similar perceptions about the strategies necessary to improve safety on the nighttime construction jobsite. Frequently, the safety threat presented by the general public is cited by nighttime construction and maintenance workers as making them feel unsafe on the jobsite. Methods to raise the awareness of the general public about nighttime construction are needed in order to improve the safety of the nighttime construction and maintenance workers from the dangers imposed by the general public. Traffic control planning by highway agencies and contractors impact the supervisors' and the workers' perceptions of safety. The results from the formal interviews with Indiana contractors and Indiana Department of Transportation (INDOT) personnel indicated that contractors are becoming more involved in traffic control planning. Increased law enforcement and public awareness were among the most important traffic control strategies for improved nighttime safety indicated by the supervisors and the workers. The presence of police enforcement, a high percentage of semi trucks in the traffic, and a high flow rate – all reduced mean speed through nighttime workzones Changeable message signs, while more expensive than work zone speed limit signs, are already being used on many nighttime workzones but were not found to affect mean speeds. Police enforcement was found to reduce mean speeds, was the most expensive method of speed control in the study. The safety garment currently used by the workers of the Indiana Department of Transportation is a yellow-green safety vest with a four-inch wide fluorescent orange strip with two one-inch strips of reflective silver material. The visibility of the safety vest currently used by INDOT can be increased by adding a secondary high-visibility PPE such as safety pants and/or retroreflective bands. Current safety training in personal protective equipment (PPE) is focused on which PPE is applicable for a certain type of job and how to use the PPE. However, training workers how to maintain the PPE will increase its useful life, resulting in savings for the owner and/or the general contractor. In order to improve the visibility of current PPE garments there should be differences in the values of retroreflectivity between the primary and secondary high-visibility PPE and larger variance in the retroreflectivity values across the garment. In addition, the garments should be changed or rotated with other garments periodically to ensure that the attention of drivers is being captured.

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CHAPTER 1. INTRODUCTION

In the last two decades, state transportation agencies have experienced a decline in new project funding, which has led to an increased focus on road rehabilitation and maintenance. The increased demand on the current highway system has caused transportation agencies to increase scheduling for nighttime work in order to alleviate daytime work zone congestion, especially during peak traffic hours. Although traffic congestion is reduced, traffic control safety in nighttime work zones remains a concern among both transportation agencies and contractors (Al-Kaisy et al. 2004). In 2003, there were 1,028 fatalities in work zones nationwide, of which 919 were related to motor vehicle accidents (NWZSIC 2005). According to the Federal Highway Administration (FHWA), approximately one-half of the fatalities occurred at night (FHWA 2005). These work zone statistics have received increased attention among agencies to evaluate planning and safety issues concerning the workers and the general public on nighttime work zones.

Moreover, a limited amount of research has been conducted in the area of night-time construction safety. Government agencies (i.e., the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP)) have published few standards of practice. Also, limited construction industry regulations exist for construction work performed at night, which is partly due to the fact that night-time construction is a relatively recent phenomenon and there is a lack of knowledge about the potential side effects of performing construction work at night. Without these standards and regulations, the construction industry has been forced to develop safety plans and implement safety practices for nighttime construction work on a company-by-company basis.

For these reasons, the Indiana Department of Transportation (INDOT) initiated a study in August 2005 through the Joint Transportation Research Program (JTRP). The goal of this one-year JTRP study is to evaluate safety issues in nighttime construction and maintenance as a step towards the improvement and development of strategies to improve quality, productivity, and safety on construction and maintenance operations on Indiana interstates and roadways. The three main objectives of the JTRP study are:

1. Evaluation of the effectiveness of safety-enhancing strategies, based on the safety perception of the workers, contractors, and owners.
2. Evaluation of traffic control planning and implementation procedures for current nighttime operations.
3. Formulation of cost-effective strategies that can maximize work zone safety in nighttime roadway projects.

1.1. Project Objectives

In partial fulfillment of the study's scope, four separate but inter-related research studies were conducted between September 2005 May 2007. The first study investigated owner and contractor safety management planning for nighttime construction and maintenance operations, while the second study investigated traffic control planning and implementation procedures for nighttime construction and maintenance operations. The third study analyzed the effectiveness of speed control measures on nighttime construction and maintenance projects and the fourth study evaluated the effectiveness of currently used high-visibility personal protective equipment (PPE) and current practices for their implementation. The following sections summarize the scope and objectives for the respective studies:

Study 1: Safety Management Planning Assessment and Evaluation

This study examines the relationship between contractor and owner safety planning on nighttime work zones and the worker perception of these practices. The study aims to improve highway agency and contractor planning by incorporating the worker's perception in safety management planning. There are three main objectives for this portion of the study:

1. Evaluation of the effectiveness of safety enhancing strategies, safety factors, and current practices on nighttime construction jobsites, to determine which have the largest influence from the nighttime construction worker's safety perspective.

2. Assessment of current project planning measures and safety practices performed by general contractors and owners in connection with the worker's perception to develop recommendations enabling more effective planning on future projects.
3. Evaluation of the components of accident prevention for nighttime construction from the perspectives of the owners, the general contractors, and the nighttime construction workers to develop recommendations for effective accident prevention strategies for future nighttime construction projects.

Study 2: Traffic Control Planning Assessment and Evaluation

Similar to the first study, this study examined whether there is a significant difference between the supervisors' and the workers' perceptions of safety practices and the safety practices implemented by the highway agencies and the contractors during nighttime traffic control planning. This study aims to improve highway agency and contractor traffic control planning for nighttime work by incorporating the two entities' perceptions of safety in planning. There are three main objectives for this portion of the study:

1. Evaluation of current nighttime traffic control safety strategies to determine which have the largest influence on safety from the supervisor's and the worker's perspective,
2. Assessment of traffic control planning and implementation procedures for current nighttime operations, and
3. Assessment of nighttime traffic control safety practices for improved safety performance during nighttime operations from the supervisor's and worker's perspective.

Study 3: Speed Control Assessment and Evaluation

This study examined the relative effectiveness of speed control methods used on nighttime construction and maintenance projects in Indiana. There are two main objectives for this portion of the study:

1. Identification and evaluation of the effectiveness of key speed control methods used in nighttime work zones, and
2. Comparison of the costs and benefits of the methods of speed control studied.

<u>Study 4: High-visibility PPE Assessment and Evaluation</u>

This study analyzed the current PPE practices in Indiana and compared different types of PPE. Previous studies have not incorporated the combination of different high-visibility PPE in the assessment, as well as the perspective of drivers regarding the visibility of PPE. Furthermore, current high-visibility training and implementation procedures for high-visibility PPE have not been addressed. There are two main objectives for this portion of the study:

1. Evaluation of the effectiveness of the current high-visibility PPE practices used to enhance worker visibility in nighttime construction.
2. Comparison and analysis of the visibility of different types of high-visibility safety garments.

1.2. Research Methodology

To meet the objectives of the first study above, a multi-step process is undertaken. A literature review was performed to identify the different factors associated with safety and nighttime construction. Additionally, a preliminary evaluation was performed on a general contractor's safety plans and on INDOT's current safety requirements and practices. Both of these tasks were used in the development of three distinct surveys investigating safety in nighttime construction operations, which were distributed to owners, general contractors, and workers. Data from the returned surveys and site visits by the researcher was then analyzed using multiple linear regression and statistical and qualitative analyses to determine the most significant safety factors, mitigation strategies, and safety practices used by general contractors.

For the second study, a state-of-the-art literature review was also performed to examine previous research that included the decision process in determining daytime and nighttime work options and the factors influencing nighttime traffic control safety. Safety management philosophies and techniques for the construction industry were also reviewed. A state-of-the-practice review was also performed to determine current practices and guidelines in nighttime work zone traffic control for both construction and maintenance operations, which included reviewing the Manual on Uniform Traffic Control Devices (MUTCD) and other FHWA documentation as well as meeting with INDOT personnel to review their safety requirements and practices for work zone traffic control.

The combination of the state-of-the-art and state-of-the-practice reviews led to the development of three surveys; one distributed to the traffic control designers, another to the supervisors, and a third survey to the workers. The surveys contained questions ranging from the project conditions to the traffic control safety procedures for nighttime work. Site visits and formal interviews with INDOT and Indiana contractors were conducted during the survey distribution to determine the implemented traffic control planning procedures for nighttime operations. The data collected from the supervisor and worker surveys was then analyzed using multiple linear regression and statistical and qualitative analyses to determine the significant traffic control safety practices from the perspectives of the supervisors and the workers.

For the third study, a state-of-the-art literature review was performed to examine previous research that studied the effectiveness of speed control methods in work zones. A state-of-the-practice review was also performed to determine current practices and guidelines in nighttime work zone speed control for both construction and maintenance operations, which included reviewing the MUTCD and formal telephone interviews with INDOT and other Midwestern DOT personnel to review their current use of speed control on daytime and nighttime work zones. The combination of the state-of-the-art and state-of-the-practice reviews led to the determination of the nighttime work zone speed control methods most frequently used within the Midwest and those considered the most effective by DOT personnel. Speed data were then collected on nighttime construction and maintenance projects throughout Indiana. The data collected during site visits were then modeled using seemingly unrelated regression estimation (SURE) to determine the effectiveness of speed control methods in nighttime work zones. Finally, a comparison was made of the relative costs and benefits of the speed control methods studied.

For the fourth study, surveys were deployed to owners, workers, and general contractors for evaluating current high-visibility practices in nighttime work zones. Videos of different high-visibility personal protective equipment were recorded in a simulated nighttime work zone and then shown to drivers who rated and compared the visibility of the garments. A descriptive analysis of the data collected from the surveys was performed and a binary probit model with random effects was developed to predict the characteristics that make it more likely to choose an assembly as more visible than the safety vest currently used by the Indiana Department of

Transportation (INDOT which is a yellow green mesh vest with four-inch wide fluorescent orange strips with two strips of reflective silver material

An overview of the statistical tools used to analyze the data collected are summarized in Table 1.1. These tools are discussed in greater detail in Chapters 3, 4, 5 and 6.

Table 1.1 Overview of statistical tools used for the analysis of the data collected during this project.

Statistical Model Used	**Description**	**Interpretation**
Multiple Linear Regression	The β coefficient may be estimated by the analytical hierarchy process or regression analysis. The percentage of variation is explained by the model using the R-squared value. Regression can also model the relationship between the explanatory independent variables and the response dependent variable, as well as evaluate the significance of the safety categories in the prediction of the response variable. A multiple linear regression model is appropriate when there are multiple independent variables.	The significance of each explanatory variable is evaluated through a p-value associated with a t-test statistic (Kutner, et al. 2005). A positive value of a coefficient in the model implies that an increase in the variable will increase the value of the dependent variable.
Seemingly Unrelated Regression	It is used when the disturbance term in one regression equation is correlated with the disturbance term in another (Mannering 2007).	A positive value of a coefficient in the model implies that an increase in the value of that variable will increase the value of the dependent variable by the coefficient times the value of the variable. A negative sign will imply the opposite.
Binary Probit Model	The binary probit model considers two discrete outcomes denoted as (1) or (2). In this project this model was used to analyze the visibility of high-visibility safety garments; in this case (1) the INDOT safety garment is more visible and (2), Assembly X is more visible.	A positive value of a coefficient in the model implies that an increase in the variable will decrease the probability of selecting the INDOT safety vest as the most visible garment and will increase the probability of selecting Assembly X as the most visible. A negative sign will imply the opposite.

1.3. Organization of the Report

In this report, the terms "accident" is used synonymously with the word "crash". Following this introductory chapter, Chapter 2 provides a review of previous research in four different areas: a) making the decision to work at night, b) factors associated with the decision to work at night, c) current safety management philosophy and application to nighttime construction, d) speed control methods and work zone safety and e) high-visibility PPE and work zone safety.

Chapter 3 summarizes includes a discussion regarding the analytical process used in order to understand the nighttime construction safety issues from the stakeholder groups (construction worker, general contractor, and owner), the analysis of the surveys distributed to the stakeholder groups to determine the effectiveness of safety-enhancing strategies, the safety factors, and the current practices on nighttime construction jobsites from different perspectives, and the results and findings from the analyses performed.

Chapter 4 summarizes the findings of the second portion of this study. This chapter follows in similar manner to that of the previous chapter providing a discussion regarding the data collection, the analytical processes used, the analysis performed, and the results and findings from the study.

Chapter 5 includes a discussion regarding the analytical process used to assess key speed control methods. Descriptions of the data collection process, the procedures used during the data analysis, as well as the results from the analyses of the speed control methods are included.

Chapter 6 provides a discussion regarding the data collection and data analysis used to evaluate current PPE practices and to compare the visibility of different types of PPE. In addition, the results from the analyses of the data are included in this chapter.

CHAPTER 2. LITERATURE REVIEW

Nighttime construction in the United States has increased over the last decade. Over 50% of national and state agencies have pushed roadwork from first shift, 7 am to 5 pm, to the "graveyard" shift, 7 pm to 6 am, in order to limit congestion on roadways and to reduce the overall impact on the general public. Further, some projects have been shifted from first shift work to continuous work (i.e., 24 hours a day) to complete projects sooner. As night work continues to become more common, the differences encountered during nighttime construction need to be further evaluated to continue to improve the level of safety on jobsites.

An understanding of what has been done to date in the area of nighttime construction is relevant to the proposed research for two reasons: 1) to determine what aspects of safety have yet to be evaluated, and 2) to understand the effect of other factors, such as visibility and cost, from the perspectives of those involved in planning. This chapter will discuss previous research in four different areas:

a) making the decision to work at night;
b) factors associated with the decision to work at night;
c) current safety management philosophy and application to nighttime construction;
d) speed control methods and work zone safety; and
e) PPE utilization and effectiveness in work zone safety.

2.1. Importance of Nighttime Work

In 1995 George Pataki, Governor of the State of New York, stated his belief that the greatest advantage for construction during off-peak hours was the minimized congestion. Governor Pataki and the State of New York enacted legislation forcing the heavily traffic-congested areas of New York City (NYC) and Long Island to consider utilizing nighttime construction on all major highway improvement projects. As a result of this legislation, many construction projects in the southern districts of New York State were moved to the night shift. In 1999, Pataki announced that rush hour traffic congestion had been reduced since 1995 due to the movement of one billion dollars worth of projects from day work to night work. The roads in NYC and Long Island would have been heavily congested if the projects had been done during the day according to Pataki and the following study. (Governor, 1999).

To evaluate the 1996 policy, the New York State Department of Transportation (NYSDOT) performed an audit of nighttime construction activities during 1998 to determine if the quality and cost of a nighttime product varied from that of a daytime product. NYSDOT studied 72 projects, cumulatively costing $550 million, constructed between January and December of 1998. The study concluded that the quality of a nighttime product did not differ significantly from the quality of a daytime product. Additional lighting needs at night accounted for the slightly higher cost of the nighttime work over the daytime cost. NYSDOT justified the additional cost through time savings due to the reduced congestion experienced by the general public. The NYSDOT study also reported traffic accidents during 1998 at night were comparable to accidents during the day (NYSDOT 1999). The positive results, namely, reduced congestion and minimal cost increases, indicated in the NYSDOT study enabled New York State to continue nighttime construction work in the NYC and Long Island regions.

During the late 1980s and 1990s, several researchers agreed with Governor Pataki that the greatest advantage for performing construction work at night is the reduction in roadway congestion and delays to the general public. (Price, 1986, OECD, 1989, Hinze and Carlisle, 1990, Elrahman and Perry, 1999, Al-Kaisy et al. 2004) By closing lanes for construction work at night when roadway traffic is already at a minimum, impact on traffic congestion is also minimized according to the studies. Further, Hinze and Carlisle (1990) and Elrahman and Perry (1998) confirmed that the minimal traffic impact continues to be the leading factor when the decision is made to work at night.

2.1.1. Leading Issues in the Decision to Work at Night

Many factors are considered during the initial decision-making process to determine when to perform construction activities. In the past 10 years, several studies have focused on developing guidelines and processes to aid state agencies and general contractors in making the decision to work at night.

The Kentucky Transportation Cabinet (KYTC) attempted to determine the leading issues considered when making the decision to work at night. Through interviews and surveys of 32 state departments of transportation (state DOTs), 20 general highway contractors and 23 engineers of the KYTC, information was gathered directly from people involved in the decision-making process. The survey concluded that a lower traffic level at night was the main criteria for choosing nighttime work for highway projects. (Hancher and Taylor, 2001)

KYTC's study resulted in the development of a tool, constructed as a simple form, to be used when making the decision to work at night. The form would be filled in during negotiations between the state DOTs and the contractors to decide which work schedule was best suited for individual projects. Five categories of issues emerged through the data collected by the survey:

- Construction Issues
- Social Issues
- Traffic Issues
- Economic Issues
- Other Issues

These categories were used to form questions which would be answered by KYTC personnel when trying to decide if daytime or nighttime construction work would be more appropriate for a particular project. By answering the questions, a more informed decision could be made by KYTC personnel. (Hancher and Taylor, 2001)

Following the research by Hancher and Taylor, Al-Kaisy and Nassar (2002) conducted an investigation of nighttime construction operations for highway maintenance and reconstruction sites. Their goal was the development of uniform guidelines and procedures for usage by the Illinois Department of Transportation (IDOT) to decide if night or day construction work was best for a particular project. Hancher and Taylor's decision-making process identified different factors pertinent to the decision of day versus night work but left the importance and weight of the individual factors to the evaluator. The research of Al-Kaisy and Nassar differed from that of Hancher and Taylor's in that it ranked the decision factors in numerical order and determined the relative importance among the factors. Data was collected through a survey sent out to state

DOTs nationwide and the nine districts of IDOT. The survey questions were divided into four categories:

1) Nighttime construction practices through the experience or perception of the state DOTs and IDOT districts,
2) Potential effects of working at night on construction variables,
3) Traffic-related issues for nighttime operations, and
4) Other social, economic, and environmental impacts of nighttime construction.

Examples of the decision factors are shown in Table 2.1. Analysis of the survey data resulted in the development of ranking and scoring procedures for the most important decision factors for nighttime construction work. The ranking was based on how important the factor was to the decision to do construction work at night, with 1 being the most important and 14 the least important. Table 2.1 shows how the IDOT sub districts scored and ranked the decision factors:

Table 2.1 Relative Importance of the Different Factors that Affect the Decision on Nighttime Construction as Reported by IDOT districts (Al-Kaisy and Nassar, 2003)

High daytime traffic	1	4.882	1	4.777
Traffic safety	2	4.176	2	4.444
Workers safety	3	3.941	4	4.111
Traffic control	4	3.706	6	3.555
Road users costs	5	3.588	3	4.222
Disruption to surrounding businesses	6	3.313	7	3.333
Noise	7	3.176	8	3.333
Freedom in planning lane closures	8	3.000	10	2.555
Scheduling issues	9	3.000	11	2.555
Productivity	10	3.000	9	2.888
Temperature	11	2.882	13	2.444
Longer work hours	12	2.706	14	2.222
Lighting Issues	13	2.647	12	2.555
Work quality	14	2.412	5	3.666

According to survey results, high daytime traffic was the most important decision factor based on its ranking, followed by safety for the drivers and the workers. The survey concluded that certain construction activities (i.e., concrete sawing and milling and removing) and maintenance activities (i.e., milling and removing, and repair of concrete pavement) were better suited for nighttime work than other activities. These activities were more appropriate to be performed at night than other activities due to the factors of material availability, the impact on traffic of the construction activity, and visibility. Al-Kaisy and Nassar's results agreed with the NYSDOT results that the administrative and construction costs are greater during the night but that nighttime construction provides the benefit of reduction in delays and traffic congestion while maintaining consistent quality. Thus, Al-Kaisy and Nassar concluded that nighttime work can be a good choice for state DOTs. Al-Kaisy and Nassar only included safety as a general category and did not explicitly describe what safety entailed during their research, unlike the previous research by Hancher and Taylor.

The University of Oregon took on a two-phase research study to develop a modeling tool to assist with making a decision about what time of day construction work should be performed. Park et al. (2001) evaluated previous literature to identify relevant decision-making factors and developed a survey to determine the importance of each factor. Their research differed from previous studies because the survey respondents weighed the factors against the other factors indicated. The survey aimed to confirm if the factors identified in previous studies were actually important within Oregon and the relative importance of the factors to each other.

Park et al.'s work yielded a list of 19 previously identified factors, in the following six categories: traffic-related parameters, construction-related parameters, social parameters, economic parameters, environmental parameters, and other. Based on this grouping, an extensive survey was developed. Each factor consisted of an indicating and a ranking component. The indicating component asked the respondent to determine the level of importance of the factor individually. A score of 1 through 7, with 7 being the most important was assigned to each factor. The ranking component asked for all the factors to be ranked in order of importance. Each factor was to be given a numeric rank from 1 through 19, with 1 being the most important. By separating the factors into these two components, Park's research team was able to check the validity of their results. The factors with the best numeric ranks received higher scores. The survey was completed by project managers and district managers in Oregon, 25 state DOTs, and contractors. Table 2.2 summarizes the cumulative survey response:

Table 2.2 Indicating Factor Scores (Adapted from Park et al. 2001)

Compiled from All Respondents = 446				
	Indicating		*Ranking*	
Group	Factor	Average	Factor	Average Score
1	Safety	6.44	Safety	2.08
1	Traffic Control	6.07	Traffic Control	4.05
1	Congestion	5.98	Congestion	4.83
1	Lighting	5.84	Quality	6.64
1	Quality	5.40	Productivity	7.32
1	Public Relations	5.32	Worker Condition	7.90
1	Worker Condition	5.19	Driver Condition	8.76
1	Productivity	5.11	Lighting	9.12
1	Scheduling	5.07	Public Relations	9.42
1	Driver Condition	5.04	Construction Cost	10.16
1	Construction Cost	4.94	Scheduling	10.23
1	Accident Cost	4.92	Accident Cost	11.13
2	Availability of Mat'/Equip' Repair	4.70	Noise	11.74
2	Communication Supervision	4.64	User Cost	11.91
2	Noise	4.57	Maintenance Cost	12.16
2	User Cost	4.52	Availability of Mat'/Equip' Repair	12.20
2	Maintenance Cost	4.46	Communication Supervision	12.61
3	Air Quality	3.27	Air Quality	15.24
3	Fuel Consumption	2.89	Fuel Consumption	16.43

Table 2.2 shows the results for all survey respondents. When the survey results are broken down by project managers, district managers, contractors, and DOTs, the results are consistent. The first phase of the research determined the most important factors in the decision and quantified the importance of each factor relative to the other factors.

2.1.2. Modeling the Decision to Work at Night

During the second phase of the Oregon study, Park et al. (2002) created a computerized decision model which enabled the user to decide if daytime or nighttime work was the better choice. Factors with average indicating scores between within 4.92 and 6.44 in Table 2.2 were considered most important in the decision. The first and second groups (shown in Table 2.2) fell between these scores. The groupings were based on where the factors could be divided, such that the factors within the groupings appeared in both the ranking and indicating factors. All factors with indicating scores below 4.92 in Table 2.2 were considered least important factors and consequently eliminated from the decision model. The remaining 12 factors were weighted and utilized in Equation 2.1:

$$U_i = \sum_{j=1}^{m} W_j \left((1/n) \sum_{k=1}^{n} V_{ijk} \right) \qquad (2.1)$$

Where: U_i= aggregate score of alternative
W_j= importance weight for factor j
V_{ijk}= score of sub-factor k of factor j on alternative i
m = factor
j = number of factors
i= alternative
k= sub-factor
n= number of sub-factors

Equation 2.1 was used to develop a computer-based decision tool. The decision-maker did not use equation 2.1 directly when making the decision to work at night. Rather, the decision-maker would answer seven to 10 questions related to the project's characteristics via the computer interface. Then the decision tool would output two numeric scores: one for daytime and one for nighttime. The higher score would be the preferred score for the decision-maker (Park et al. 2002).

The two-phase study by Park et al. (2001, 2002) has potential benefits and limitations. This study successfully identified and weighted different factors that affect nighttime work. The decision model developed in this study has potential for use in a real work environment in Oregon because the computer interface asks simple questions about the project, including the location and type of construction activities performed. The average user, with knowledge of the project characteristics, is capable of interacting with the model effectively. One limitation of the research is the limited applicability of the decision model outside of Oregon. A question on the user interface asks in which county in Oregon the project is located and equation 2.1 uses traffic and climate information specifically for Oregon roads and regions. The decision model therefore would have to be generalized before being implemented outside of Oregon. The decision model lacks quantified values for factors when there are considerable differences between states, construction policies, maintenance operations, and any other environmental or regional differences. Another limitation is that the study used previous literature to develop the list of decision factors. Most of the factors and contractor feedback used came from the KYTC study (Hancher and Taylor, 2001). Construction factors could vary due to the construction regulations, weather, and construction practices in other states.

Bryden and Mace (2002), sponsored by The National Cooperative Highway Research Program (NCHRP), developed a procedure to assist engineers responsible for scheduling construction and maintenance work in evaluating night work alternatives against other schedules (Bryden and Mace, 2002). This procedure enables the decision-maker to choose the different shifts for comparison, unlike the Oregon study. For example, the decision-maker could choose to compare a day and night shift, or a 10- hour night shift versus an eight-hour night shift. Bryden and Mace's procedure offers a detailed, quantitative method for choosing the best work schedule. The method takes the engineer's input about project characteristics and chooses the most cost-effective traffic control plan for minimizing community impacts, enabling the work to be completed on schedule, minimizing congestion, and ensuring the safety of the public and the workers.

The procedure developed by Bryden and Mace (2002) evaluates the different available traffic control plans for daytime and nighttime work. Information would be gathered about the specific construction or maintenance activities to be performed and then available traffic control options would be developed. The volume/capacity relationship would be checked to ensure each option's traffic control plan allows for acceptable levels of congestion and delay. (Bryden and Mace, 2002)

The engineer would perform a comparative analysis using the cost of traffic control to select the best traffic control option. Factors such as device rentals, lighting, setup/takedown, that impact the cost of the project would be identified and quantified. Each cost factor is given a weight, from one through four, with four signifying that the factor does not impact safety or the general public and one being a level of unacceptable impact. A rating of one through three is assigned to each factor, with one being a baseline rating and a rating of three assigned to critical factors. An effectiveness rating and an effectiveness/cost score could then be calculated. The traffic control option with the highest qualitative effectiveness rating but with a high effectiveness/cost score would be preferred and chosen. Table 2.3 shows a cost-effectiveness analysis worksheet:

Table 2.3 Cost-Effectiveness Analysis Worksheet (Adapted from Bryden and Mace, 2002)

		Option 1		**Option 2**		**Option 3**	
Traffic Control Cost		**$4.4 M**		**$6.0M**		**$5.5M**	
Objective	Weight	Rating	Weighted	Rating	Weighted	Rating	Weighted
Community/ Traffic Impact	2	3	6	2	4	4	8
Safety	1	2	2	3	3	3	3
Constructability	1	3	3	2	2	3	3
Effectiveness Rating			11		9		14
Effectiveness/ Cost			2.5		1.5		2.55

As shown in Table 2. 3, Option 2 would be unacceptable since the effectiveness to cost rating is low. Options 1 and 3 have close effectiveness/cost scores. To select the preferred option, a more detailed analysis with just Option 1 and Option 3 should be performed.

The decision procedure outlined by Bryden and Mace (2002) enables the engineer to perform an analysis to select the most cost-effective traffic control plan from different work schedules, indirectly choosing either a daytime or nighttime schedule. This NCHRP research is different from previous research because the procedure developed enables the engineer to select cost factors that are unique to a given construction or maintenance project and unique to a specific traffic control plan. Also, the procedure enables costs, a priority to highway agencies and contractors, to be included in the decision process methodology. However, there are several limitations to Bryden and Mace's procedure. Although the traffic control plan is important, there are additional components of nighttime construction that should be considered when making the final decision. The weights in their procedure are based on the engineer's judgment and the weights heavily influence the final decision. Potentially, several engineers might have different final decisions on the same project using this procedure. Finally, the procedure is developed for highway agencies and it is unclear if contractors hired by highway agencies would benefit from using this procedure because the highway agencies specify in bid documents the type of traffic control and when the work is to be performed.

Based on the decision tools and procedures developed to date, progress has been made towards formalizing a process for deciding if nighttime work is appropriate. The primary factors such as safety, traffic levels, worker well-being, and cost, need to be identified, weighted, and scored in order to compare to other options. However, in some cases working at night may be the only option for a general contractor or state agency. When night work is the only option, a process and set of tools must be available to design accurate traffic control and safety plans.

2.2. Parameters Influencing a Nighttime Construction Project

Construction performed during nighttime hours is influenced by distinctive parameters due to atypical work conditions. Without natural light, visibility is decreased jeopardizing the safety of the workers, productivity potentially may be lower, and costs have a tendency to increase. Some state agencies are no longer giving general contractors the option of working at night on specific projects; rather, projects are bid with the work specified for nights only or 24 hours a day. The parameters of nighttime work, including decreased visibility for workers and the glare potential for traveling motorists, can have a direct impact on the safety of the workers and general public. Studies have been done to better understand the distinct parameters associated with night work and have attempted to improve the conditions associated with construction and maintenance activities at night.

2.2.1. Safety Concerns of Nighttime Construction

Most vital to nighttime construction, and as important as daytime construction, is the safety of the construction workers and the safety of the general public. Safety can be jeopardized by many different parameters, some of which are controllable and some are not. Uncontrollable parameters, such as driver condition, substance abuse, and worker fatigue, can endanger the safety of the workers. By focusing on controllable variables, such as providing adequate lighting on the jobsite, improving the visibility of the workers, and setting up a traffic zone to minimize unwanted entries by motorists, unsafe conditions on nighttime jobsites can be minimized.

2.2.1.1. Adequate Lighting for Visibility

Lighting takes on a dual importance during night work, increasing visibility for workers and motorists while offsetting worker fatigue experienced due to disrupted circadian rhythms. By providing adequate, appropriately placed lighting, workers are able to better see the activities and motorists are not disturbed by the glare, which may lower the odds of a motorist entering the work zone.

Traffic barrels, cones, equipment, and personal protective gear in the traffic zone are outfitted with reflective strips that rely on adequate lighting for effectiveness. When light strikes the reflective strips, they are designed to become visible in the darkness. Without sufficient lighting on the worksite, the visibility of the workers is decreased and safety is compromised as the potential for accidents increases. The quality and cost efficiency of construction can be directly affected by the lighting levels and configuration. Nighttime construction products, such as concrete and asphalt pavement, require visibility to ensure proper finishing and compaction at a specific quality level. Lighting was reported to be one of the most significant factors affecting the nighttime construction parameters of quality, cost, productivity, and safety (Kumar, 1994). At night lighting is needed for the workers to be able to view the jobsite, productivity can be less causing for a longer duration, and additional safety equipment such as Personal Protective Equipment (PPE) is needed which can raise the cost.

Ellis et al. (2003), sponsored by The National Cooperation Highway Research Program (NCHRP) and the Transportation Research Board (TRB), developed illumination guidelines for specific activities frequently performed during nighttime highway work. NCHRP attempted to develop guidelines for the use of temporary roadway lighting for construction and maintenance activities. Ellis et al (2003) surveyed state DOTs about which maintenance and construction activities were frequently performed at night. Twenty-eight DOTs' replies were included in the generation of a list of activities frequently performed by DOTs at night. To generate guidelines for nighttime illumination categories, illumination guidelines from other industry sectors were applied to specific nighttime work activities performed by the construction industry (Ellis et al. 2003).

The illumination guidelines were broken down into three illumination categories as shown in Table 2.4. Ellis et al. (2003) also suggested specific activities for each illumination category.

Table 2.4 Summary of Illumination Guidelines (Ellis et al. 2003)

Category	Illumination (lx)	Height of Candles	Recommended For	Example Activities
Category I	54 lx	5 ft	General Illumination of the Work Zone. Mainly for visibility in the area where the crew is working	• Excavation • Embankment, filling and compaction • Shoulder rework • Landscaping
Category II	108 lx	10 ft	Illumination on and around the construction equipment. Use for seeing tasks being worked on	• Resurfacing • Concrete pavement construction • Bridge decks • Pot hole filling
Category III	216 lx	20 ft	Tasks that present high visual difficulty, requiring attention from the observer.	• Traffic signals • Highway lighting system • Crack filling • Maintenance of Electrical Devices

Ellis et al. (2003) recommended minimal lighting requirements and placement of lighting for various types of construction equipment frequently used at night. To ensure the appropriateness of the illumination categories and the placement of activities within the categories, the guidelines were tested by being placed on construction jobsites. Contractor suggestions and on-site evaluation enabled modification of the preliminary guidelines for any problems encountered and to meet the needs of the construction industry.

The University of Illinois (El-Rayes and Hyari, 2003) conducted research to investigate the current illumination techniques, guidelines, and lighting situation on construction jobsites. A survey distributed to state DOTs, contractors, and IDOT engineers identified three main lighting problems: 1) non-uniformity of lighting levels, 2) road users experiencing glare, and 3) insufficient levels of lighting. To meet the need for guidelines for nighttime construction lighting, El-Rayes and Hyari (2003) created a tool to design the lighting needs for highway nighttime construction projects. The tool, an automated decision support system (DSS), is able to determine lighting plans to maximize average luminance and lighting uniformity in the work zone, minimize glare produced from the lighting system, and minimize the cost. The DSS design variables included: type of lamps, lamp lumen output, lighting tower locations, luminary aiming angle, lighting tower rotations, mounting height, and the lighting equipment selection.

However, without OSHA requirements or laws providing the minimal lighting requirements, highway agencies and general contractors are forced to use their own discretion in designing the guidelines of lighting. Ellis et al. (2003) and the tool developed by El-Rayes and Hyari (2003) have the capability to improve lighting schemes on nighttime construction sites and are inexpensive solutions capable of improving safety for both the workers and the general public. A limiting factor in both studies is the minimal public input. Although the general public was included in Ellis et al's study, the general public sample consisted of state DOT workers not directly involved in nighttime construction. General public opinion on lighting needs and glare issues could potentially improve lighting and safety on jobsites. The general public can give a first-hand perspective of the reduction or non-reduction of glare due to the newly designed lighting regulations and requirements.

2.2.1.2. Worker Identification through Personal Protective Equipment

Personal Protective Equipment (PPE) protects workers from potential construction hazards and undertakes the new role at night of identifying the worker in the darkness. PPE includes, but is not limited to, hard hats, high visibility vests and clothing, earplugs, and eye protection glasses. High visibility vests and clothing are used during the day, but at night the reflective strips identify the worker to his peers and the nearby general public. Over the last 10 years, the standards for PPE visibility have been re-evaluated and improvements offered to improve worker identification.

The Manual on Uniform Traffic Control Devices (MUTCD, 2001) has explicit standards for high visibility clothing to ensure that a person is clearly identifiable when the standard is met. In previous and current editions of the MUTCD, for nighttime work, all high visibility garments must be retro-reflective and visible from a minimum distance of 300 meters or 1,000 feet. In 1994 the Minnesota Department of Transportation (MNDOT) questioned the sufficiency of the standard after a construction worker was killed in a work zone traffic accident. MNDOT's study determined the 1,000 feet minimum visibility standard was not being met and turned to industry for help with the development of a more visible garment to increase the safety of workers on a construction site. Industry responded to MNDOT by creating a new two-piece garment. Servatius evaluated the effectiveness of the new two piece garments in 1996 and concluded that the two-piece garment was more visible at night (Servatius, 1996) than the one-piece garments. Now MNDOT requires high visibility vests, caps, and pants for their workers to raise worker visibility (MNDOT, 1997).

In 1997, Cottrell analyzed night work zone traffic control patterns for the Virginia Department of Transportation (VDOT) (Cottrell, 1997). To understand the difficulties the general public faced while driving through work zones at night, part of the general public was surveyed after driving through a specific work zone. The motorists had poor visibility of the work zone, equipment, and workers. Cottrell concluded that two-piece garments enabled the workers to be more visible when they bent over to perform construction tasks (Cottrell, 1997). A National Institute of Occupational Safety and Health (NIOSH) study offered further recommendations for improving worker visibility. NIOSH recommended that workers wear arm and knee bands in order to enhance visibility when the worker was in a non-erect position. Another recommendation by NIOSH was the placement of strobe lights on the vests of workers to better identify the workers in work zones. (Pratt et al. 2001).

2.2.1.3. Traffic Zone Set-Up Variations

State agencies and contractors use an assortment of techniques and equipment to design and set-up different traffic zones. An effective, reliable traffic zone has the potential to minimize accidents and increase safety for workers and the general public. Studies during the late 1990s provide empirical evidence that suggests the accident rate in work zones is higher than the normal accident rates at those locations when no work zone is present. (Al-Kaisy et al. 2004) To move the car and pedestrian traffic out of the area of the work zone different mechanisms are used to a) alert the traffic to the work zone, and b) move the traffic away from the work zone. These mechanisms include signs, arrow boards, cones, drums, and permanent barricades.

One issue associated with the traffic zone area is the potential for reduction in work area for the workers during the night due to the darkness. A study done by Al-Kaisy and Hall (2000) concluded that the capacity of the work zone is lower at night than in the daytime based on qualitative data and observations. The study indicates a 5% reduction will take place on a well-lit work zone after darkness. Additionally, the study reports a larger reduction than 5% takes place in work zones in rural areas. (Al-Kaisy and Hall, 2000) Due to reduced roadway lighting the whole work zone may not be completely visible. Hence, workers have to provide sufficient "buffer" between themselves/the work zone and the moving traffic.

Cottrell (1997) examined traffic control of night work zones to understand potential problems and safety hazards. The research data was collected on interstates and primary arterials since most night work in Virginia is performed on high-volume roads.

To identify current practices by state transportation agencies, a survey was distributed to every state DOT and Cottrell observed seven different night work zones through site visits. The survey responses and the site visits identified eight problems related to nighttime work zones:

- Poor visibility
- More impaired drivers at night than during the day
- Higher speeds and lower volumes of motorists
- Insufficient lighting for workers at night on the jobsite
- Noise restrictions placed on the construction operations
- Worker fatigue
- Drivers who do not expect night work zones
- Glare (Cottrell, 1997)

Less than ten motorists drove through each of just four different work zones, thus the survey sample size was small. Using the DOT responses, motorist feedback, information from previous studies, observations by Cottrell and through onsite conversations with VDOT staff, seven solutions were developed. Table 2.5 shows the solutions and implementation strategies:

Table 2.5 Benefits and Implementations of Solutions to Improve Traffic Control on Nighttime Construction Sites (Cottrell, 1999)

Solutions	Benefit of Solution	Implementation of Solution
Improve the visibility of traffic control devices	Provides the traveling public with additional information as to where the work zone is located	• Use drums in the taper area for lane closures instead of cones • Use multiple cones stacked together or weights on cones to keep in place • Require contractor to have a staff member assigned to implement and maintain all traffic control devices
Improve the visibility of workers	Minimize accidents by making the full body range of the worker visible within and outside the work zone	• Require workers to wear hard hats with retro reflective material visible on all sides • Utilize retroflective bands on limbs and major hinge points (knees and elbows) (Brich, 1998)
Improve the visibility of work vehicles	Avoids workers and traveling public being distracted by multiple vehicles flashing lights. Additional awareness of the location of the work vehicles can be gained by workers and the general public	• Use New York DOT(NYSDOT, 1995) guidelines: • All vehicles display an amber revolving light at all times and four-way flashers when stopping or moving slowly • Require warning lights and flashers be turned off when vehicles are moving at normal speeds within traffic or out of traffic. Flashers and warning lights should be used when slowing, stopping, or exiting travel lanes.
Reduce speeding and increase driver attention	Slows traffic down and makes the drivers aware of the upcoming work zone	• Use police officers and position police officer to maximize visibility • Use a PCMS for work zones with messages matching road conditions
Reduce glare from work lighting	Enables clear vision for oncoming traffic and prevents motorists from entering the work zone due to the inability to see	• Aim lights toward the work zone • Check to make sure lights are at the proper height and aimed downward to avoid glare
Manage other safety risk factors	Enables better protection for the workers from errant motorists.	• Use intrusion alarm to give a sound when motorists vehicle enters the work zone • If possible, leave a buffer lane between the open lane and the lane where work is occurring

Cottrell (1999) states there is a limitation to this research: most solutions were identified through the experience of the researcher and the DOT workers rather than investigative research. Also, a limited number of sites were visited and the general public sample was too small to be considered statistically sufficient. In the future, a better method to gather general public opinion and driver and passenger opinion needs to be utilized.

2.2.2. Construction-Related Parameters: Productivity and Quality

Diverse on-site activities, combined with the unique parameters for every construction project, create an inherent difficulty in studying the productivity of nighttime construction. The factors constrain nighttime construction include lighting and fatigue. Without adequate lighting, the quality of a nighttime construction project has the potential to be comprised. Fatigue caused by the workers' disrupted circadian rhythms, can cause for lower levels of productivity during nighttime construction. Few researchers have studied the productivity and quality differences between nighttime and daytime construction and their final products.

Ellis and Kumar (1993) used Florida Department of Transportation (FDOT) projects to analyze the productivity of nighttime construction projects. Productivity was explored on the I-95 corridor project in St. Johns County, Florida. Data was accrued at various times throughout the project for two activities: milling existing pavement and placement of the structural course. This data was separated on the basis of the local conditions, traffic conditions, and project type. Since daytime data from the same project was unavailable, Ellis and Kumar used the FDOT average productivity rates for comparison purposes. The analysis concluded that for the activities of milling and structural course placement the productivity at night on the I-95 projects was higher than the FDOT average daytime productivity.

Ellis and Kumar's (1993) study design and analysis hade two limitations, however. First, the benchmark productivities are of limited use as a reference. If the same project, on I-95, had been performed during the day, the daytime productivity actually could have been higher than the FDOT average productivity and higher than the nighttime productivity. In addition, since only two activities were analyzed, it is difficult to generalize the conclusion, beyond these two activities.

The Washington State Department of Transportation (WSDOT) asked a team of researchers to evaluate the impact of a full weekend closure on Interstate 405 Tukwila to Factoria in August of 1997. This closure entailed closing an entire direction of traffic, from 8 pm on Friday until 5 am on Monday morning, enabling continuous work, 24 hours a day, throughout the weekend. There were two objectives for the evaluation: 1) to compare the option of a full weekend closure with other roadway closure alternatives, and 2) to compare the construction quality between the nighttime and daytime work (Dunston et al. 2000). The full weekend closure option offered the research team an opportunity to compare production quality between day and night on the same project. Also, the researchers were able to compare the productivity rates of the full weekend closure with a project on I-5 where work had been performed only during the nighttime hours (Dunston and Mannering, 1998). A full weekend-closure has the benefit of less time lost since startup and shutdown activities have to be performed only once as opposed to multiple times for a nighttime only project.

To evaluate the quality during the closure, quantitative and qualitative parameters were used. Surface smoothness (ride-ability), in-place density, and gradation were the quantitative parameters. Samples and measurements of the quantitative parameters were taken during the day and night from portions of the work zone. Other construction problems or defects with the pavement surface, in the final product, were qualitatively analyzed. Quantitative variables of surface smoothness, in-place densities, mix gradation, and production rates were used. The study concluded that the overall quality for both night and day production of the final product evaluated using the quantitative variables was better than average when compared with historical data from Washington State Department of Transportation. Further, the quality of the product produced from nighttime paving statistically showed no difference from the quality of the product produced from daytime paving (Dunston et al. 2000). Further, when compared with the I-5 nighttime only project, productivity was found to be about 20% higher on the I-405 project (Dunston and Mannering, 1998). Table 2.6 shows the comparison of productivity on the I-405 project.

Table 2.6 Comparison of Daytime and Nighttime Paving Productivity

Daytime Productivity			**Nighttime Productivity**		
Day	Paving Direction	Hourly Production Rate (tons/hr)	Day	Paving Direction	Hourly Production Rate (tons/hr)
Saturday	South	413	Friday	South	372
Sunday	South	308	Saturday	South	277
Saturday	North	398	Friday	North	365
Sunday	North	334	Saturday	North	340
Average Hourly Productivity:		363.25	Average Hourly Productivity:		338.5

Average productivity during the day was 363.25 tons per hour and the nighttime paving productivity was approximately 338.5 tons per hour. Nighttime productivity was about 7.3% lower than the paving productivity experienced on the I-405 project during the day.

Lee et al. (2002) undertook a research study for the California Department of Transportation (Caltrans) to determine construction productivity under different work shifts. The research consisted of a case study on I-10 near Los Angeles where 20 lane-miles were rebuilt using a fast-setting hydraulic cement concrete. The work shifts analyzed were one, 55-hour weekend closure and repeated 7-hour and 10-hour nighttime closures. The variables controlling the productivity were the concrete delivery and the concrete discharge.

The project was composed of the following ten activities: 1) set traffic control, 2) install moveable concrete barrier, 3) slab demolition, 4) cleaning sub base, 5) drill tie bar, 6) install dowel baskets, 7) concrete paving, 8) concrete curing, 9) saw cut, and 10) pavement marker. Productivity was measured in terms of the number of slabs placed per closure per hour of closure. Table 2.7 compares the production of the different work shifts:

Table 2.7 Comparison of Productivity for Different Construction Windows (Lee et al. 2002)

	7-Hour Nighttime Closure	**10-Hour Nighttime Closure**	**55 Hour Continuous Weekend Closure**
Net Working Hours (Concrete Pouring)	2	5	43
Auxiliary Hours (Mobilization, Curing, Demobilization)	5	5	8
Typical Production (Slabs per Closure)	15	50	615
Productivity (Slabs per Hour)	7.5	10	14
Major Resources	7 dump trucks, 4 mixer trucks	7 dump trucks, 8 mixer trucks	21 dump trucks, 12 mixer trucks

The highest productivity was experienced during the weekend closure. The addition of three hours to the seven hour shift increased productivity by 33% per hour for the 10-hour shift. The rationale behind the increased production for the 10-hour shift, versus the 7-hour shift, was the addition of three net working hours to the shift. The weekend closure was 54% more productive than the average nighttime closure which can be attributed to the minimization of hours spent mobilizing, curing, and demobilizing. (Lee et al. 2002)

Dunston et al (2000) found that daytime productivity was higher, whereas Ellis and Kumar (1993) found nighttime productivity was higher. However, the weekend closure productivity was found to be better than nighttime only productivity (Lee et al. 2002). The limitation to all three studies is the insufficient sample size: the Dunston et al (1998, 2000) study involved one project, Ellis and Kumar examined eight projects, and Lee et al (2002) examined one case study. Current conclusions to date are inconclusive regarding the comparison of productivity and the quality of daytime and nighttime construction projects on roadways.

2.2.3. Indirect Influence of Other Parameters on Cost

An important cost benefit to nighttime construction is the reduction in road user costs. (Al-Kaisy et al. 2004) Road user costs are composed of three main components: 1) value of travel time spent by drivers and passengers, 2) accident costs, and 3) vehicle operating costs. Of these three costs, the value of time offers the largest savings (Al-Kaisy et al. 2004). Most of the research on cost has been done indirectly by measuring other parameters, including productivity.

Hinze and Carlisle (1990) studied different variables affected by nighttime construction projects. The researchers concluded that there was an increase in the cost of nighttime operations due to the following variables: higher engineering inspection costs, additional traffic control devices, additional artificial lighting arrangements, and labor. Ellis and Kumar (1993) examined construction cost differences between daytime and nighttime activities. The following combination of eight different construction and maintenance activities, performed regularly by the FDOT during the day and night, were investigated: regular excavation, removal of existing pavement, milling existing asphalt pavement, asphalt paving prime coat, asphalt paving tack coat, Class I miscellaneous concrete, Type S asphalt concrete, and asphalt concrete friction. Cost data on these activities were collected from more than two hundred projects, which were completed during the early 1990's. Ellis and Kumar statistically calculated the mean unit cost and standard deviation for each activity. In most cases, for the eight selected activities, nighttime projects performed by FDOT tended to have lower costs than the same activities performed during the day. On average, the costs of daytime construction on roadway projects were 36% higher than nighttime work. The costs were less for all activities except Class I miscellaneous concrete, which had higher nighttime costs.

Ellis and Kumar's (1993) study of eight FDOT construction activities has several limitations. Although all of the projects were constructed in Florida, variations in the construction situation and project location could cause the unit cost data to be drastically different across the same state. More conclusive results could have been reached had Ellis and Kumar grouped the 200 projects first by activity and then by projects constructed under similar situations. However, since no construction project is inherently the same, herein the difficulties lie in comparing the costs of daytime and nighttime construction by unit cost. Ellis and Kumar (1993) found nighttime construction to be less expensive, but Hinze and Carlisle (1990b) postulated that nighttime construction was more expensive. Cost should never be an option when safety is at stake; however, cost is an important consideration for state agencies when allocating funding to various projects.

2.2.4. Effect on Nighttime Construction Workers

The potential impact of nighttime construction on the workers and their families has been the subject of minimal research. In 2001, a team of researchers offered some insight into the human factors associated with nighttime construction work. Due to concerns raised by general contractors and the New Jersey Department of Transportation (NJDOT), a study was conducted by NJDOT, the United States Department of Transportation (USDOT), and the Federal Highway Administration (FHWA) to assess the impact of human factors on nighttime jobsites. Holquin-Veras et al (2001) assessed factors using field surveys, focus groups, and interviews. Although the workers on the jobsite were the primary focus, other stakeholders, such as highway engineers, construction workers (laborers), field supervisors, and contractors were included in the study. Due to limited financial constraints, the researchers surveyed 30 workers at four different construction sites in New Jersey. There was an almost unanimous agreement that nighttime work negatively impacted workers' body rhythms and had a negative impact on the social and family life of workers. Only a meager 17% of the workers received additional financial compensation for working at night and all were willing to forfeit the additional compensation for daytime work. Further, the workers found Mondays and Fridays to be the most challenging days for dealing with the negative factors associated with nighttime work. Finally, the workers had high levels of concern about their ability to spend quality time with their families and nutritional concerns due to their disrupted eating habits.

Holquin-Veras et al. (2001) concluded that nighttime construction is a multi-faceted problem with a complex tradeoff between the benefits to society of doing work at night and the impacts on the human factors of the workers. Focus group meetings enabled the researchers to gain direct input from union leaders and workers regarding potential solutions to problems associated with night work that arose from the survey. Even though, due to the study's limitations, Holquin-Veras were unable to offer sound recommendations, several suggestions were offered to minimize the impact on the night worker:

1) *Institute a four-day work week* to lessen the effects of sleep deprivation.
2) *Provide pay differentials* to compensate workers for the societal benefits. Pay differentials could also boost morale.
3) *Itemize traffic enforcement costs within contractor bids.* Law enforcement on-site has the potential to minimize accidents and increase safety on nighttime work sites.
4) *Provide temporary accommodations* for workers with a significant commute time (more than two hours) to alleviate sleep deprivation and improve productivity.

Institution of these suggestions could potentially lessen the impact of night work on workers (Holquin-Veras et al. 2001).

The study done by Holquin-Veras et al. (2001) provided broad insight into the possible effects of night work on workers, but there were some limitations to the study. All the projects studied had 24 hour work schedules with two shifts. There is a potential to work three eight to 10-hour shifts, with possible overlapping of shifts. Perhaps, a shorter shift would reduce the social burdens placed on a nighttime worker. Also, only 30 workers were surveyed on four projects in one state in the U.S. A larger sample size could provide a more accurate representation of the nighttime construction impacts on workers.

2.3. Investigating Safety Management

The Occupational Safety and Health Administration (OSHA), FHWA, and the Association of General Contractors (AGC) have provided information on safety management concepts and researchers have studied effective safety practices in the construction industry. In 1970, OSHA was formed to establish safety guidelines and criteria for the U.S. workplace. A safe workplace, as defined by OSHA (Occupational Safety and Health Administration, 2005), is free of both health hazards and dangerous conditions to ensure the safety of every employee. Since construction sites contain unique safety hazards from heavy equipment, materials, and construction activities, OSHA has specific guidelines for the construction industry. These specific standards are classified as 29 CR 1926 and employers are required to implement them on all jobsites and in all work environments. OSHA continuously upgrades its standards for the construction industry to try and improve safety on-site.

2.3.1. Safety Management Philosophy

OSHA standards can be interpreted as employers providing a safe work environment for employees (Koehn and Surabhi, 1996). Contractors and state agencies use a safety management philosophy to control safety procedures, policies, and practices. Part of safety management is the prevention of accidents before their occurrence and the investigation of near-miss accidents and incidents after occurrence on construction sites. Safety management can take various forms within state agencies and by general contractors. The safety management philosophy undertaken is dependent on typical construction activities performed, previous accident history record, location of work, and individual company or agency characteristic. For example, FDOT's safety management philosophy can differ from that of NYDOT or of a west coast general contractor. However, the underlying principle behind a safety management plan is a safe workplace and is common in all plans.

> Safety management may be defined as the aspect of overall management function that determines and implements the safety policy. This will involve a whole range of activities, initiatives, programs, etc., focused on technical, human and organizational aspects and referring to all the individual activities within the organization, which tend to be formalized as Safety Management Systems (SMS) (Papadakis, 1997; Harms-Ringdahl, 2004).

A safety management philosophy is developed by companies and organizations to reflect the company's' commitment to the safety of their workers. A SMS should be run similar to other company functions and frequently evaluated to ensure that safety is controlled in all work environments (Peterson, 1971). A safety management philosophy is developed by companies and organizations to reflect the company's' commitment to the safety of their workers. A SMS (Safety Management System) should be run similar to other company functions and frequently evaluated to ensure that safety is controlled in all work environments (Peterson, 1971).

Although OSHA does not specify the exact template for written safety management systems or policies, the company must continue to comply with all safety regulations, and should include written programs such as:

a) Hazard Communication program (29CFR1910.1200(e)(1)),

b) Exposure Control Plan if there are employees with occupational exposure (29CFR 1910.1030(c)(1))

c) PPE assessment (29CFR 1910.132(d)(2)

d) The control of hazardous energy (29CFR 1910.147(a)(3)(i))

e) Emergency Action plan (29CFR 1910.38, 29CFR 1926.35)

f) Recordkeeping (29CFR 1904.0)

Wilson and Koehn (2000) indicated that interest in increasing safety awareness has risen in the past 10 years. Construction companies have come to realize their livelihood is dependent on control of worker-related injuries. Many researchers and contractors believe that safety programs and safety guidelines save companies money. Hinze's (2000) research showed a negative impact on construction companies when insurance premiums are large. High premiums include increasing costs of medical treatment, convalescent care, and the potential for lawsuits and are the result of a construction company having a high accident rate. In the 1980s a series of large liability suits held construction companies liable for worker injury and caused a significant rise in workers compensation costs, which forced companies to realize the need for safety management. Other reasons behind having a safety program include, but are not limited to, awareness of the impact of safety performance on overall project costs, possible adverse effects on a company's reputation with potential clients, and moral and legal obligation to provide a safe workplace to employees (ABC, 1990).

Most research studies have focused on the perspective of a management philosophy for general contractors and only limited focus has been on the perspective of highway agencies. Also, studies conducted on safety management philosophy do not state whether nighttime work presents a unique situation not covered by a daytime safety management plan.

2.3.2. Models of Accident Causation Applicable to Nighttime Construction

After the unfortunate event of an accident on a construction site, investigations are undertaken to determine the cause of the accident. Investigations tend to attempt to discover why the accident occurred on that site and why a particular type of accident happens in general. An accident causation model attempts to identify the root cause of accidents in order to reduce similar accidents to a minimum in the future. Most accidents within the construction industry are classified within two model types: behavioral root cause models and type of accident models.

An accident type model, within the construction industry, was developed by Hinze et al. (1998). Accident type models place all accidents within the construction industry into categories as identified by OSHA. The five code categories are falls, struck-by, caught in/between, electric shock, and other. Hinze et al. developed 20 different cause categories that would be better suited as accident cause categories. The researchers believe that if accidents were grouped into 20 code categories, instead of five, more relevant data could be gathered when accident investigation is conducted and more relevant regulations could be implemented.

During 2002, Toole conducted a study to determine if owners, architects and engineers, general contractors, or subcontractors should be responsible for different aspects of safety on a construction site (Toole, 2002). All of the parties were surveyed for an understanding of the current situation of safety on-site. The survey results showed unclear safety responsibilities for any specific group. Toole identified four reasons for their lack of consensus:

- Unclear establishment of the safety responsibility of the involved parties in construction standards;
- Conflicts between the text of OSHA regulations and OSHA behavior;
- Lack of court backing to safety assignment: contractual clauses assigning safety roles on projects have not carried much weight in court;
- Recent literature pushing for design professionals' safety obligations.

In an attempt to ensure safety in the future, Toole developed a framework for assigning safety roles on a jobsite and analyzed the ability of each party to influence the root causes of potential accidents. He identified eight root causes, which individually or in combination, could cause accidents. (Toole, 2002) Table 2.8 outlines eight root causes and factors needed to prevent root causes. The key assumption in Toole's analysis is that the behavior of employees may be the primary cause of an accident. He identified the necessary factors to prevent a root cause from occurring and then discussed which party involved would be best suited to influence a given factor.

OSHA uses three cause levels when performing a detailed analysis of an accident. The main finding using OSHA's accident causation level is that all construction accidents are traceable to the basic level, which includes management safety policy and decisions, personal factors, and environmental factors. Figure 2.1 outlines the OSHA accident causation levels.

Table 2.8 Factors Needed to Prevent Root Causes of Construction Accidents (Toole, 2002)

Root Cause of Accident	Factors Necessary to Prevent Root Causes
Lack of proper training	Have expertise in task, have expertise in training requirements, able to interview, test, or observe employee, have access to prior training records
Deficient enforcement of safety	Able to monitor work on frequent basis, know safety requirements for task, able to enforce safety
Safe equipment not provided	Know what safety equipment is required for task, able to provide and enforce use of equipment, know inspection and maintenance history of equipment being used
Unsafe methods or sequencing	Know standard methods and sequencing for task, able to observe actual methods and sequencing, able to control methods and sequencing
Unsafe site conditions	Know proper site conditions, able to observe actual site conditions, able to control site conditions
Not using provided safety equipment	Able to observe employee constantly, able to influence behavior through evaluations, and so on
Poor attitude toward safety	Interact with worker frequently, able to influence attitude through evaluations, and so forth
Isolated, sudden deviation from prescribed behavior	Cannot predict or prevent unless employee's emotional or physical condition contributed and this condition was obvious to others

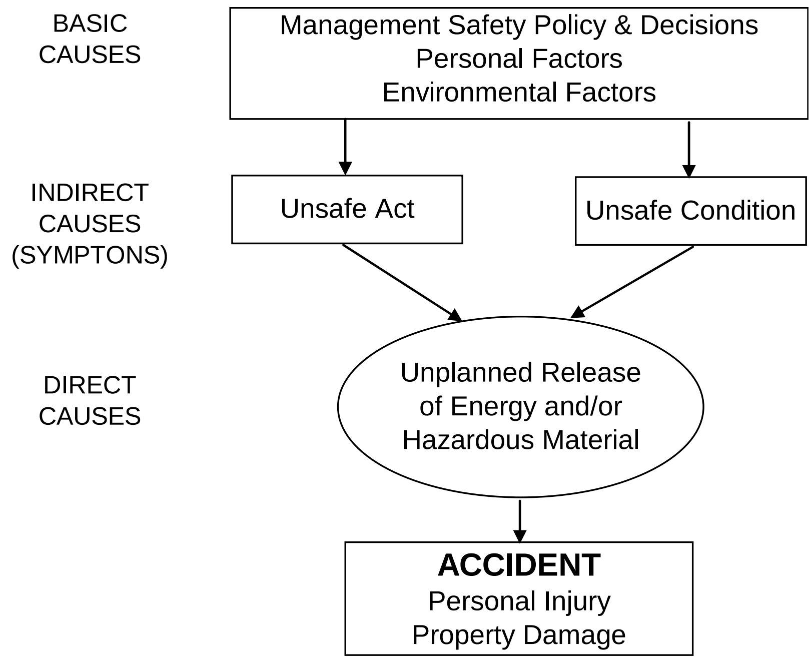


Figure 2.1 OSHA Accident Causation Levels (Adapted from OSHA, 2005)

OSHA determined that ineffective safety management, at the basic level, can be a direct cause of an employee accident. Safety policies, directives, and initiatives all need to be established within a safety management plan.

2.3.3. Techniques Used for Safety Management

Safety management philosophy is implemented in a construction company through a safety management plan or system. This plan or system communicates to employees what the employer is doing to ensure safety on the worksite. Included within the plan are the employer's specific policies, guidelines, and practices that employees are expected to follow in order to create a safe work environment. The Construction Industry Institute (CII), Associated Builders and Contractors (ABC), OSHA, and the Associated General Contractors of America (AGC) have provided guidelines for different components of safety management (e.e., personal protective equipment and lighting) to include within a safety management plan.

CII's document titled Zero Injury Techniques (Liska et al. 1993) is commonly referenced during the development of safety management plans which identified over 170 techniques used to improve safety. Information was collected through 482 interviews on 25 projects by 15 different construction firms regarding which techniques were most effective and important. From the information gathered, five high-impacts zero accident techniques were identified:

- Pre-project / pre-task planning for safety,
- Safety orientation and training,
- Written safety incentive programs,
- Alcohol and substance abuse programs,
- Accident/incident investigations (Liska et al, 1993).

These five techniques were found to be the most effective way for construction firms to manage on-site safety.

Hinze and Wilson (2002) did a follow up study to determine if there were additional methods, beyond the five aforementioned zero accidents techniques, capable of improving the safety record of an already safe company. Data was collected by administering a survey to construction companies. Eighteen different companies responded to the survey and were asked about the five high impact techniques and any additional safety techniques, beyond the previous five, found to be effective for their individual company. There was general agreement from the construction firms that the five high impact techniques played a key role in alleviating accidents on-site. The information gathered suggested all of the companies were implementing various programs to facilitate improved safety performance on their individual jobsites. Also, the companies were in agreement that implementation of safety programs enabled for continual improvement of safety ratings. Recordable injury rates, lost-time injury rates, or experience modification ratios were the safety ratings specified. Overall, the follow-up study by Hinze and Wilson indicated that changes are continuously made in safety management programs, and as new ideas arise, further changes are made within companies.

In prior research, the construction companies surveyed or interviewed did not identify whether the company or employee worked primarily during day or night shifts. Thus, it is difficult to gauge what type of safety management works well with the unique circumstances associated with nighttime construction. An evaluation needs to be done in the future to understand what safety management techniques work best during nighttime construction projects.

2.4. Speed Control Methods and Work Zone Safety

Speed is cited as a related factor in 30 percent of all fatal crashes and in 12 percent of all crashes (Bowie and Walz, 1994 as cited in Stuster et al. 1998). The Federal Highway Administration (FHWA) defines an accident or fatality as being speed related if at least one of the following criteria are met: (1) driver-related factor of driving too fast for conditions or exceeding the posted speed limit, or (2) driver charged with a speeding-related violation (other than driving too slow), or (3) vehicle speed was estimated to be at least 10 mi/h over the posted speed limit. Excessive speed extends the distance needed for a vehicle to stop and increases the distance the vehicle travels before the driver can react to a hazard.

2.4.1. Speed and Safety

There is also a relationship between vehicle speed and crash severity. The greater the speed at which occupants must absorb the energy released by the vehicle at impact, the greater the probability and severity of injury (Committee for Guidance on Setting and Enforcing Speed Limits 1998). Kinetic energy is determined by the square of the vehicle's speed. Thus the probability and severity of injuries from a crash increase exponentially with vehicle speed (Stuster et al. 1998).

In addition to driver injury in the event of a work zone traffic accident, it is also important to understand that workers (pedestrians) are at high risk. A study led by Walz in 1983 analyzed the relationship between the potential pedestrian injury severity and the impact speed of the vehicle. Figure 2.2 depicts this relationship between the impact speed and the injury severity. Impact speed is the velocity the vehicle is traveling at the time of impact with the pedestrian. The probability for survival for a given Injury Severity Score (ISS) was estimated from 952 cases and is shown in Figure 2.3 (Walz et al. 1983 as cited in McLean et al.1994). Using Figure 2.2 and Figure 2.3, the probability for survival can be calculated for each possible impact speed. For instance, if a vehicle traveling 45 km/hr were to strike a pedestrian, the pedestrian would have an ISS of approximately 22 according to Figure 2.2. This number can then be used on Figure 2.3 to see that the pedestrian has a 27% chance of survival. In the average nighttime work zone in Indiana, the speed limit is 45 mph, which is equivalent to 72.4 km/hr. If a vehicle traveling through a work zone at the speed limit was to hit a worker, that worker's chance of survival is less than 7%. The link between speed and safety further supports the objectives of this research, to study the effectiveness of speed control measures with the expectation that lower speeds and speed variance improve safety.

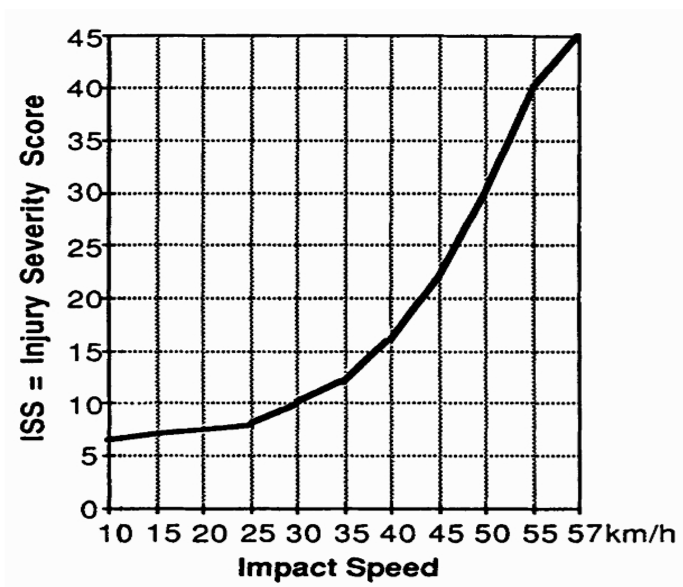


Figure 2.2 Relationship Between Impact Speed and Injury Severity Score (ISS)
(Walz et al. 1983 as cited in McLean et al.1994)

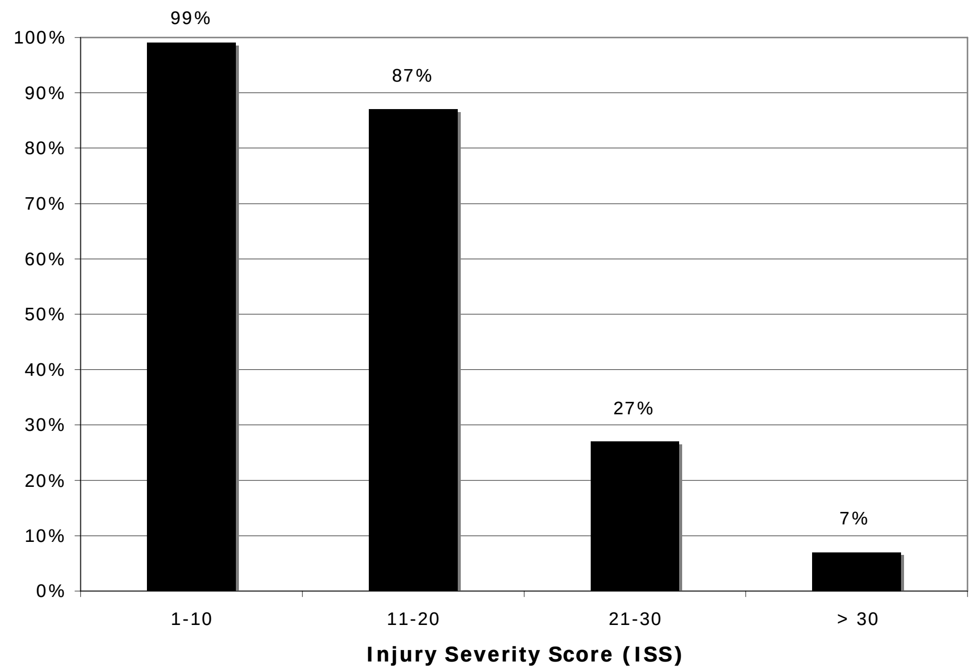


Figure 2.3 Probability of survival as a function of ISS
(Walz et al. 1983 as cited in McLean et al.1994)

2.4.2. Speed Control for Work Zones

Five techniques for managing and controlling vehicle speeds through work zones have been included in this research. A brief overview of each speed control method and corresponding studies of its effectiveness will follow.

2.4.2.1. Regulatory and Advisory Speed Limit Signs

The primary purpose of a speed limit is to enhance safety by reducing the risks imposed by drivers' speed choices (Committee for Guidance on Setting and Enforcing Speed Limits 1998). Speed limits enhance safety in two ways. First, they establish an upper limit on speeds aiming to reduce both the probability and severity of crashes. Second, speed limits have a coordinating function—to reduce dispersion in driving speeds (Lave 1985 as cited in Committee for Guidance on Setting and Enforcing Speed Limits 1998). More uniform speeds are associated with fewer vehicle conflicts.

Regulatory signs are used to relay information to motorists about a reduced speed limit at the work zone while advisory speed limit signs indicate a recommended safe speed through the temporary work zone (Maze et al. 2000). Regulatory speed limits are intended for 24-hour continuous posting established in long-term projects where it is imperative for the motorist to reduce speed in order to safely navigate through the hazards over the length of the project (Brewer et al. 2005). One of the main issues in work zone traffic management is the credibility and effectiveness of the work zone signs (Benekohal et al. 2003). A contributing factor to this issue is using static signs that do not reflect the work zone operating conditions. A study by Benekohal in 2003 surveyed 37 state DOTs and found that 70% of DOTs said that major contributing factors for the loss of credibility of work zone signs were: 1) failure to remove signs when work activity is done, 2) incorrect information, 3) lack of enforcement, and 4) the over use of signs.

In 2000, Maze conducted a survey of 63 state transportation agencies (response rate of 62%). Of the 34 agencies that responded, 28 included the use of regulatory speed signs among the strategies employed at their work zones. Only two agencies believed that posting regulatory speed limit signs is effective in reducing work zone speeds. Ten agencies felt that they are partially effective. Only eight state agencies that responded considered advisory speed signs applicable as a speed reduction strategy in work zones. Of those eight, two believed advisory speed limit signs were effective in reducing work zone speeds (Maze et al. 2000).

2.4.2.2. Work Zone Speed Limit Assemblies

To improve credibility and driver compliance, many states have developed their own work zone speed limit assembly. These signs notify drivers of an upcoming work zone and attempt to improve credibility by containing additional phrases such as “When Flashing” in Indiana or “Where Workers Present” in Michigan to the reduced speed limit sign. These work zone speed limits are regulatory speed zones generally established in short-term stationary construction or maintenance work zones for worker safety (Brewer et al. 2005). They are intended for use where the workers are adjacent to the lane open for vehicular traffic. Work zone speed limits are posted only during continuous worker activity when workers are present and adjacent to moving traffic (Brewer et al. 2005). Figure 2.4 shows a work zone speed limit sign in Indiana.

Figure 2.4 Indiana work zone speed limit sign (I-65 Project R-29140, Nov. 2, 2006)

2.4.2.3. Police Enforcement

The use of police enforcement in work zones is often effective in reducing speeds and improving safety in work zones and there are few adverse effects (Arnold 2003). A number of studies support this observation.

A study conducted in six work zones on rural and urban highways in Texas found that a stationary patrol car reduced averages speeds by 4 to 12 mph (6 to 22 percent speed reduction). The study also found that a circulating patrol car reduced speeds by 2 to 3 mph (3 to 5 percent speed reduction) (Richards et al. 1985 as cited in Arnold 2003).

Noel, Dudek, Pendleton and Sabra conducted a study on a six-lane freeway in Delaware to determine the effect of the presence of law enforcement on vehicle speeds (Noel et al. 1988 as cited in Maze et al. 2000). Police enforcement was studied using 1) a stationary patrol car with flashing lights and active radar and 2) with an officer standing on the roadside motioning the traffic to slow down. The study found that mean speeds were reduced by 2.4 mph under the first strategy and by 5.1 mph for the second enforcement strategy.

Benekohal, Resende and Orloski evaluated the impact of the presence of patrol cars on vehicle speeds at rural interstate work zones in Illinois (Benekohal et al. 1992a as cited in Maze et al. 2000). In the study, a patrol car circulated through the work zone for four hours. Speed data were collected with the patrol car circulating and also after the police left, to determine the lasting impact on speeds. The study found that while the patrol car was circulating the mean speeds of passenger cars and trucks in the work zone were reduced by about 4 and 5 mph, respectively. One hour after the patrol car left the mean speed of cars and trucks increased by about 2.5 and 0.5 mph, respectively. This study concluded that a lasting speed reduction for trucks could be obtained by periodically placing circulating patrol cars in a work zone.

The Minnesota DOT examined the effectiveness of police enforcement at work zones on three different sites (Minnesota DOT 1999 as cited in Maze et al. 2000). Using a laser gun, speed data with and without police enforcement were collected. The original posted speed limit on the divided interstate was 70 mph. The speed was reduced to 40 mph in the work zone area. The study found that the 85th percentile speed was reduced from 51 to 43 mph when the police enforcement was present in the work zone.

Another speed control method is drone radar. Drone radar is an electronic radar system that transmits in the microwave-frequency band (Maze et al. 2000). Vehicles equipped with radar detection devices perceive radar signals transmitted from the drone as the presence of police enforcement. The purpose of using drone radar in a speed reduction program is to reduce the 85th percentile speed, rather than the average speed, because it is assumed that the fastest group of drivers is more likely to possess radar detectors (Maze et al. 2000). In 1991, Ullman studied the effectiveness of drone radar in reducing speeds in eight highway and interstate work zones (Ullman 1991 as cited in Maze et al. 2000). The study was performed in 30 to 45 minute segments throughout the day with the drone radar being switched on and off. The drone radar data were compared with the data from the next 30 to 45 minute period to provide comparison data for every portion of the day. Average speed reductions for all eight sites were between 0.2 and 1.6 mph when the drone radar was active.

Benekohal, Resende and Zhao studied the effectiveness of a drone radar at a rural interstate work zone in Illinois (Benekohal et al. 1992b as cited in Maze et al. 2000). During the first hour of deployment of the radar gun, reductions in mean speed of 8 to 10 mph were noted through the work zone. However, when the experiment was continued for a few more hours, no speed reduction occurred. The researchers discovered by listening to CB conversations that motorists were quickly able to determine that no police were present in the work zone.

In short, it is generally accepted that one of the most effective ways of controlling speed in a work zone is to have a staffed police car positioned at the beginning of the work zone with its lights flashing and radar on (Arnold 2003). The high cost of employing police enforcement in work zones makes it impractical for common use. On high risk or high profile projects police enforcement is highly recommended.

2.4.2.4. Changeable Message Signs

A changeable message sign (CMS) is used in work zones to alert drivers of an upcoming change where unexpected traffic or detour situations exist. They are commonly used to increase driver awareness and are able to convey more information than traditional static signs. Various messages have been tested to determine the effect of the message on vehicle speeds. Portable CMSs are often used to display a reduced advisory speed, statement to reduce speed, or proceed with caution (Brewer et al. 2005).

An increasing number of portable CMS models have the capability of speed detection using a radar emitter similar to a speed display monitor (Brewer et al. 2005). Since the CMS with radar gives a sense of personalized communication to speeding drivers, they feel urged to slow down (Garber and Srinivasan 1998).

The Texas Transportation Institute examined the effectiveness of a CMS with radar, a speed display monitor, and orange-bordered speed limit signs in two work zones in Texas (Brewer et al. 2005). The speed display and CMS systems were deployed at different times in the same work zone. Data were collected at six points throughout the work zone (including 1 mile upstream and 1 mile downstream of the work zone). The CMS with radar reduced mean speed for both cars and trucks at the two nearest measurement locations downstream. The most significant reduction in mean speed was 2.1 mph for passenger cars and 1.3 mph for trucks. Speed trailers were also found to reduce mean speeds at the two nearest measurement locations downstream of the device. The most significant reduction in mean speed was 3.1 mph for both passenger cars and trucks. Decreases in the 85th percentile speed were also seen for both the CMS with radar and the speed display trailer. Orange-bordered speed limit signs did not consistently improve speed limit compliance and should be used with other speed control measures. The orange borders were shown to improve visibility of speed limit signs.

The Maine Department of Transportation evaluated the use of a radar activated CMS to reduce the incidence of speeding in construction work zones (Thompson 2002). The message "YOU ARE SPEEDING!!!" was used. The proportion of speeding vehicles was reduced by 11% and the average speed went from 54.7 mph before the sign was activated to 48.2 mph after the sign was activited.

The Georgia Department of Transportation conducted another study of CMS with radar (Dixon and Wang 2002). The selected work zone had a speed limit of 45 mph. The message "YOU ARE SPEEDING, SLOW DOWN NOW" was programmed to appear on the CMS if vehicle was traveling over 50 mph and "ACTIVE WORKZONE, REDUCE SPEED" otherwise. Data were collected on a rural two-lane highway for three consecutive weeks to evaluate the immediate and novelty effects. CMS with radar (CMR) provided significant speed reductions (6 to 7 mph) adjacent to the sign. The CMR was effective throughout the duration of the study. The study recommends use of this strategy in close proximity to the active work area. The study site was 12 miles long and the active work area was approximately 6 miles downstream of the CMR. It was seen that vehicles that reduced their speed near the sign sped back up before reaching the active work area.

The Virginia Transportation Research Council evaluated the duration of exposure of the CMS with radar on its effectiveness in reducing speeds (Garber and Srinivasan 1998). Speed reduction was between 8 and 9 mph with the CMS with radar activated. It was found to remain an effective speed control system for up to seven weeks.

2.4.2.5. Rumble Strips

The purpose of rumble strips is to alert drivers of potential hazards. They produce vibrations and audible rumble effects when motorists drive over them (Maze et al. 2000). Rumble strips do not force drivers to slow down; however, they do alert the driver of a change ahead.

McCoy and Bonneson evaluated the effectiveness of rumble strips at a work zone, which required motorists to stop at the beginning of the work zone (McCoy and Bonneson 1993 as cited in Maze et al. 2000). Three sets of rumble strips were installed. Mean speeds were reduced by 0.8, 1.7, and 2.9 mph at each location as vehicles neared the work zone.

In 2002, Meyer conducted a comparison of the Swarco Rumbler and asphalt rumble strips on two work zones in Kansas. The Kansas Department of Transportation uses rumble strips in advance of work zones where two or more lanes of traffic traveling in opposite directions are forced to share a single lane. Temporary traffic signals are used to control traffic flow through the work zone. Rumble strips are used to alert drivers of the change ahead. Each Rumbler rumble strip consists of a 4 ft long piece of black rubber with three raised ridges. It is applied to the pavement using contact cement. Reflective white and yellow are also available instead of black. The manufacturer, Swarco, states that the Rumbler is "ideal to effectively influence driver behavior where speed reduction, advance notice of upcoming construction zones or potentially critical traffic situations need to be managed" (Horowitz 2002). The study used three measures of effectiveness; the vehicle speed reduction, sound levels inside the vehicle, and vibration of the vehicle body. The speed reduction was found to be approximately the same for both the Rumbler and asphalt rumble strips. The Rumbler strips were faster to install but more expensive. Temporary rumble strips like the Rumbler aim to replace asphalt rumble strips on temporary applications like work zones.

Horowitz also evaluated the Rumbler rumble strip, but in white, at a rural intersection of two highways (Horowitz 2002). The Rumbler was found to significantly reduce average vehicle speeds by 1.3 mph at the two data collection points located 1106 feet and 800 ft away from the stop line at the intersection.

The Missouri Department of Transportation tested the Rumbler in advance of a work zone to evaluate its ability to reduce traffic speed (Virkler 2002). Rumble strips were set up in both the northbound and southbound driving lanes. Mean speeds were found to be lower using the Rumbler in the northbound lanes; however, the rumble strips did not have a significant effect on speed in the southbound lane. Thus, a significant reduction in mean speed was not found. In summary, the study found that reductions in speed were not consistent.

As part of the Midwest Smart Work Zone Deployment Initiative, Ron Sims and team in Kansas and Mark Virkler in Missouri each conducted evaluations on removable orange rumble strips. The study by Sims found the removable rumble strips were able to reduce speeds prior to a work zone by 0.4 to 2.9 mph (Sims 2000). The study by Virkler found the mean and 85th percentile speeds showed improvement with the rumble strips in place (Virkler 2000). The only negative change was a tendency for increased speed variance.

The Texas Transportation Institute evaluated portable rumble strips at reducing speeds in rural maintenance work zones (Fontaine and Carlson 2001). The results were mixed with cars experiencing less than a 2 mph reduction in mean speed and trucks with speed reduction of up to 7.2 mph. The percent of vehicles exceeding the speed limit was reduced when the rumble strips were in place.

Overall, rumble strips have not proven to consistently reduce speeds. They do increase driver awareness and should be used in work zones to alert drivers of potential hazards such as a stop ahead.

2.4.3. Speed Control Summary

This section discussed the importance of speed control on work zones and some of the many methods of speed control being used today. Prior studies have evaluated speed control by measuring mean speeds, 85th percentile speeds, and speed variance. It is believed that police enforcement is the most effective. However, very few studies have looked specifically at the effectiveness of speed control during nighttime operations. New methods are continually being developed because there is not yet a proven method to invoke speed limit compliance through work zones. The most effective speed reductions will probably involve some combination of the techniques described in this literature review (Maze et al. 2000). The third study within the project aims to assess the speed control methods currently used on Indiana interstate nighttime construction and maintenance work zones. Table 2.9 presents a summary of prior speed control studies and their reported speed reductions.

Table 2.9 Summary of Speed Reductions Found in Prior Studies

Speed Control Type	Reported Speed Reduction	Study
Police Enforcement	4-12 mph reduction in mean speed from a stationary patrol car 2-3 mph reduction in mean speed from a circulating patrol car	Richards et al. 1985
	2.4 mph reduction in mean speed from a stationary patrol car 5.1 mph reduction in mean speed from an officer standing on the roadside motioning traffic to slow	Noel et al. 1988
	4-5 mph reduction in mean speed from circulating patrol car	Benekohal et al. 1992a
	8 mph reduction in 85th percentile speed	Minnesota DOT 1999
Changeable Message Signs with Radar	2.1 mph reduction for passenger cars 1.3 mph reduction for trucks	Brewer et al. 2005
	5.5 mph reduction in mean speed	Thompson 2002
	6-7 mph reduction in mean speed	Dixon and Wang 2002
	8-9 mph reduction in speed	Garber and Srinivasan 1998
Rumble Strips	0.8-2.9 mph reduction in mean speed	McCoy and Benneson 1993
	1.3 mph reduction in mean speed	Horowitz 2002
	None	Virkler 2002
	0.4-2.9 mph reduction in speed	Sims 2000
	< 2 mph reduction in mean speed for passenger cars Up to 7.2 mph reduction in mean speed for trucks	Fontaine and Carlson 2001

2.5. High-visibility PPE and Work Zone Safety

The need to be visible is always a critical issue for worker safety; but due to the lack of natural lighting, visibility becomes an even greater consideration for safe nighttime operations. Crews working during low-light hours are about two and one-half times more likely to be struck by a motor vehicle than those working during the day (3M 2000). Improving worker visibility is a potential answer to reducing such accidents because the sooner a driver detects a worker, the more likely a struck-by incident can be prevented (ANSI/ISEA 207-2006). Sant (2001) identified the use of high-visibility clothing as the first solution to decrease "struck-by" hazards by increasing the visibility of the worker, and stated that then must be used whenever the workplace contains hazards related to low visibility or proximity to moving vehicles or equipment.

There are several standards regarding high-visibility safety garments, which include: (1) the British Standard Protective Clothing – High Visibility Clothing BS EN 471 1994; (2) European Standard Retroreflective Materials and Devices for Road Traffic Control Purposes AS/NZS 1906.4 (1997) and; (3) the Canadian Standard of High Visibility Safety Apparel CAN/CSA Z96-02. The International Safety Equipment Association (ISEA), in conjunction with the American National Standard Institute (ANSI), published the American National Standard for High Visibility Safety Apparel and Headwear, known as ANSI/ISEA 107-2004. This publication provides recommendations for the use and design and testing of high-visibility apparel. In 2006, ANSI/ISEA released a new set of standards ANSI/ISEA 207-2006 "Safety Apparel for Public Workers" which establishes performance criteria for the materials to be used in safety vests, specifies minimum areas, placement of the materials, and features that are specifically needed by public safety sectors (ANSI/ISEA 207 2006).

Conspicuity is defined by the ANSI/ISEA 107-2004 as the characteristics of an object influencing the probability that it will come to the attention of an observer, especially in a complex environment which has competing objects. Providing high-contrast between clothing and the environment against which it is seen, may increase conspicuity. High-visibility safety apparel is a type of PPE that is intended to provide conspicuity during both daytime and nighttime usage (ANSI/ISEA 2004).

ANSI/ISEA 107-2004 defines three performance classes for high-visibility apparel, depending upon the minimum area of the materials to be included in the safety garment; Table

2.10 describes each performance class. Appendix B of this ANSI standard states that several factors affect the conspicuity of safety garments. Arditi et al. (2003) summarized these factors as follows: (1) the speeds of vehicle and moving equipment, (2) the level of complexity and/or confusion of the background, (3) the level of separation of the worker from the work zone, (4) the level of attention scattering and/or diverting, (5) the level of inclement weather conditions, and (6) the nearness of work to traffic. Table 2.11 provides a guide regarding performance classes which must be used under different conditions of traffic speed and volume.

Table 2.10 ANSI/ISEA performance classes and description (ANSI/ISEA 2004)

Classification	**Description**
Performance Class 1	Provides the minimum amount of required material to differentiate the wearer from the work environment.
Performance Class 2	Superior visibility for wearers by the additional cover of the torso and is more conspicuous than Performance Class 1
Performance Class 3	Greater visibility to the wearer in both complex backgrounds and through a full range of body movements by placing retroreflective material on the arm and/or leg.
Performance class E	Waistband trousers and shorts which meet all the requirements for retroreflective and background material in performance Classes 1, 2, and 3.

Table 2.11 PPE categories and working conditions for which a Performance Class is applicable (Sant 2001)

Conditions	**Performance Class**		
	Class 1	**Class 2**	**Class 3**
Speed of Traffic	25 mph	25-50 mph	Above 50 mph
Volume of Activity	Low	Medium	High
Minimum Area of Background/Retroreflective Material	217 in^2/155 in^2	775 in^2/201 in^2	1240 in^2/310 in^2

2.5.1. Components of High-Visibility Safety Garments

High-visibility PPE is composed of a fluorescent background color and retroreflective material. Fluorescent material emits optical radiation within the visible range at wavelengths longer than absorbed, and such emission ceases upon removal of the source of irradiation (ANSI/ISEA 2004). ANSI/ISEA 2004 suggests the use of fluorescent yellow-green, orange-red and red, as background colors. Retroreflective material is designed to reflect light at an oblique angle back toward its source (3M 2006). This material is used in high-visibility safety vests because it can be seen from far greater distances on the roadways than dark or fluorescent-colored fabrics (Blauer 2005). ANSI/ISEA 2004 uses the photometric performance level to measure the effectiveness of the retroreflective material in returning light to its source (ANSI/ISEA 2004).

The American Society for Testing and Materials (ASTM) F923-94a standard provides guidelines for using high visibility materials for individual safety at night. This guidance states that if high-visibility materials are selected and used appropriately, it is not necessary to use large amounts of retroreflective material to meet these requirements. In addition, ASTM F923-94a recommends increasing the detectability of the person by using retroreflectors with the following characteristics:

- Sufficiently bright as positioned on the pedestrian to be detected at distances of interest, such as stopping sight distance (SSD) and decision sight distance (DSD).
- Provides noticeability from all directions (360° visibility), regardless of whether the pedestrian is in motion.
- Furnishes recognition cues that the object sighted is a human being and not an inanimate road object or vehicle.
- Reveals the motion of the human being as much as possible but is not totally dependent on it for its effect (ASTM F923-94a).

ANSI/ISEA 107 provides guidance for the design of high-visibility safety garments. This guidance includes minimum widths of retroreflective or combined-performance materials, spacing between multiple bands, distance from the bottom edge of the garment, and placement of material on the legs. In addition, ANSI/ISEA 107 requires that retroreflective, combined performance and background materials shall be placed on the headwear in order to provide 360° visibility of the wearer. This headwear should be used only in conjunction with other high-visibility safety garments (Carbin 2000). Table 2.12 shows the minimum amount of visible materials for each performance class as specified in the ANSI/ISEA 107 standard.

Table 2.12 Minimum areas of visible material (ANSI/ISEA 2004)

	Performance Class 3	**Performance Class 2**	**Performance Class 1**	**Performance Class E**	**Headwear**
Background Material	0.80 m^2 or (1240 in^2)	0.50 m^2 or (775 in^2)	0.14 m^2 or (217 in^2)	0.30 m^2 or (465 in^2)	0.05 m^2 or (78 in^2)
Retroreflective or combined-performance material Photometric performance	0.20 m^2 (310 in^2) Level 2 or Level 1	0.13 m^2 (201 in^2) Level 2 or Level 1	0.10 m^2 (155 in^2) Level 2 or Level 1	0.07 m^2 (108 in^2) Level 2 Or Level 1	0.0065 m^2 (10 in^2) Level 2
Combined performance material used without background material Photometric performance			0.20 m^2 (310 in^2) Level 2 or Level 1		0.05 m^2 (78 in^2) Level 2 or Level 1

ANSI/ISEA 207-2006 is a new standard that is not based on performance classes but rather on the minimum areas of visible material being a combination of the minimum requirements in the performance classes of ANSI/ISEA 107-2004. It states that the background material should not be less than 450 in^2, which lies in Performance Class 1 in ANSI/ISEA 107-2004, and that retroreflective or a combined-performance material with background material should be not less than 201 in^2, which lies in Performance Class 2 in ANSI/ISEA 107-2004. In addition, the new standard suggests the use of red for fire service, blue for law enforcement, and green for Emergency Medical Service.

A wide variety of high-visibility PPE is available to improve worker visibility, which can be grouped into six categories. Table 2.13 shows examples of the available high-visibility PPE in each category.

Table 2.13 Currently high-visibility PPE

High Visibility PPE Category	Examples
Safety vests	Regular safety vest Self illuminating safety vests (LED)
Safety shirts	Long sleeves, short sleeves, winter shirts, t-shirts
Safety pants	Long pants (trousers), short pants
Headgear	Hard hats, caps, winter hats, hard hat high-visibility cover
Outerwear	Coats, rain suits, windbreakers, coverall/jumpsuit
Accessories	Retroreflective strips, ankle and hand bands, high visibility gloves, sash belts, batons, flashers

ANSI/ISEA 107-2004 includes guidelines for care labeling and markings. The maximum number of washes is included on the label of the safety garment, as well as the trademark, designation of the product, size, and performance class, among other things (ANSI/ISEA 107-2004). Figure 2.5 shows the typical label for a safety vest.

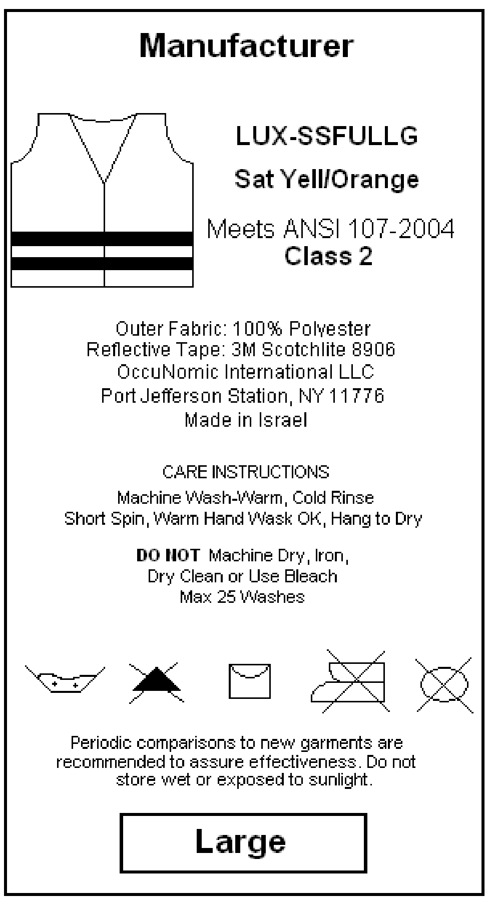


Figure 2.5 Typical safety vest label (based on Occunomix International LLC Products)

2.5.2. Assessing the Nighttime Effectiveness of High-Visibility PPE

Many studies have assessed the retroreflectivity of signs, pavement markings, and safety garments during the day and at night in order to evaluate their conspicuity. The effectiveness of high-visibility garments in the nighttime hours has been evaluated by determining the distance between the pedestrian and the point at which the driver recognizes the presence of a pedestrian. Researchers have also evaluated the characteristics of safety vest luminescence using computer software and by obtaining the perspectives of human evaluators on their visibility.

Luoma (1995) studied the effects of retroreflector positioning on the recognition of pedestrians. The study consisted of testing four retroreflector positions at different locations and conditions: (1) torso, (2) wrist and ankle (3) major joints, and (4) no retroreflector. Thirty-two subjects were seated in the passenger seat of an automobile which was driven on a dark road. Each subject was asked to press a button when they detected the presence of a pedestrian and the recognition distances were measured. The study found that pedestrians with retroreflectors at the major joints of their bodies had the greatest mean recognition distance (249m), followed by pedestrians with the material at the wrists and ankles (241m), torso (136), and no retroreflectors (35m).

Sayer and Mefford (2000) examined the effect of color contrast in visibility during both the daytime and nighttime. Twenty drivers sat in a parking lot and were asked to assess different Class 2 safety vests in a paired comparison. The two vests to be compared were mounted 16.50 meters from the drivers, and barrels and signs were placed between the drivers and the vest, thereby simulating a work zone. The findings of the study suggest that for daytime visibility, combinations of color contrasts, not only within the vest but also a contrast relative to the surroundings, were most effective. In the nighttime hours, the luminescence of the safety vest was visible, rather than the color contrast of the vests.

In 2002, research conducted by the University of Kansas that was funded by the Midwest Smart Work Zone Deployment Initiative (MSWZDI) compared three different models of self-illuminating vests with a Kansas Department of Transportation (KDOT) standard safety vest with respect to their nighttime visibility. Self-illuminating safety vests have the same characteristics as the standard ones, but also contain blinking or continuous light-emitting diodes (LEDs). The safety vests evaluated were orange with reflective yellow trim. The experiment took into consideration different parameters, such as the vehicle orientation and the distance from the automobile to the safety vest. The test set-up consisted of mounting the vests at the average height of a worker and recording the vests using a digital video camera. The video data was evaluated using a software that calculated the visibility indices for each of the vests. The study found that LEDs had little effect on the visibility of the vests when the automobile was oriented directly at the vests. In addition, at eccentricities greater than 30 degrees, almost their entire glow was generated by the LEDs. The self-illuminating vests were more visible than the KDOT reflective vests under all conditions (Meyer 2002).

Sayer et al. (2002) conducted a study to assess the effects of color on the detection of pedestrians by both normal and color deficient drivers. Twenty male participants, ten normal and ten color deficient, were asked to sit in the driver's seat of a stationary automobile and observe a darkly dressed pedestrian walking along the road. The pedestrian was wearing different colors of retroreflective markings on the legs. Four retroreflective colors were evaluated in the study: green, yellow, red, and white. Each color was evaluated at two levels of retroreflective power: low and high. Two scenarios were tested: (1) the pedestrian walking in the central field of view of the participant and (2) the pedestrian walking in the participant's peripheral field of vision. The pedestrian walked towards the driver and the distance between the automobile and the pedestrian at which the pedestrian was detected was measured. Then, the pedestrian walked away from the automobile and the distances at which the pedestrian or the retroreflective markings disappeared were measured. The study found that the effect of the participants' ages was not significant; and for persons with normal color vision, the color of the retroreflective marking affected the distance at which the pedestrian was detected.

Arditi et al. (2003) evaluated the effectiveness of six safety vests in highway work zones. The testing set up consisted of three torso mannequins, placed next to each other perpendicular to the work zone boundary, clothed in different combinations of the six safety vests. A video camera was placed on the shoulder of the work zone to record the different set-ups during various ten-minute periods. The video was converted into snapshots in order to evaluate their luminescence using a computer software. Some factors considered in this experiment were lighting, weather conditions, type of setting (urban or rural), volume of traffic, and location of the vest related to the boundary of the work zone. The front and one of the sides of the safety vests were evaluated. In the same study, Arditi et al. (2003) displayed the six safety vests to graduate students in a parking lot. The students were asked to rate the safety vests in terms of their 360° visibility, their conspicuity against the background, the brightness of the retroreflective material, their configuration, and their overall perceived effectiveness. The rating was based on a five-point scale: not acceptable (1), needs improvement (2), ok (3), very good (4), and excellent (5). Combining the results of the survey and the site tests, the researchers found that two of the vests that did not have the largest amount of retroreflective material were superior to the other vests. These two safety vests were very similar, having the same overall color (yellow) and retroreflective material color (silver) (Arditi 2004).

In the same study, Arditi et al. (2003) distributed a survey to the Illinois Department of Transportation (IDOT) operations personnel, and resident engineers, as well as general contractors in Illinois and other state DOTs. The survey pertained to the performance of their currently used high-visibility safety garments regarding their visibility, conspicuity, reflectivity, wearability, durability, comfort, configuration, and perceived effectiveness. The majority of the respondents indicated that the performance of their safety vests was very good. In addition, the survey asked about the importance of garment design and safety features, such as definability of the human form, location of the retroreflective material, 360° visibility, the amount of retroreflective material, the brightness of the retroreflective material, and the acceptable loss of color and brightness. The majority of the respondents indicated that all of these features were very important to them.

Sayer and Mefford (2004) assessed the attributes of retroreflective personal safety garments on pedestrian conspicuity at night. Ten drivers were asked to drive an instrumented automobile at 25 mph through a simulated work zone on a 2.75-miles oval test track while attempting to detect pedestrians in the work zone. Eighteen Class 2 and Class 3 vests and jackets, which were ANSI 107-1999 compliant, were evaluated in this study. In each trial, a pedestrian was located either in or opposite to the work zone, walking in place, moving the arms and legs, and turning to provide a 360° view of the garment. The detection distances were calculated using the coordinates of the vehicle and the pedestrian, which were obtained using a differential global positioning system. The data was analyzed in terms of the garment classification/configuration, the retroreflective trim color and intensity, the pedestrian placement, driver age, and driver gender. The study found that Class 3 jackets were significantly more conspicuous than either the Class 3 or Class 2 vests and that younger drivers detected a pedestrian at significantly greater distances than older drivers. The blaze orange color was found to be the most conspicuous of the retroreflective trim colors. Table 2.14 shows the results of the mean detection distances obtained for each factor of the experiment.

Table 2.14 Mean detection distances for each factor (adapted from Sayer et al. 2004)

Factors		**Mean detection distance (m)**
Garment classification/configuration	Class 3 jackets	355
	Class 3 vest	311
	Class 2 vests	29
Retroreflective trim color	Dark-clad comparison	<100
	Silver/white	329
	Blaze orange	344
	Fluorescent red	288
Retroreflective trim intensity	Low intensity trim	314
	High intensity trim	325
Pedestrian placement	Within illuminated work zones	369
	Driver’s left	272
Driver age	Younger	432
	Older	208
Driver gender	Males	339
	Females	300

In a second study, Sayer and Mefford (2004) assessed the effects of retroreflective arm treatments, pedestrian arm motion, scene complexity, and pedestrian orientation on the detection distances of older drivers. Twenty-four drivers with a mean age of 68.8 years drove through a route and indicated to a researcher when they were confident of seeing a pedestrian. The pedestrian was wearing one of three ANSI/ISEA 107-1999 compliant garments. The detection distances were calculated through a differential global positioning system. The study found that the garment and pedestrian orientation were not significant factors. Furthermore, the study found that both the scene complexity and arm motion had a significant effect on the results. Medium scene complexity reduced the mean detection distance by 21 meters (69 feet) while arm motion increased it by 22 meters (72 feet). These results relate closely with a study by Johansson (1973) that considered the perception of motion patterns characteristic of living organisms or biological motion. This study found that there is an interaction between the visual information from biological motion and from the corresponding figurative contour patterns that ease the recognition of the person when he/she is in motion.

Hirasawa et al. (2006) conducted an experiment in a simulated work zone to determine the most recognizable uniform colors as perceived by users during the winter and autumn seasons in the daytime and nighttime hours and at dusk. Two lighting conditions were evaluated at nighttime: spotlighting and balloon lighting. Four colors were evaluated in this study: dark blue, red, yellow, and orange. The analysis was based on the color recognition distance and the worker confirmation distance. The color recognition distance is the distance from the roadway worksite to the point on the road where the subject could determine the color of the uniforms. The worker confirmation distance was determined by Hirasawa to be the distance from the roadway worksite to the point where the subject could determine that there were people working; and this study found that the most recognizable colors were yellow during daytime and orange at dusk and nighttime.

In the same study, Hirasawa et al. (2006) studied the influence of construction safety measures on overall satisfaction in Japan. A survey was distributed to traffic safety contractors and trucking companies to obtain their satisfaction level regarding different safety sub-items within the following safety measures: construction information signs, traffic control personnel, electric signboards, construction signals, and crash cushions. For instance, the use of a safety vest, color of the uniform, daytime visibility, and nighttime visibility were the safety sub-items evaluated under the traffic control personnel safety measure. The satisfaction was measured based on a five-point scale: (1) dissatisfied, (2) somewhat dissatisfied, (3) neither satisfied nor dissatisfied, (4) somewhat satisfied, and (5) satisfied. The study found that the highest score indicated by both traffic safety contractors and trucking companies was for the nighttime visibility of electronic signboards. The lowest score in satisfaction was for the nighttime visibility of construction information signs, followed by the nighttime visibility of traffic control personnel (Hirasawa et al. 2006).

2.5.3. High-Visibility PPE Selection Criteria and Training

The Occupational Safety and Health Administration (OSHA 3151 2000) recommends the establishment of a PPE program. **Error! Reference source not found.** shows the steps to establish such a program.

The OSHA 10-hour training course is part of the OSHA Outreach Training. The course reviews the hazards associated in construction through a review of OSHA regulations and focuses on the prevention of injuries associated with the hazards. The following topics are addressed in this training: electrical safety, fall protection, excavations, cranes, materials handling, storage, use and disposal, tools-hand/power, scaffolds, stairways and ladders, and personal protective equipment.

It is vital to develop detailed hazard information to ensure that the most appropriate PPE is selected (Camplin 2003). 3M (2005) suggests six steps for selecting high-visibility safety apparel:

- **Step 1:** Review the ANSI/ISEA 107-2004 standard and relevant regulations.
- **Step 2:** Conduct a survey of the worksite low-visibility hazards to determine the appropriate class of garments. The survey should account for speed, weather conditions, worker proximity to traffic, task loads, lighting levels, and the traffic control plan.
- **Step 3:** Design or find concept garments that meet the needs of the project. Remember to take a comprehensive approach to garment design in order to balance your requirements for garment functionality, comfort, and durability.
- **Step 4:** Review the design choice with a visibility demonstration.
- **Step 5:** Write a specification based on specific performance criteria and require the use of certified components only.
- **Step 6:** When the safety apparel is issued to workers, provide them with training that explains the purpose and use of their new high-visibility garments.

2.5.4. Regulating the Use of High-Visibility PPE

In April 2006 the Federal Highway Administration (FHWA) proposed to add to the Code of Federal Regulations (CFR) a new section entitled 23 CFR 634 Worker Visibility. In order to decrease the likelihood of worker fatalities or injuries, the new regulation requires the use of high-visibility safety apparel for workers who are working within the federal-aid highway right-of-way and who are exposed either to traffic or to construction equipment within the work area. The final rule was approved on November 2006 and provides a two-year grace period from that date, at which time compliance with the rule will be required. This new regulation is based on the MUTCD and the ANSI/ISEA 107-2004 standards. It provides specific requirements, such as the use of garments with ANSI/ISEA 107 Performance Class 2 or 3. However, this new regulation needs improvement in the area of implementation guides (Cottrell 2007). Table 2.15 summarizes the recommendations by Cottrell (2007) for improving the final Federal Regulation on Worker Visibility.

Table 2.15 Suggestions for Improving the Federal Regulation on Worker Visibility (Cottrell 2007)

Area	Subjects	How to improve
Garment appearance	Color, contrast, coverage, driver recognition, retroreflectivity, shape, and uniqueness	- Reiterate ANSI/ISEA 2004 recommended standard colors for background garment color. - Recommend luminance contrast ratios of 2.50 for daytime and 3.00 for nighttime. - Develop recommendations for the shapes and patterns of retroreflective trim.
Clothing management	Availability, durability, and replacement schedules	- Develop guidance for durability and garment replacement cycles.
Periods and times of usage	Season (winter, summer) and time of day of work activity	- Nothing suggested.

2.5.5. Practices to improve worker visibility in nighttime work zones

The Occupational Safety and Health Administration (OSHA) regulates some of the practices for the use of PPE. According to OSHA Standard 1926.28(A), the employer is responsible for requiring the wearing of appropriate personal protective equipment in all operations where there is an exposure to hazardous conditions or where this standard indicates the need for using such equipment.

The 2003 edition of the FHWA Manual on Uniform Control Devices (MUTCD) stipulates that all workers exposed to the risks of moving roadway traffic or construction equipment should wear high-visibility safety apparel satisfying the requirements of the ANSI/ISEA 104-2004. In addition, the MUTCD states that the selection of the appropriate class of high-visibility safety garment is the responsibility of a competent person designated by the employer and specifies that the apparel background color shall be either fluorescent orange-red or fluorescent yellow-green. The retroreflective material shall be orange, yellow, white, silver, yellow-green, or a fluorescent version of these colors; it shall be visible at a minimum distance of 300 m (1,000 ft); and shall be designed to clearly identify the wearer as a person. According to the MUTCD, for daytime and nighttime activity, flaggers shall wear high-visibility safety apparel meeting the requirements of ANSI/ISEA 2004 for Performance Class 2. For nighttime activity, the MUTCD states that flaggers' high-visibility safety apparel shall meet the ANSI/ISEA Performance Class 3 (MUTCD 2005).

Each state has developed its own practices on the type of high-visibility safety garments required. The Maryland State Highway Administration requires that full-length, high-visibility reflective clothing (tops and bottoms) be worn by all workers during nighttime construction and maintenance work (Servatius 1996). The Iowa Department of Transportation provides their employees with a yellow-green and orange safety vest which was developed by the Minnesota Department of Transportation. The New York Department of Transportation states that hard-hats and high visibility apparel shall be provided to all employees who require them (NYDOT 2003). INDOT changed its traditional orange tops to fluorescent yellow-green shirts with silver retroreflective material in 2006. INDOT safety officials indicated that their traditional safety garments did not stand out enough among traffic control devices, such as the orange cones and signs used in most construction sites (Kim 2006). As of Fall 2005, only 20% of the state DOTs were using ANSI/ISEA 107 compliant PPE (Cottrell 2007).

Documented training to workers also is a key element in order to increase worker safety (Camplin 2003, Bacon 2002, Laws 2002, Corbin 2000, OSHA 2000). Every employer should verify that all employees have received and have understood the required training through written certification (INDOT 2004). The OSHA 10-hour General Industry Outreach Training includes a section on PPE, which covers examples of PPE, establishing a PPE program, and training requirements.

2.5.6. Summary of prior research efforts in PPE for nighttime conditions

The use of high-visibility safety apparel is crucial to guaranteeing safety of the nighttime workers. ANSI/ISEA 107 2004 provides guidelines for the design and selection of high-visibility safety apparel and headwear. Many studies have evaluated the effectiveness of safety vests. Some of these studies have focused on the performance of currently used high-visibility garments from states such as Illinois and Minnesota. However, none of these studies have been conducted in Indiana, nor have they incorporated the combination of different high-visibility PPE in the assessment, as well as the perspective of drivers. Furthermore, current high-visibility training and implementation procedures have not been addressed.

CHAPTER 3. EVALUATION AND ASSESSMENT OF NIGHTTIME SAFETY MANAGEMENT PLANNING

To evaluate current safety practices on nighttime construction projects, and to develop methods to prevent accidents, it is essential to identify how safety factors influence the safety perspectives of the workers involved in nighttime construction. A safety factor is any action, practice, or condition that can affect the safety of a construction worker or a member of the general public. This provides a means to determine how intervention and/or mitigation strategies can be effectively developed and implemented. Based on the identification of safety factors (through review of prior research efforts in nighttime construction safety) and preliminary evaluations of safety plans of contractors who have been involved in nighttime construction operations, two distinct surveys were development to investigate the role of different safety factors in nighttime construction operations. One survey was geared towards general contractors and the other towards workers. A copy of both the contractor and worker surveys is provided in Appendix B and C, respectively. In addition, on-site visits allowed the researchers to observe safety practice on nighttime construction sites.

Data from surveys were analyzed using multiple linear regression and statistical and qualitative analyses to determine the most significant safety factors, mitigation strategies, and safety practices used by general contractors.

The multiple linear regression analysis consisted of five steps: 1) selection of the safety factor categories, 2) selection of the dependent variable for the regression analysis, 3) estimation of the weight of each safety category/factor, 4) testing of the model for assumptions in multiple linear regression, and 5) testing of the significance of the final model. The regression analysis and evaluation of the safety management plans of the general contractor provided the basis for determining whether the general contractors give importance to the same safety factors as the workers did.

The surveys were administered between the months of June and September of 2005. The nighttime construction workers sampled were at jobsites in the states of Illinois, Ohio, and

Indiana. Less than three percent (2.8%) of the surveys came from outside the Midwest. Worker surveys were administered either directly on nine construction sites or obtained by mail and email from 107 nighttime construction workers. Initially 140 surveys were deployed for a response rate of 76.4%. Table 3.1 shows the distribution of the survey respondents by state.

Table 3.1 Worker Sample Distribution by State

State	Responses Received
Florida	3
Illinois	34
Indiana	60
Ohio	10
Total Number of Response Received:	107

Surveys were also distributed to 22 general contractors who have performed nighttime construction work in the past or present. To avoid having a sample of general contractors with different geographical and climate differences than the workers surveyed, 77% of the contractors surveyed were from the states of Illinois, Indiana, and Ohio. Safety directors, project managers, and project superintendents from the general contractor community participated in the survey. Eighteen surveys from 13 different general contractors were returned (response rate of 59%). Table 3.2 summarizes general information about the business characteristics of the 13 general contractors.

Table 3.2 General Contractor Sample Distribution

Company Identification	Annual Revenue Range (Million)	Number of Worked Hours (In a year)	Number of Night Hours Worked	Region of Country or National
A	> $750	9,509,491	950,944	Midwest & National
B	$250 - $500	---	50,000	Midwest & National
C	> $750	25,000,000	2,500,000	Nationwide
D	$50 - $250	---	---	Midwest
E	$50 - $250	1,800,000	---	Midwest
F	$50 - $250	1,226,328	1,000	Nationwide
G	$500 - $750	700,000	2,500	Midwest
H	> $750	5,000,000	800,000	Nationwide
I	$50 - $250	300,000	3,000	Midwest
J	< $50	---	1000	Midwest
K	$50 - $250	400,000	1,200	Midwest

Based on the analyses of surveys and observations of nighttime construction operations, three components of safety management were obtained – (a) a model for gauging the safety of nighttime construction operations from the perceptive of workers, (b) an evaluation of safety management strategies for general contractors, and (c) identification of key mitigation strategies from the perspective of workers. The following sections describe these components.

3.1. Model of Nighttime Construction Safety from the Perception of Nighttime Construction Workers

The survey distributed to nighttime construction workers asked them to rate (based on a five-point scale) their perception of safety while performing their job during nighttime hours. The overall safety score, i.e., safety perceived by workers on-site (score), was the dependent response variable in the analysis. A multiple linear regression model was used to evaluate the worker's perspective of overall safety on a nighttime construction jobsite and to determine which safety factors have the largest influence on the worker's safety perception. The factors selected for the safety assessment were divided into different categories as listed in Table 3.3. Variables such as age, experience, and gender were excluded as explanatory variables within the model. The associated safety cost factors were the independent, explanatory variables.

Table 3.3 Summary of Explanatory Variables in General Model

Safety Category	Explanatory Variables (Abbreviation used in Model)
Safety Training	Worker receives OSHA 10-hr training (*st*)
	Worker attends pre-activity safety meetings (*st2*)
Personal Protective Equipment (PPE)	Worker required to wear PPE (*ppe2*)
	Level of safety felt by a worker from wearing PPE (*ppe*)
Lighting	Site lighting for the worker to feel safe (*light*)
	Worker experiences adequate communication difficulties from lighting (*light3*)
Traffic Control & Law Enforcement	Traffic control devices exist on the project (*tc*)
	Law enforcement is available on site for traffic mitigation (*le*)
Off-Site Safety Management	Required mandatory drug testing for workers (*dt)*
	Disciplinary action program for unsafe practices (*sm*)
	Safety incentive program is available (*sm2*)
	Additional pay to the worker for working at night (*ap*)
	Worker is too tired to drive home at night (*tired*)
Accident History	Worker has been involved in an accident during nighttime work (*ai*)
	Worker has been injured working construction before this project (*ai2*)
On-Site Safety Management	Worker’s perception of the level of care by the supervisor about the safety of his workers (*ossm*)

The relationship between the response variable and the independent variables, the explanatory variables, was evaluated using SAS software to perform a statistical analysis. The statistical analysis assumes the data acquired from the worker surveys fits the multiple linear regression model shown in Equation 3.1:

$$Score = \beta_0 + \beta_1 st + \beta_2 st2 + \beta_3 dt + \beta_4 ppe + \beta_5 ppe2 + \beta_6 light + \beta_7 light3 + \beta_8 tc + \beta 9le + \beta_{10} sm + \beta_{11} sm2 + \beta_{12} ap + \beta_{13} tired + \beta_{14} ai + \beta_{15} ai2 + \beta_{16} ossm + \varepsilon_i \tag{3.1}$$

where:

Score represents the overall safety score of the nighttime construction worker from the worker's perspective; and the estimated β coefficients represent the increase or reduction of the safety score by each safety factor, or explanatory variable

β_0 is the intercept;

β_1 and *st* are the regression coefficient and associated explanatory variable identified in Table 3.3; and

ε_i *represents* the error term.

The significance of the factors and fitness of the model in multiple linear regression were then evaluated using the correlation between the response and explanatory variables, the wellness of fit of the model for multiple linear regression by assessing the F-value and *p-value* in the ANOVA analysis, the *p-value* of each explanatory variable, and the R^2 value, respectively. For a 95% confidence level, *p-values* less than 0.05 in the ANOVA table signify that the regression model is significant. The ANOVA table output had an F-value of 3.44 and a *p-value* of 0.004. A *p-value* less than 0.05 indicates that the multiple linear regression model in Equation 1 is a good fit for the data and that the analysis is significant. (Kutner et al. 2005)

The p-values of each explanatory variable were evaluated to do a preliminary determination of which explanatory variables were the most significant in predicting the safety score (i.e., the selection criteria discussed later actually choose the subset models). Since all 16 explanatory variables were included in the model, the *p-values* of each explanatory variable could be compared to each other to determine the significance of the individual explanatory variables versus the other explanatory variables. For this portion of the preliminary analysis, a liberal significance value of 0.35 is chosen and any explanatory variables with p-values less than 0.35 are considered potentially interesting. The explanatory variables deemed potentially significant in the general model based on the liberal p-value criteria are *st2*, *ppe*, *ap*, *tired*, and *ossm*.

The R^2 value signifies the amount of variation of the response variable explained by the model. When all 16 of the explanatory variables were included in Equation 1, then 52.92% of the variation of the data may be explained. The high value of R^2 indicates that Equation 1 fits the data well. Hence, a subset of Equation 1 needs to fit the data equally or nearly as well as all 16 explanatory variables.

The subset of explanatory variables consists of the most significant variables that explain the safety score of the workers. By eliminating extraneous variables that add little to explain the variation of the response variable, some of the highly correlated variables could be eliminated. Four different criteria are used to select the subset model: (1) R^2, (2) Mallow's C_p criterion, (3) AIC, and (4) SBC. The subset models were generated and Table 3.4 shows the values for the four criteria in each of the best two subset models for each number of explanatory variables, i.e., the two best subset models with one explanatory variable, the two best subset models with two explanatory variables, etc., in the model.

Table 3.4 Values of Selection Criterion Parameters

# in Model	R^2	C(p)	AIC	SBC
~~1~~	~~0.3147~~	~~9.3281~~	~~-25.1256~~	~~-20.74626~~
~~1~~	~~0.1850~~	~~22.8211~~	~~-13.6907~~	~~-9.31143~~
2	0.4204	0.3279	-34.1803	-27.61131
~~2~~	~~0.3666~~	~~5.9244~~	~~-28.3251~~	~~-21.75618~~
3	0.4683	-2.6561	-37.8713	**-29.11269**
3	0.4591	-1.7024	-36.7437	-27.98504
4	0.4971	**-3.6537**	-39.5465	-28.59821
4	0.4955	-3.4917	-39.3426	-28.39434
5	0.5156	-3.5792	**-40.0200**	-26.88210
5	0.5019	-2.1567	-38.1837	-25.04582
6	0.5187	-1.9098	-38.4542	-23.12665
6	0.5184	-1.8750	-38.4084	-23.08083

Three subset models were identified from the selection criteria (bold entries in Table 3.4). Table 3.5 summarizes the three-subset models and the explanatory variables in each of the subset models.

Table 3.5 Three Best Subset Models of Equation 4.1 for the General Model

Model Identification Number	Number of Explanatory Variables	R^2	Variables in the Model	Selection Criteria Met
1	3	0.4683	*ppe, ap, ossm*	*SBC*
2	4	0.4971	*ppe, ap, ossm, st2*	*C(p)*
3	5	0.5156	*ppe, ap, ossm, st2, tired*	*AIC*

A multiple linear regression was performed on each of the three subset models identified by the C_p, AIC, and SBC selection criteria. Four criteria were used to choose the third model as the best subset model: 1) the highest R^2 value of the three subset models, 2) the highest adjusted R^2 value of the three subset models, 3) the *p-value* for the ANOVA analysis was significant, and 4) all of the explanatory variables in the model were significant at a 0.15 significance level. Table 3.6 summarizes key aspects of the SAS output for each of the three-subset models.

Table 3.6 Comparison of Models from the Subset Analysis

	Model 1	Model 2	Model 3
F-value for ANOVA Table	18.20	15.07	12.77
p-value for ANOVA Table	<0.0001	<0.0001	<0.0001
Explanatory Variables: p-values for parameter	ppe: <0.0001	ppe: <0.0001	ppe: <0.0001
	ap: 0.0213	ap: 0.0137	ap: 0.0267
	ossm: 0.0010	ossm: 0.0029	ossm: 0.0022
		st2: 0.0664	st2: 0.1203
			tired: 0.1353
R^2	0.4683	0.4971	0.5156
Adjusted- R^2	0.4425	0.4641	0.4752

The R^2 value corresponding to Model 3 is 0.5156, i.e., signifying that 51.56% of the variation of the response variable is explained by model three. The R^2 value in Model 3 (51.56%)

was close to the R^2 for the model including all 16 explanatory variables (R^2 = 52.92%). The predicted safety score based on the worker's perspective (on the i^{th} construction site) is represented as shown in Equation 3.2:

$$\text{Score}_{\text{ith}} = -0.25743 + 0.46257\,ppe + 0.40319\,ap + 0.43255\,ossm + 0.4225\,st2 - 0.29141\,tired \quad (3.2)$$

Equation 3.2 is the fitted model. The negative sign on the coefficient before the *tired* explanatory variable signifies that safety on a nighttime construction site is lowered when the workers are very tired at the end of their shift to drive home. Additional variables *ppe*, *additional pay* (*ap*), supervisors caring about the safety of their employees (*ossm*), and *pre-activity safety meetings (st2)* all significantly and positively contribute to safety on a nighttime construction site according to the workers. Although the coefficients of each of the explanatory variables in the model are almost equivalent to each other, the values that the explanatory variables may take are different. *ppe* and *ossm* take values on a scale of one to five whereas *tired*, *ap*, and *st2* are binary explanatory variables that take a value of either one or zero.

The assumptions (regarding linearity, constant variance and normal errors) were tested in order to determine whether or not the error term (ε_i) was identically and independently normally distributed with a mean of zero and a variance of σ^2. These assumptions were found to be valid; thus, the multiple linear model in Equation 3.2 was concluded to be valid and multiple linear regression was determined to be the appropriate mode of analysis in this portion of this study.

3.2. Analysis of Safety Management Philosophies and Strategies for General Contractors

A survey was distributed to general contractors in order to gather information about their nighttime construction safety management philosophies and safety practices, in order to determine the different safety practices used most often by comparing the safety management techniques of different general contractors. Six categories of general contractor's safety management plans were compared: 1) pre-construction, safety-related policies, 2) safety training, 3) safety incentive programs, 4) accident investigation, 5) perception of owner involvement in safety management, 6) perception of safety on the jobsite for the nighttime construction workers. Table 3.7 summarizes the responses from the general contractors in the first four categories.

Table 3.7 Summary of a Portion of the General Contractors Survey Responses

Category	Question	Yes	No
Pre-Construction, Safety-Related Policies	Does the contractor have a written safety program?	100% (13 of 13)	0% (0 of 13)
	Does the contractor have a safety committee?	84.6% (11 of 13)	15.4% (2 of 13)
	If the contractor had a safety committee, is their a member of the construction workforce on the committee	81.2% (9 of 11)	18.8% (2 of 11)
	Are safety records a criteria for pre-qualification of subcontractors	76.9% (10 of 13)	23.1% (3 of 13)
Safety Training Requirements	Is the contractor's staff (i.e., foreman, superintendent, project manger) required to receive OSHA-10hr training?	69.2% (9 of 13)	30.8% (4 of 13)
	Does the contractor use the practice of toolbox meetings?	100% (13 of 13)	0% (0 of 13)
	Does the contractor use the practice of pre-wok safety meetings (e.g., before excavation)?	92.4% (12 of 13)	7.6% (1 of 13)
Safety Incentive Program	Does the contractor have a formal safety incentive program?	84.6% (11 of 13)	15.4% (2 of 13)
Accident Prevention Mechanisms	Does the contractor agree that the investigation of accidents after their occurrence could improve safety performance on the jobsite?	100% (13 of 13)	0% (0 of 13)
	Does the contractor have a formal document explaining the procedures to investigate accidents and near misses?	76.9% (10 of 13)	23.1% (3 of 13)

Pre-construction and Safety-Related Policies: The category pre-construction and safety-related policies included questions about the contractor's safety program, safety committee, and pre-qualification of subcontractors. All of the respondents to the general contractors' survey were safety conscious and used a general safety program for all employees. The general contractors having safety committees indicated that the personnel included on the committees were employees with different job descriptions, responsibilities, and different positions in the management hierarchy of the general contractor's structure This enabled the committees to gain safety information from a variety of perspectives about safety. Sixty-nine percent of all responding contractors and eighty-one percent of responding contractors with safety committees included craft workers, tradesmen, or general laborers on the safety committee enabling the workers to voice concerns about on-site safety from a firsthand perspective. The administration of safety strategies on the construction jobsite by the subcontractor was perceived to be a direct reflection of the safety requirements imposed and enforced by the general contractor. Seventy-seven percent of the general contractors responding to the survey indicated that safety records were required by subcontractors as pre-qualification.

Safety Training Requirements: The safety management plans of general contractors tend to include safety training for new employees or refresher courses for all employees. Only 70% of the general contractors indicated requiring their personnel to be certified in OSHA 10-hr training; thus, not all personnel on a construction site have the same type of safety training (i.e., OSHA-10hr training) as the nighttime construction workers. As shown further in Table 3.7, 92.4% of the general contractors used the practice of pre-work safety meetings and all of the general contractors used the practice of toolbox meetings.

Safety Incentive Programs: According to the CII document titled "Zero-Accident Technique" (Liska et al. 1993), safety incentives are useful in reducing accidents on construction jobsites. 84.6% of the general contractors surveyed had a formal safety incentive program and the two general contractors reporting no formal incentive program were the smallest of the responding contractors (based on their annual revenue). The incentive programs described by the general contractors varied as to who was rewarded for safe practices on the construction jobsite, how rewards were determined, and the types of rewards received. In general, higher cash rewards for good safety performance tended to be awarded to the general contractors' staff according to the responses. Construction workers typically received gifts, meals, clothing items, or small cash amounts.

Accident Prevention Mechanisms: CII's document "Zero-Accident Techniques" (Liska et al. 1993) cited accident investigation as a key component in eliminating accidents, indirectly managing safety, on construction jobsites by identifying the causes (reasons) of the accident. Two of the three general contractors who did not have a formal process for accident investigation were the smallest companies by revenue, indicating that the size of the company may directly influence how many formal documents are used. All the general contractors surveyed routinely performed formal jobsite investigations; but the frequency of formal jobsite inspections varied by general contractor.

Perception of Owner's Role in Safety Management

The owner has direct influence on the safety practices of a general contractor and may require inclusion of specific safety provisions in the contract documents. To determine the level of interest of the owner, the general contractor was asked how frequently the owner becomes involved in the safety aspects of the project. Overall, the general contractor perceives the owner as having limited involvement in safety on the construction jobsite as shown in Figure 3.1.

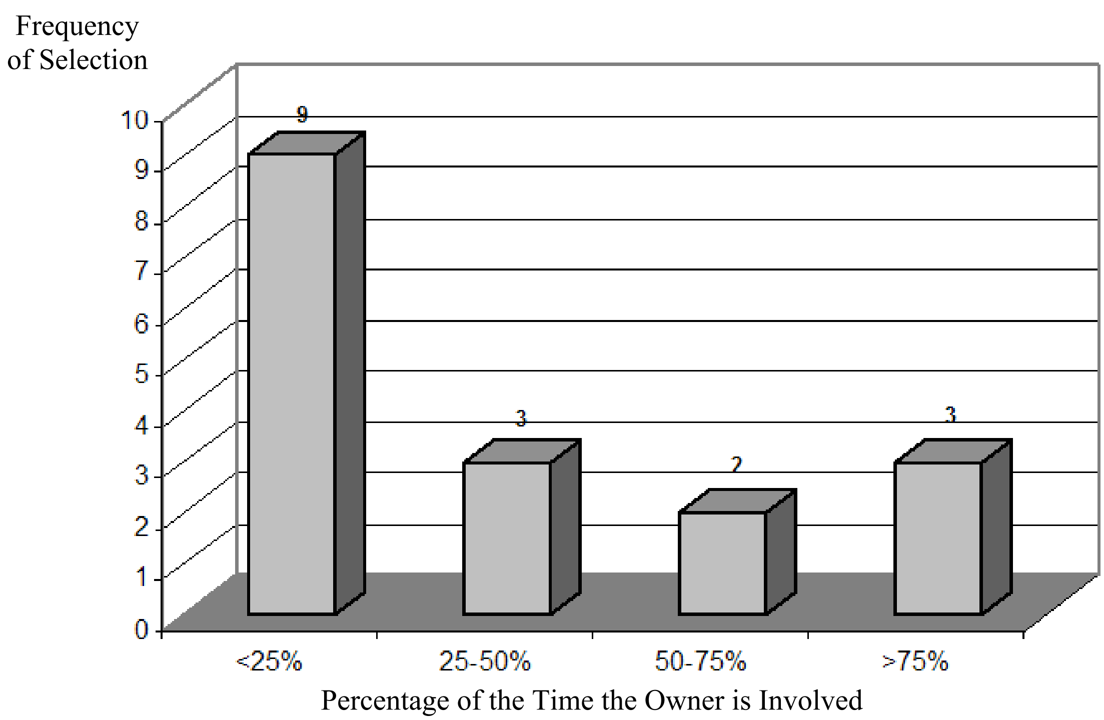


Figure 3.1 Frequency of Owner Involvement in Safety-Related Aspects from the Perspective of the General Contractor

Nine of the respondents (52.9%) perceived owner involvement in safety-related aspects to be less than 25% of the time. From the perspective of the general contractor respondents, owners have the potential to participate in safety more than they do at present.

3.2.2. Self Perception of Safety on the Jobsites

General contractors are responsible for the safety of the project managers, superintendents, foremen, and other personnel that the general contractor places on the nighttime construction jobsite. The general contractors were asked to rate the level of safety on a nighttime construction worksite for the workers on a five-point scale (with 1 signifying “unsafe” and 5 signifying “completely safe”). Eighteen respondents (100%) to the general contractor’s survey rated the jobsites as an average of 4.28 on the level of safety. Figure 3.2 shows the frequency of the responses.

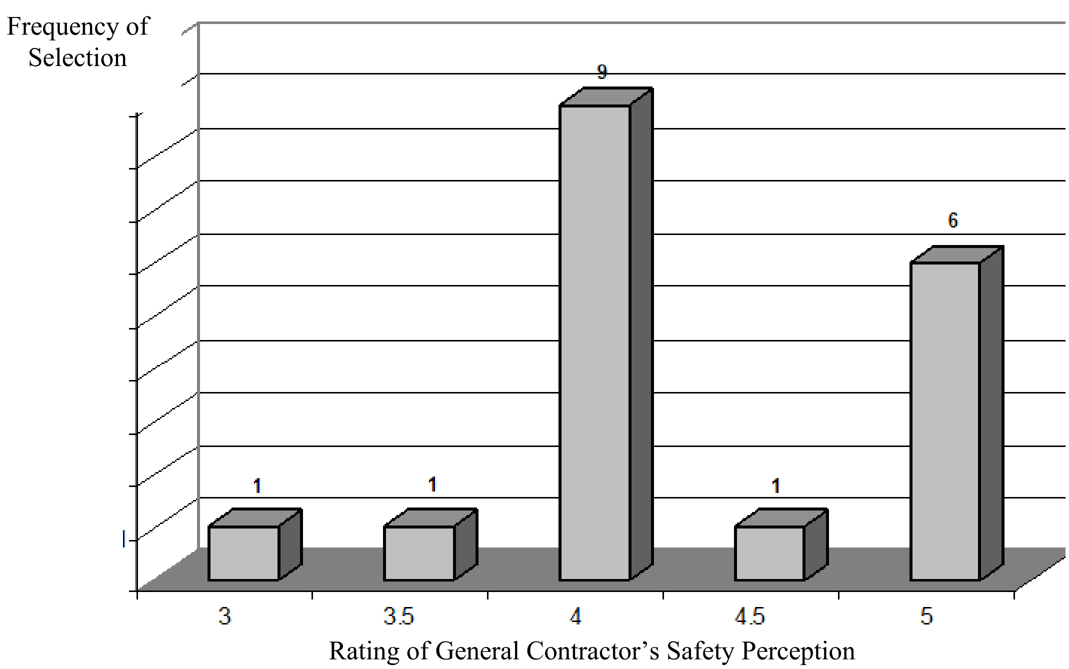


Figure 3.2 General Contractor’s Perception of the Safety of the Nighttime Construction Site

All of the respondents to the general contractor's survey rated their jobsites as a minimum of three (in terms of safety, half-way between "unsafe" and "completely safe") for the nighttime construction workers, with more than half of the general contractors (50%) perceiving their jobsites to be close to completely safe for workers (safety rating of 4).

3.3. Accident Prevention from the Workers' Perspective

To prevent unsafe activity on nighttime construction jobsites, the root causes of worker accidents must be identified. Additionally, the reasons why a worker engages in unsafe practice must be determined before effective methods to prevent workers from engaging in unsafe practice can be developed. Nighttime construction workers are able to give a firsthand perspective of the importance of unsafe construction practices. In this portion of the study, each nighttime construction worker was asked to choose three unsafe construction practices (from the predetermined list) that are principal causes of accidents and fatalities in nighttime construction from their perspective. This list was developed based on findings by Liska et al. (1993), Matos (2004), and Irizarry (2005). Table 3.8 presents quantitatively the distribution of the responses.

Table 3.8 Potential Causes of Unsafe Practices from the Nighttime Construction Worker Perspective

Potential Causes of Unsafe Practices	Number of Workers Selecting this Option	Percentage of Total Selections
General Public Irresponsibility *	56	20%
Lack of Lighting	55	19.64%
Workers' Irresponsibility **	43	15.36%
Lack of Communication	33	11.79%
Lack of Proper Training	25	8.93%
Misuse of Personal Protective Equipment	20	7.14%
Insufficient Traffic Control	20	7.14%
Other***	16	5.71%
Insufficient Personal Protective Equipment	7	2.50%
Lack of Supervision	5	1.79%

*In the surveys, general public irresponsibility was defined as any unsafe practice caused by a member of the general public not associated with the nighttime construction project nor associated with a worker employed by the general contractor or owner.
**Worker irresponsibility was defined as an unsafe practice caused by a worker employed by the general contractor that the general contractor for which safety mitigation techniques was in place to prevent. An example of worker irresponsibility would be the case when a worker injuries his leg because he failed to tie off when working over 20 feet above the ground and for which safety training had been provided to convey the importance of tying-off.
***Enables survey respondents to fill in their own personal opinions for other causes of unsafe practices.

By focusing on the most important causes of accidents, safety planning and training may address such causes. The workers most frequently selected general public irresponsibility (20%) and lack of lighting (19.64%) as the most significant causes of unsafe accidents on nighttime construction jobsites. The three most frequently selected unsafe practices were (a) lack of lighting (19.64%), (b) worker irresponsibility (15.36%), and (c) lack of communication (11.79%).

3.4. Mitigation Strategies from Two Distinct Perspectives

General contractors seek to use the mitigation strategies that they believe (based on their experience) are most likely to prevent the occurrence of accidents. Ten safety strategies were identified from previous literature, personal communication with the Indiana Department of Transportation Employees, and Table 3.9 (Liska et al.1993, Hayes and Monroe, personal communication, May 9, 2005).The general contractors and workers were asked in the surveys to score the level of importance of each of the ten preventive measures using a ten-point scale (1 signifying “it does not help my safety” to 10 signifying “it is essential to my safety”).

Table 3.9 Identification of Factors Influencing Safety of Nighttime Construction Operation

Safety Factor	Importance of Factor	Research Studies
Category 1: Construction Worker Welfare		
Safety Training	Information provided to the worker through training increases safety awareness and alerts workers to potential hazards on construction jobsites.	Liska et al. (1993)
Sleep Deprivation	Proper amounts of quality sleep for the worker improves judgment and awareness on the jobsite at night. When working with heavy machinery and construction equipment, the safety of a worker and his co-workers potentially can be impaired by an exhausted worker.	Holquin-Veras et al. (2001)
Circadian Rhythms	The body wants to sleep at night, when it is dark, because of natural circadian rhythms. These rhythms need to be ignored by the worker at night. Improper sleep during the day leads to tired workers.	Holquin-Veras et al. (2001)
Category 2: Worker and Jobsite Visibility		
PPE	Hardhats, reflective clothing, gloves, etc. protect workers from potential construction hazards and identify the location of the workers in the darkness on a jobsite.	Servatius (1996), Cottrell (1997), MNDOT (1997), Pratt et al. (2001)
Lighting	Activities performed should be visible to the workers and motorists. Lighting may help offset worker fatigue experienced due to disrupted circadian rhythms. Proper lighting lowers glare for the traveling motorists.	Ellis et al. (2003), El-Rayes and Hyari (2003)
Communication	Construction personnel need to exchange and receive directions, instructions, and feedback.	Toole (2002)
Category 3: Traffic Work Zones		
Reduction in Jobsite Area	The work area of a traffic zone is smaller at night, because the worker has to provide sufficient “buffer” between themselves/work zone and moving traffic.	Al-Kaisy and Hall (2000)
Proper Signage	Without properly placed and visible signage, motorists are sometimes unable to see the worksite until it is too late.	Cottrell (1997)

Traffic Control Devices	Through proper placement of these devices, motorists are given information as to where the work zone is located.	Cottrell (1997)
High Roadway Traffic Speeds	Motorists traveling at high speeds through the work zones can cause injury to the driver and workers if they lose control of their vehicles.	Cottrell (1997)
Category 4: Safety Management Philosophy of General Contractor and Owner		
Commitment of Employer to Safety	According to OSHA's accident causation levels, ineffective safety management by the employer has the potential to lead to worker accidents.	Koehn and Surabhi (1996), OSHA (2005)
Accident Investigation	Accidents are investigated to determine the root causes. Strategies are put in place to prevent the root causes from occurring to prevent future accidents.	Liska et al. (1993), Hinze et al. (1998), Toole (2002), OSHA (2005)
Safety Incentive Programs	Incentives have the potential to raise safety consciousness and motivate workers to perform all actions safely.	Liska et al. (1993)

A multiple linear regression model, with safety score as the response variable and the various mitigation strategies as the explanatory variables, was ineffective for this analysis. The R^2 coefficient is quite small for this multiple linear regression analysis and no subset model is statistically significant. Thus, a regression analysis was uninformative on the mitigation strategies. Therefore, a simple comparison was performed. The values calculated for the contractors and workers were compared to each other to identify if potential gaps existed in the scoring of each mitigation strategy between the two groups. Figure 3 shows the distributions of the average scores of the contractors and workers for each safety mitigation technique or safety practice.

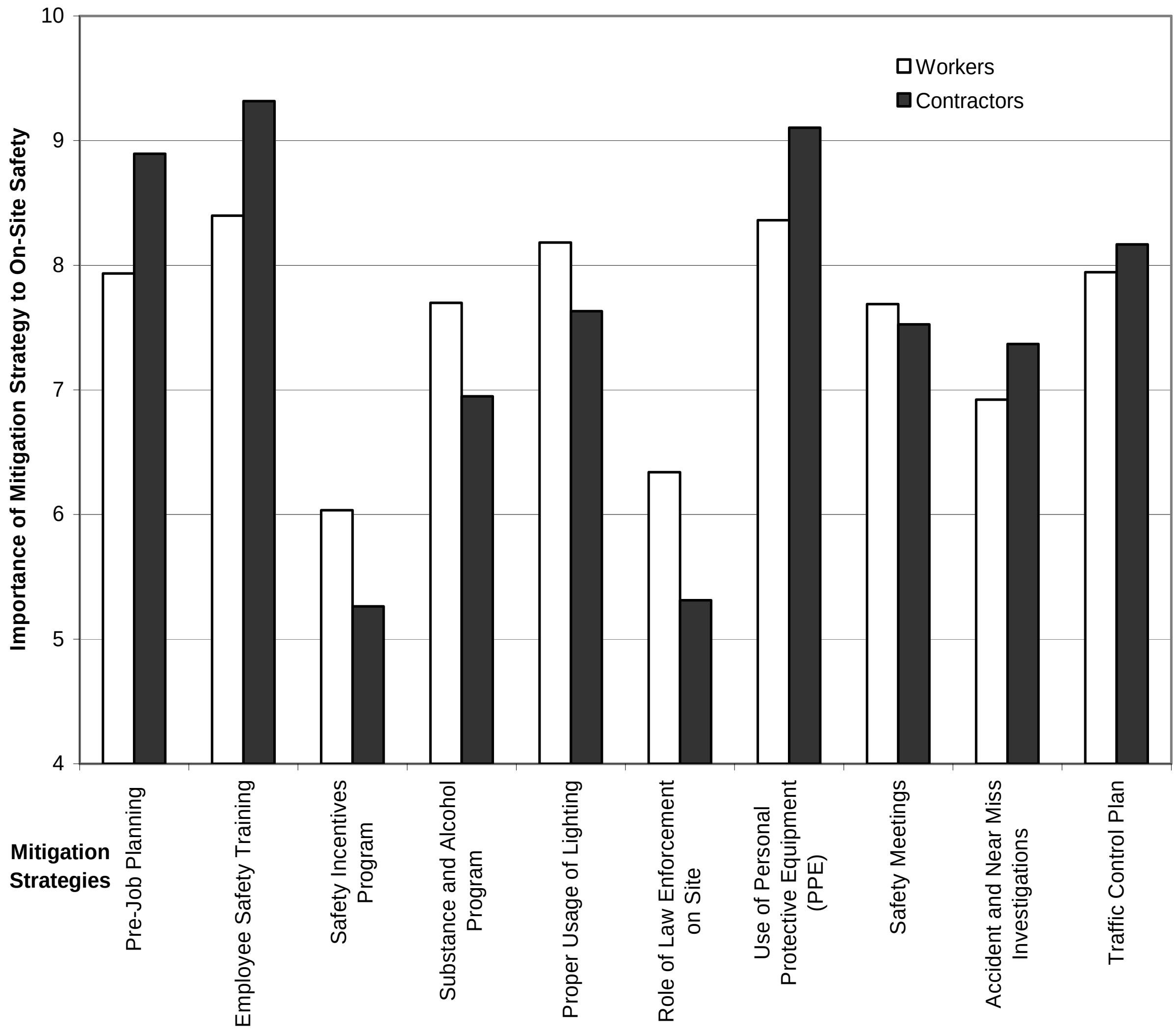


Figure 3.3 Comparison of Mitigation Strategies from Two Perspectives (General Contractors, n =18, and Workers, n=107)

For most mitigation strategies, the workers gave relatively similar average scores than the general contractors did. The largest difference of average scores exists in the role of law enforcement on site, with a difference of 1.03 existing between the average scores of the workers and the contractors. Compared to the workers' average scores, the contractors' spread of average scores was much more drastic. Table 3.10 displays the five highest average scores from the contractors and the workers.

Table 3.10 Comparison of Highest Average Scores: Perspectives of the Contractor and Worker

Ranking	Contractor	Worker
1	Employee Safety Training	Employee Safety Training
2	Use of personal Protective Equipment	Use of personal protective Equipment
3	Pre-Job Planning	Proper Use of Lighting
4	Traffic Control Plan	Traffic Control Plan
5	Proper Use of Lighting	Pre-Job Planning

The contractors and the workers assigned the highest scores to the same five mitigation strategies. However, the order of the mitigation techniques, by average score, was different in each of the perspectives. The contractors and workers agreed that employee safety training and use of personal protective equipment were the most essential mitigation strategy for personnel and workers on nighttime construction sites.

3.5. Conclusions

The safety management practices of the general contractor heavily influence the perception of safety of nighttime construction workers. Workers and general contractors have similar perceptions about the strategies necessary to improve safety on the nighttime construction jobsite. Further, the mitigation strategies chosen by both groups are similar to the safety factors that significantly influence the nighttime construction worker's perception of safety.

The safety factors identified in the multiple linear regression performed on the data collected from the workers indicated that PPE, pre-activity safety meetings, sufficient lighting, the level of care of their supervisor felt by the worker, and how tired the worker feels to drive at the end of their shift were all statistically significant. Some of these factors are already incorporated into general contractor's safety management practices (i.e., PPE, and pre-activity safety meetings). Other factors (i.e., sufficient lighting standards, improving supervisor's concern for their worker's safety, and mitigation strategies to prevent tired worker accidents while from driving home), should be incorporated into safety management practices to improve not only the safety level perceived by the worker on a nighttime construction jobsite, but also the actual safety environment on site.

Workers identified PPE as a significant safety factor and both groups surveyed identified its use as important for nighttime construction safety. Pre-activity safety meetings, employee safety training, and the proper use of lighting were identified as significant safety factors from the multiple linear regression analysis. In addition, it was also found that the perception of the nighttime construction workers is significantly influenced by the illumination of the jobsite.

3.5.1 Limitations

The scope of this portion of the study was limited primarily to the tri-state Midwest region. Thus, the information gathered may not include important nighttime safety factors that may be relevant for other regions in the United States, to account for parameters such as weather conditions, communication issues, type of project, etc. These limitations precluded the inclusion of variables such as location, weather, and average temperature in the analysis. Additionally, since the majority of construction is not performed at night, the percent of general contractors performing nighttime construction work is limited. Also, almost all of the respondents to the general contractor survey had EMR values less than 1.00, signifying that the pool of respondents tends to have higher safety records. Typically over half of general contractors have EMR values greater than one (1.00 being the average EMR for a general contractor). The analysis identified irresponsible behavior from the general public (i.e., driving under the influence, speeding through work zones, and ignoring signs where construction workers are working) as a significant cause of accidents involving nighttime construction workers. No information was gathered from the general public about the effectiveness of traffic control zones, identification of the nighttime construction workers in the darkness, or the level of glare.

3.5.2 Recommendations

Special consideration is needed to be given to the distinct safety attributes associated with the maintenance workers performing a variety of work tasks in each individual shift. The development of a nighttime safety training program for INDOT's maintenance crews is highly recommended. A sufficient sample of surveys from nighttime construction workers that are part of maintenance crews should be distributed, collected, and analyzed to determine the best model for this subset of roadway workers. Also, additional explanatory variables directly relevant to maintenance crews should be included in the model. Examples of these explanatory variables include the safety perception of the worker during each work task, the size of the work zone, the safety perception of the worker about the speed of traveling motorists, and quantitative speed data collected about the motorists traveling through maintenance work zones.

Frequently, the safety threat presented by the general public is cited by nighttime construction workers as making them feel unsafe on the jobsite. The safety perspective of the general public also needs further examination to determine what the opinion/awareness of the general public are relative to safety of nighttime construction workers and operations. Also, methods to raise the awareness of the general public about nighttime construction are needed in order to improve the safety of the nighttime construction workers from the dangers imposed by the general public.

The multiple linear regression analysis of the construction worker survey indicated that the amount of illumination of the job site is a significant variable on the worker's perspective of safety on a nighttime construction jobsite. One of the goals of the NIOSH study is the improvement of lighting on nighttime construction jobsites. This portion of the research verified the importance of lighting, especially on roadway projects. By determining best practices for lighting on nighttime construction jobsites, the communication on the jobsite can improve. Workers will have better visibility of their supervisors, other workers, and the location of equipment on the jobsite and can clearly observe the activities being performed. Improved communication on nighttime construction jobsites should improve the level of safety on the jobsite. Limited involvement of the owners on nighttime construction jobsites was frequently cited by general contractors as a possible reason to explain failures in the safety procedures. A study of contract documents for nighttime construction jobsites should be performed to determine what the owner requires of general contractors in terms of safety. To improve owner involvement in safety planning, owners could require specific safety mitigation strategies within the contract documents, and owners could utilize the money saved due to reduced congestion for improvement of working conditions and thereby improve the level of safety for the nighttime construction workers.

The final recommendation for future research is the development of best practice guidelines for nighttime construction. The guidelines would inform general contractors about unique nighttime safety parameters. The best practices guidelines should include a list of unique problems frequently encountered on nighttime jobsites and methods to implement that address each of the problems. Extensive research should be performed to identify methods that address the frequent problems encountered on nighttime construction jobsites during the development of the best practices guidelines.

CHAPTER 4. EVALUATION AND ASSESSMENT OF NIGHTTIME TRAFFIC CONTROL PLANNING

The previous chapter evaluated safety management philosophies from the owner, contractor and worker perspective. The results provided insight into ways to improve general planning on nighttime work zones. The analysis prescribed in this chapter supplements the previous chapter and investigates nighttime safety issues as they relate specifically traffic control. The research steps as they relate to the research framework for this portion of the study are illustrated in Figure 4.1.

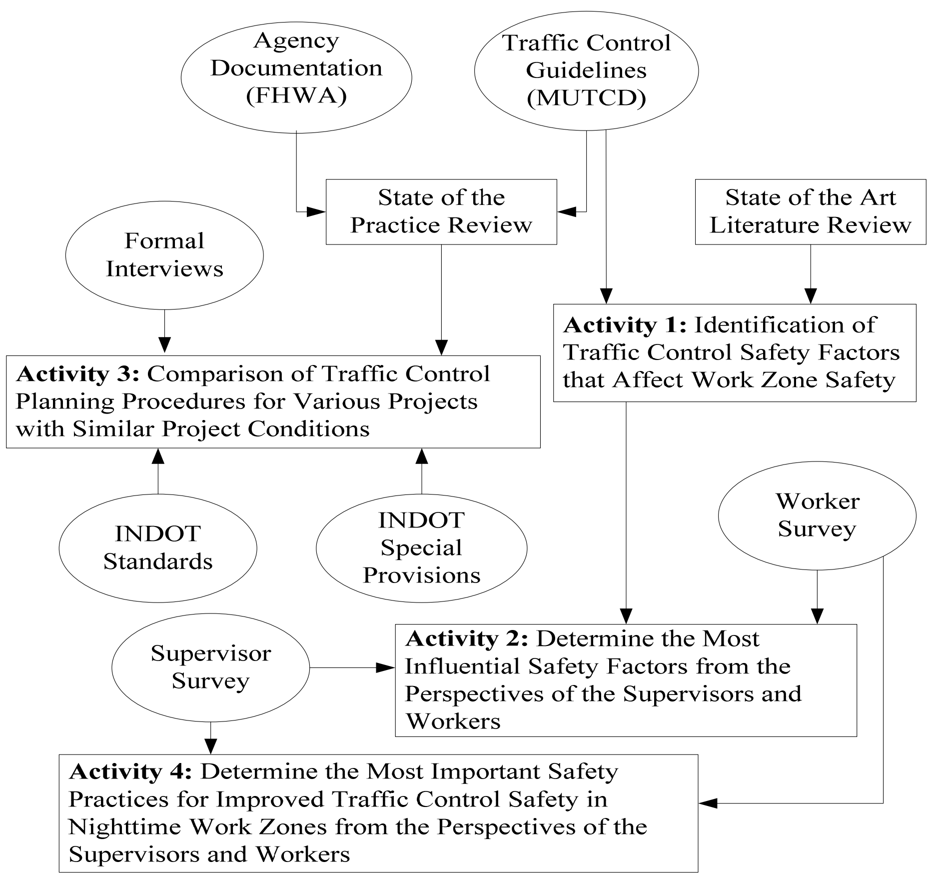


Figure 4.1 Research Activities in Relation to the Research Framework

4.1. Methodology

This portion of the study investigates planning and implementation procedures for nighttime traffic control. The following section identifies the primary entities involved and their roles in both phases of the project. Based on each of the entities respective roles and the information identified during the literature review formal interviews were conducted and surveys were developed. This section also provides and overview regarding survey development, administration and the formal interviewing process.

4.1.1. Entities Involved During Nighttime Traffic Control Planning

The designers responsible for work zone traffic control plans are assigned with the task of developing safe traffic flow for the road users while maintaining a safe work environment for those in the work zone. The designer must follow the traffic control guidelines established by the highway agency, which the designer must trust will provide support in deciding design alternatives (e.g., detours, crossovers, lane closures).

A survey was developed for the designer to determine the level of involvement the designer had in planning. Some of the issues that were addressed in the survey were the guidelines used in design, traffic control plan characteristics and special considerations. The designer was also asked to identify the extent of the implementation for each issue and the traffic control planning costs for the project. A copy of the designer survey is provided in Appendix D.

Survey administration consisted of administering surveys to the traffic control designer via email and mail in Indiana during the months of August and September 2005. The designer sample pool included INDOT design engineers, ODOT design engineers, and Indiana design consultant firms. The designers surveyed were involved in the development of traffic control plans specific to either nighttime work or both daytime and nighttime work shifts. A zero response rate was received from both the design consultants and the DOT design engineers.

Previous research led this researcher to believe the majority of traffic control design engineers were employed by transportation agencies. The survey was designed for transportation engineers who could address project-specific questions. It was discovered during survey administration that the majority of traffic control plans for long-term stationary construction projects in Indiana are currently developed by design consultants if the traffic control requirements are not covered completely by INDOT's Standard Drawings and Specifications. Therefore, the design consultants felt the survey questions exceeded their scope of work, resulting in a zero response rate.

In order to assess the safety-in-design aspect of traffic control planning, formal interviews were conducted with INDOT's Greenfield District Construction Engineers and Indiana Contractors in early February 2006. These interviews allowed the researcher to further understand the design and review process, the roles of those involved, and the considerations used for nighttime work. Traffic control plans and specifications for similar nighttime construction projects were also reviewed. Intermediate stationary projects similar to those visited during survey distribution were chosen for assessment. The formal interview questionnaire that was developed is provided in Appendix G.

4.1.2. Entities Involved During Nighttime Traffic Control Implementation

The workforce involved in a construction project can be classified into two general positions; supervisor and worker. Supervisors are responsible for their own safety and the safety of the workers under their supervision, as well as the work being performed. The supervisor must ensure the company's safety regulations are implemented and that current safety practices and procedures are followed by the worker, which includes properly assigning and training a worker to perform an activity. The supervisor therefore expects that the company provides adequate safety policies for varying project conditions to support the safety decisions required for a safe work environment.

Highway agencies and contractors expect that workers in a work zone are responsible for completing their work in a safe and efficient manner, and that workers are aware of safety at all times. The worker must observe safety practice rules and instructions outlined by the company, which include following safety procedures for specific work activities, and attending frequent safety meetings and training. The worker expects the employer to maintain a safe work environment and to provide proper supervision over their work and safety.

Information identified through an extensive literature review and state-of-the practice review identified safety strategies for improved safety performance. The safety strategies for improved safety performance are summarized in Section 4.2.3 of this study. The reviews also identified traffic control safety factors. Spadaccini (2005) defined a safety factor as an action, practice, or condition that can affect both the safety of the worker and the general public. This study focuses on traffic control safety factors for nighttime construction and maintenance activities. A traffic control safety factor is defined as a traffic control action, practice, or procedure which affects the safety of a worker or the general public. These actions, practices, or procedures can be either directly related to traffic control (i.e., device selection, device maintenance, and safety training) or indirectly related (e.g., worker visibility and lighting requirements). Indirect factors can be classified as general construction safety factors or traffic control safety factors. For example, lighting is an important safety factor that provides the workers adequate visibility to complete tasks within the work zone. In this case, it is classified as a general construction safety factor. Lighting can also be classified as a traffic control safety factor when lighting provided could be inadequate for performing traffic control operations. A summary of the traffic control safety factors identified are shown in Table 4.1.

Table 4.1 Summary of the Traffic Control Safety Factor Categories

Category	Importance	Sources	Safety Issue (Explanatory Variable)
Design	Location of devices increases motorist awareness and ensures proper traffic flow control through the traffic space and within the activity area. Control of motorists' speed through the work zone decreases the potential for injury to the drivers and workers.	Pratt et al. (2001), MUTCD (2003)	1. Influence of work zone buffers on safety. 2. Availability of law enforcement. 3. Influence of law enforcement on safety.

TTC Maintenance	Competent personnel involved during temporary traffic control implementation and maintenance provide proper supervision during temporary traffic control operations.	Pratt et al. (2001), MUTCD (2003)	1. Traffic control devices properly maintained. 2. Frequency of routine inspections.
Worker Visibility	Proper retroreflective personal protective equipment establishes the location of workers and increases driver awareness.	Cottrell (1999), Pratt et al. (2001), MUTCD (2003)	1. Requirements for wearing PPE. 2. Influence of PPE on safety.
Lighting	Proper lighting reduces glare and decreases potential for driver accident, while improving workers' ability to communicate.	Cottrell (1999)	1. Adequate lighting for communication. 2. Adequate lighting to perform work.
Safety Training	Proper training increases worker safety awareness to potential safety hazards.	Liska et al. (1993), MUTCD (2003)	1. Pre-activity safety meetings are provided.

The information regarding the traffic control strategies for improved safety performance and traffic control safety factors was then used to develop a survey for the supervisor and the worker. A copy of both the supervisor and the worker survey are provided in Appendix E and F, respectively. The surveys were developed for both the highway agencies and contractors involved on nighttime construction and maintenance projects. Typical roadway construction projects include bridge construction and roadway paving, while roadway maintenance projects include roadway and bridge patching. Survey distribution focused in the Midwest due to similar project conditions. Survey distribution was divided into two activities; sampling of construction and maintenance workers. The supervisor and worker surveys for construction operations were administered via email, U.S. mail, and site visits from September 2005 through November 2005. Response rates are shown in Table 4.2.

Table 4.2 Construction Supervisor and Worker Response Rates by State

Respondent	Location	Reponses Received	Response Rate
Construction Supervisor	Indiana	17	100.0%
	Illinois	5	50.0%
Construction Worker	Indiana	27	75.0%
	Illinois	11	34.4%

Surveys were also administered to the supervisors and workers involved in nighttime maintenance projects in Indiana. The surveys were administered during site visits in January 2006. During the time this research was conducted, September 2005 to February 2006, only two maintenance crews performed night work in Indiana, both of which were located in the city of Indianapolis. A complete sample was obtained for the INDOT maintenance crews, which included two supervisors and 23 workers.

4.2. Data Analysis

The data analysis performed in this portion of the study is three-fold. The first analysis is a comparison of traffic control planning procedures for similar projects to determine current safety planning practices for nighttime operations. The second analysis uses multiple linear regression to determine the most influential traffic control safety factors from the supervisors' and workers' perspective. The final analysis determines traffic control strategies for improved safety performance from the perspectives of the supervisor and the worker. The following sections discuss the results from the individual analyses.

4.2.1. Project Assessment of Intermediate Traffic Control Zones

Traffic control planning for Indiana highway construction can range from detailed plans to referencing Standard Drawings, Standard Specifications, and the MUTCD. The design engineers at the Indiana Department of Transportation (INDOT) are responsible for initially addressing work zone traffic control for every project. Once the initial review of project conditions has been completed, the engineer will determine whether the traffic control design can be developed by INDOT, design consultants, or the contractor. In order to properly assess the traffic control planning procedures performed on nighttime projects, several current nighttime construction projects with similar project conditions and role assignments were identified. In February 2006, a preliminary interview with INDOT personnel identified five intermediate stationary traffic control work zones. Formal interviews were then conducted with INDOT designers, construction engineers, and contractors involved on the construction projects. The questionnaire is included in Appendix F. The project assessment consisted of two steps: (1) determining the primary steps in traffic control planning and implementation and the roles of the entities involved, and (2) comparing and contrasting the components of traffic control planning among the various projects. The results from the formal interviews allowed for the development of the traffic control planning and implementation process throughout an intermediate stationary construction project's life cycle. The process and the corresponding responsibilities of INDOT and the contractor are illustrated in Figure 4.2.

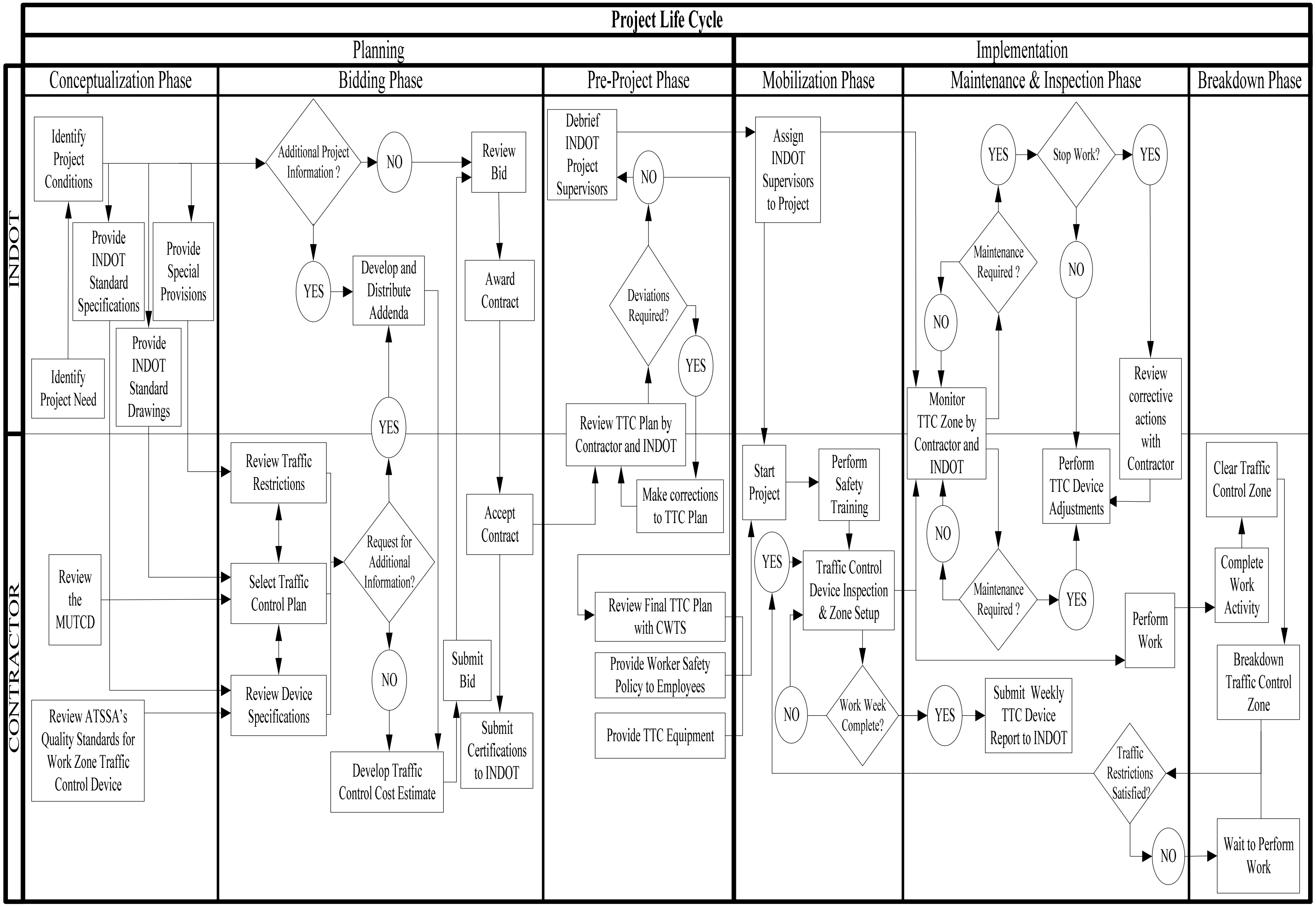


Figure 4.2 INDOT and Contractor Communication during Traffic Control Planning and Implementation

The traffic control planning and implementation process is divided into several phases: the conceptualization phase, the bidding phase, the pre-project phase, the mobilization phase, the maintenance and inspection phase, and the breakdown phase. Within each phase there are several steps which require coordination between INDOT and the contractor:

- *Conceptualization Phase*: INDOT engineers first determine the need for the construction project and evaluate the project conditions. The design engineer reviews INDOT's lane closure policy and determines the traffic restriction times. The restriction times are then included in the project's Special Provisions, with other project specific information that includes contractor submission requirements. Special Provisions also may supplement the Standard Drawings and Specifications. The Standard Specifications provide the contractor with information regarding traffic control device equipment specifications and construction requirements. Among these requirements, the contractor is required to provide an American Traffic Safety Service Association (ATSSA) Certified Worksite Traffic Supervisor (CWTS), certify that the traffic control devices meet NCHRP 350 crash standards, and complete weekly traffic control device reports during construction.
- *Bidding Phase*: This phase includes four distinct items: traffic control plan development, addenda, bid submission, bid award, and contract acceptance. The contractor will first reference the INDOT Special Provisions, INDOT Standard Specifications, INDOT Standard Drawings, the MUTCD, and ATSSA's "Quality Standards for Work Zone Traffic Control Devices," and from there develop a traffic control plan for the project. If the contractor has a request for additional information or INDOT has additional information regarding the work zone traffic control, the information is included in addenda. Based on the information provided to the contractor, an estimate is developed by the contractor. The contractor then submits the traffic control estimate in the project bid. The bid is reviewed by INDOT and a contract is awarded to the lowest responsible bidder. Upon the contract acceptance, the contractor submits the required certifications, which include the CWTS certification, contact information, and device certification.
- *Pre-Project Phase*: The contractor first reviews the traffic control plan with an INDOT engineer. If deviations are required by INDOT, the contractor provides the corrective actions to the traffic control plan. The INDOT engineer then debriefs other project supervisors. The contractor's CWTS or representative also debriefs their supervisors.

- *Mobilization Phase*: Once the project is approved by INDOT to start, the contractor mobilizes equipment, materials, and workers. The contractor's supervisors debrief the workers and provide adequate training for the work activities, which includes review of the work zone limits and traffic control device setup and breakdown. The CWTS then performs the initial traffic control layout and ensures that the traffic control devices meet acceptable ATSSA quality standards.
- *Maintenance and Inspection Phase*: This phase includes monitoring the traffic control zone during work operations. The contractor is responsible for ensuring the integrity of the traffic control zone by inspecting and maintaining the traffic control devices. If an INDOT supervisor deems the devices or layout is unsafe or non-conforming with INDOT standards, the supervisor can cease all work until the contractor has performed the necessary corrective actions.
- *Breakdown Phase*: This phase consists of two distinct activities: clearing the traffic control zone and breakdown of the traffic device equipment. The contractor first completes the work activity and properly removes those working within the work zone. The contractor then removes the traffic control device equipment required for removal by the INDOT specifications and provisions. The contractor must comply with the lane closure and traffic restriction stated in the Special Provisions, providing a sufficient amount of time to perform these operations in a safe and efficient manner.

The five projects and their project characteristics are summarized in Table 4.3. The projects were state-funded asphalt resurfacing projects performed at night on interstate highways and high volume state roads. Three contractors were involved on the five projects, which were completed in the 2005-2006 timeframe.

Table 4.3 Nighttime Intermediate Stationary Project Summary

Project	Location	Contractor	Project Completion	Contract Value	Traffic Control Contract Percentage
1	I-70	Contractor X	May 2006	$1,567,000	8.07%
2	US31	Contractor Y	April 2005	$896,442	2.21%
3	I-65	Contractor X	Nov 2005	$2,815,900	1.74%
4	SR135	Contractor X	Aug 2005	$1,599,490	3.78%
5	SR67	Contractor Z	Sept 2005	$3,874,004	1.50%

For each project several planning components were addressed: the entities involved in planning, references used in planning, special considerations in planning, and future considerations in planning. The results from the formal interviews are provided in Appendix G. The similarities found among the various projects were:

1. The contractors were required to provide an adequate traffic control plan that met INDOT standard specifications and drawings.
2. No additional documents were referenced for nighttime considerations (e.g., FHWA's Traffic Control Handbook for Mobile Operations at Night)
3. The contractors did not deviate from the standard specifications and drawings.
4. No formal traffic control plan was required for submission to INDOT.
5. The contractors reviewed the maintenance on traffic with INDOT before work activities started.
6. The contractors' CWTS were all ATSSA certified.
7. The contractors were all required to submit CWTS certification, and certification of traffic control devices.
8. The contractors subcontracted construction signs.
9. The contractors inspected traffic control devices daily and submitted traffic control device reports on a weekly basis.

10. The contractors' safety practices included pre-activity safety meetings to review the traffic control limits and traffic control setup and breakdown procedures. The contractors did not review specific safety hazards specific to nighttime work.

The information provided by the contractors was further examined to identify variation among entities involved in traffic control planning, documentation used in traffic control design, project considerations for nighttime work, and further considerations for nighttime work. The differences in planning are summarized in Table 4.4.

The entities involved in the contractor traffic control planning vary among companies. Some of the employees are certified by ATSSA, while others are not. The ATSSA supervisor course provides the employee useful information regarding proper planning and implementation of a safety work zone. The ATSSA supervisor training course also recently included a nighttime component for traffic control. The additional references used during traffic control planning also vary between contractors, but coincide with the training provided by the ATSSA. The entities that have been certified reference additional documents in traffic control planning for nighttime work than do the entities that are not certified.

Table 4.4 Summary of Contractor Differences in Traffic Control Planning

Category	Contractor	Comment
Contractor Entities Involved in Traffic Control Planning	X	• Asphalt Manager.
	Y	• ATTSA Certified Asphalt Manager
	Z	• Estimator • ATTSA Certified Asphalt Manager
Traffic Control Design	X	• No additional references
	Y	• INDOT Work Zone Safety Manual
	Z	• ATSSA "Guide to Temporary Traffic Control in Work Zones"

Project Considerations	X	• Work zone speed limit signs to mitigate traffic speeds • Additional amounts of barrels in the taper • Decreased cone distance in the activity area
	Y	• Flagmen used to control traffic at intersections
	Z	• Additional arrow boards used at intersections • Additional cones at termination tapers • Additional drums at merge taper
Further Considerations	X	• Work with INDOT to post speed limit signs on future jobs to mitigate traffic speeds
	Y	• Use shadow vehicles during traffic control setup to provide an additional buffer for those setting up the traffic control zone and the road users
	Z	• Decrease traffic control areas without impeding work zone buffers, to avoid additional confusion to motorists

The project considerations also varied among contractors. The contractors stated that considerations are made on a project-by-project basis. Contractor X included additional devicing in the tapers, approaches, and crossovers to lessen road user confusion and to provide additional protection for their workers. Contractor X also provided speed limit signs to reduce traffic speeds. Contractor X provided an off-duty law enforcement officer to further mitigate speeding for Project 1. Contractor Y provided flagmen to control and direct traffic at intersections. Contractor Z's considerations included additional devicing in tapers and additional arrow boards at approaches and crossovers. Future project considerations among the contractors also varied from speed mitigation to procedures involving traffic control setup.

The project assessment identified several planning issues for nighttime work. First, if the design engineer determines that the project conditions coincide with INDOT Standard Drawings and Specifications, the onus is on the contractor to adequately plan the work zone traffic control. Second, the training and experience of those involved in traffic control planning vary among contractors, which results in varying levels of planning. Third, although the contractors do not reference documents which provide additional considerations for improved safety, some of the considerations mentioned in the documents are included within their planning (e.g., additional devicing and speed control).

4.2.2. Traffic Control Safety Factor Evaluation

Multiple linear regression was used to determine the impact that certain traffic control safety factors have on the perceptions of safety felt by supervisors and workers. The analysis consisted of several stages: (1) regression model identification, (2) testing the model for assumptions, and (3) determining the significance of the model. The results from the supervisor and worker regression analyses were compared to determine the traffic control safety factors that were most influential from both perspectives.

The steps included in developing the regression model for the supervisor and the worker included: (1) defining safety factor categories for the supervisor and the worker, (2) identifying the independent and dependent variables, and (3) modeling the relationship. The safety factor categories defined for the supervisor and the worker analyses are shown in Table 4.5 and Table 4.6 respectively. For each safety category, corresponding safety issues were identified. The safety issues represented the independent, explanatory variables in the regression analysis. It is important to note that while the majority of the explanatory variables are consistent between the two entities, there were some additional safety issues which were addressed in one model and not the other. One example is the *m2* variable in the supervisor model. The supervisor is aware of traffic control device inspections required during implementation of the traffic control plan. The worker is typically not expected to know the level of inspection of these devices. Therefore the *m2* variable was only addressed in the survey administered to the supervisors. Another example is the worker visibility explanatory variables, while the supervisor may require the worker to wear personal protective equipment (PPE) onsite, it is the worker's individual responsibility to wear the PPE. Therefore, the *wv1* and *wv2* variables were only addressed to the worker.

Table 4.5 Summary of Explanatory Variables in the Supervisor Model

Traffic Control Safety Factors	Explanatory Variables *(Abbreviation used in Model)*	Response
Design	Adequate work zone buffers are provided *(d1)*	(Yes/No)
	Law enforcement available to control traffic speeds *(d2)*	(Yes/No)
TTC Maintenance	Traffic control devices properly maintained *(m1)*	(Yes/No)
	Inspection performed routinely *(m2)*	(Yes/No)
Lighting	Adequate lighting for supervisor to communicate *(lt1)*	(Yes/No)
	Adequate lighting for supervisor to perform work *(lt2)*	(Yes/No)
Safety Training	Pre-activity safety meetings are provided *(sm1)*	(Yes/No)

Table 4.6 Summary of Explanatory Variables in the Worker Models

Traffic Control Safety Factors	Explanatory Variables *(Abbreviation used in Model)*	Response
Design	Adequate work zone buffers are provided *(d1)*	(Yes/No)
	Law enforcement available to control traffic speeds *(d2)*	(Yes/No)
	Worker's level of safety with law enforcement present *(d3)*	(1-unsafe to 5-most safe)
TTC Maintenance	Traffic control devices properly maintained *(m1)*	(Yes/No)
Worker Visibility	Worker is required to wear PPE *(wv1)*	(Yes/No)
	Worker's level of safety from wearing PPE *(wv2)*	(1-unsafe to 5-most safe)
Lighting	Adequate lighting for worker to communicate *(lt1)*	(Yes/No)
	Adequate lighting for worker to perform work *(lt2)*	(Yes/No)
Safety Training	Worker attends pre-activity safety meetings *(sm1)*	(Yes/No)

Surveys administered to the supervisors and to the workers also asked the respondents to rate their perceptions of safety felt within the traffic control zone, which is referred to as the traffic score. In both cases, the rating was based on a five-point scale and represented the dependent response variable for the analyses. Equation 4.1 represents the relationship between the dependent variable (Traffic Score) and the multiple independent variables. The impact of each traffic control issue on the overall predicted safety score is determined by the model's estimate of the β coefficient for each safety issue.

$$\text{Traffic Score}_i = \beta_0 + \beta_1 X_{i1} + \ldots + \beta_k X_{ik} + \varepsilon_i \qquad (4.1)$$

Where;

Traffic Score$_i$ represents the response variable for the ith respondent, i = 1, 2, 3…n;

X_{ik} represents the ith response value of the kth explanatory variable;

β_0 is the intercept;

β_1 to β_k represent regression coefficients associated with the explanatory variables; and

ε_i represents the independently normally distributed (i.i.d.) random error with a mean of zero and a variance of σ^2, $\varepsilon_i \sim$ i.i.d N $(0, \sigma^2)$. (Kutner et al. 2005)

The analysis procedures using multiple linear regression are the same for the supervisor and worker models. Therefore the analysis described in this section will outline the procedures required for general regression analysis, and the term "model" will refer to both the supervisor and worker models.

A preliminary analysis was performed to check whether using multiple linear regression was useful for the model. The model included all of the explanatory variables. The preliminary analysis determined the fit of the model, the significance of the factors in the model, and the correlation between the explanatory and response variables. The preliminary analyses were assessed by examining the p-value and F-value in the ANOVA analysis, the R^2 value, and the correlation matrix. The desired results from the preliminary analysis are to minimize both the p-value and F-values, maximize the R^2 value, and determine which response variables are correlated and require further examination as subset models are selected. The typical p-values for both the model and the explanatory variables are chosen to be statistically significant when using a 5% significance level. The goal is to determine which explanatory variables are more important than other explanatory variables. The significance level for the explanatory p-values was determined based on the preliminary results.

After the general model was proven to be a good fit for the data, the next step was to eliminate extraneous explanatory variables. For this step, several selection criteria were used: (1) Adjusted $R_{a,p}^2$, (2) Mallow's C_p criterion, (3) Akaike's Information Criterion (AIC_p), and (4) Schwarz' Bayesian Criterion (SBC_p). The selection criteria used ensures the appropriate safety issues are selected for the subset models. Although all four criteria selection methods may not yield the same subset model, the application of these criteria allowed for a more complete evaluation. Selection of the best subset model was determined by selecting the subset model with the maximum R^2, significant p-value and F-value for the model, and the significant p-values for the explanatory variables from the ANOVA analysis.

The subset models were tested for the assumptions made in order to perform the multiple linear regression analysis. The primary assumption is that the error term (ε_i) is independently normally distributed with a mean of zero and a constant variance. The residuals in each model represent the difference between the response values for each of the explanatory variables and the predicted safety score. To verify the assumptions and to identify potential outliers which could affect the each model, three diagnostic tests were performed which examined the residuals variance, normality and independence.

The final models were used to determine the most significant traffic control factors. The traffic control factors with the largest parameter estimates were deemed as the most significant factors, since these traffic control factors had the greatest impact on the overall predicted safety score.

4.2.2.1. Preliminary Analysis

The initial intent of the regression analysis was to determine the most influential traffic control safety factors for both the supervisors' and the workers' involved in construction and maintenance operations. The statistical analysis also required that all of the questions included in the model were answered by the respondent. Of the 24 supervisor surveys, only 21 answered all of the questions in the model, which decreased the usable sample size. Similarly, of 61 worker surveys received only 49 were able to be used during the analysis. With the overall decrease in sample size only three models were significant; general supervisor and worker models which combined both the construction and maintenance samples, and construction worker model.

4.2.2.2. Model Results and Limitations

For each of the three models there were explanatory variables which had parameter estimates that were counter-intuitive to general practice. Table 4.7 summarizes the parameter estimates for the respective explanatory variables significant to each model. It is important to note from a statistical stand-point that serious multicollinearity did not exist in any of the models. Additional statistical analyses included simple regression (to determine if the effects were correlated with other variables) and interaction plots (to determine if the sign changed at different levels).

Table 4.7 Parameter Estimate Summary for Significant Explanatory Variables

Model	*d1*	*d2*	*d3*	*m1*	*m2*	*wv1*	*wv2*	*lt1*	*lt2*	*sm1*
General Supervisor	1.348	-	NA	-	-	NA	NA	**0.351**	-	-
General Worker	1.180	0.510	-	-	NA	-	0.320	-	**- 0.600**	**- 0.810**
Construction Worker	1.210	0.386	0.200	-	NA	-	0.210	-	**- 0.447**	**- 0.730**

The first model examined was the general supervisor model. It was determined the positive sign of the parameter estimate for *lt1* was counter-intuitive to general practice. The explanatory variable represents whether or not the supervisor feels poor lighting makes it difficult to communicate during work activities. The assumption is if the supervisor feels the lighting is poor during communication with a worker or supervisor, the result should have a negative affect on the overall safety score. The parameter's estimate sign is the opposite of this assumption, which results in a positive influence on safety when poor lighting is present.

Simple regression between the explanatory variable and the corresponding response variables showed the parameter estimate was still positive, i.e., the majority of the respondents who answered yes to the question (related to poor lightning) had a high response score (higher safety score). The results of the simple regression showed that other explanatory variables did not have an affect on the parameter's sign. The researchers concluded that the reason for the parameter's sign was that the majority of those who responded did not understand the intent of the question. With a larger supervisor sample this issue could potentially be eliminated. While this subset model was the best selection from a statistical basis, the difference between the R^2 values for the two models is minimal. Based on the data collected and the intent of the model, the final subset model selected shown in Equation 4.2.

$$\text{TScore}_{ith} = 2.75 + 1.25(d1) \tag{4.2}$$

Examination of the second and third models determined that the negative parameter estimate signs for both *lt2* and *sm1* were counter-intuitive to general practice. The *lt2* variable represents whether or not the worker has adequate lighting to perform their work. The assumption is if the worker has adequate lighting to perform work, the result then should indicate an increase in the overall safety score. The parameter estimate is negative, which is contrary to this assumption, resulting in a decreased safety score. The *sm1* variable represents whether or not the worker attends pre-activity safety meetings. The assumption is if the worker attends the meetings, the result should then indicate an increase in the overall safety score. The parameter estimate is negative, which is contrary of this assumption, resulting in a decreased safety score.

Simple regression was performed on each of the explanatory variables, which yielded a smaller negative parameter estimate for each variable. Second, the interaction between each explanatory variable and the other variables were examined to determine if there was a significant interaction that could affect the sign of each parameter. The only significant interaction was between *d1* and *lt2*. The interaction plot between the two variables offered no additional explanation.

From a qualitative standpoint, there are several reasons which could explain this phenomenon. When analyzing perceptions it is in the researcher's best interest to attain the larger sample size possible in order to increase the accuracy of the parameter estimate. For this analysis, an initial sample size of 61 workers was received. In order to include a worker survey within the model, the survey had to have responses to all of the explanatory variables, which decreased the overall usable sample to 49 respondents. Although statistically both the model and the parameter estimates were significant, an increase in the total number of responses could have more accurately reflected the parameter estimate signs for both *lt2* and *sm1*. Another reason could have been the scale chosen for the response variable. The traffic control safety score ranges from one to five; with the exception of three respondents, the workers all responded with a score equal to or greater than three. A larger range could have introduced more variability in the response variable, which could have more accurately depicted the relationship between the safety score and the *lt2* and *sm1* response variable. Both the *lt2* and *sm1* binary variables are representative of whether or not a specific practice is utilized. The effectiveness of each variable are not included within the model. For example, *sm1* represents whether or not the worker attends safety meetings, it does not incorporate discussions regarding specific safety practices nor does it address the effectiveness of the safety practices covered during those meetings. The researchers' conclusions are twofold: (1) the explanatory variables that have the largest influence on safety perception have been identified and (2) the explanatory variables that are contradictory to the original assumptions are still significant and require evaluation in future research.

4.2.2.3. Model Comparison

The worker and supervisor results were compared to determine the most influential traffic control safety issues for nighttime work. Table 4.8 summarizes the results from the three analyses. The comparison shows that design, worker visibility, lighting, and training have the most influence on safety perception. Although both the worker and the construction worker general models had more explanatory variables for regression analysis than the supervisor general model, all three models had at least one traffic control design issue present in the final model. The most significant explanatory variable was *d1*, which yielded the highest positive parameter estimate in all three models. The results from the analyses concluded that the most influential traffic control safety category based on the perception of safety from the supervisor and the worker is traffic control design.

Table 4.8 Summary of Important Traffic Control Safety Factor Categories

Model	Traffic Control Safety Category	Explanatory Variables
General Supervisor	Design	*d1*
General Worker	Design, Worker Visibility, Lighting and Training	*d1, d2, wv2, lt2, sm1*
Construction Worker	Design, Worker Visibility, Lighting and Training	*d1, d2, d3, wv2, lt2, sm1*

4.2.3. Traffic Control Strategies for Improved Safety

There are several safety practices and procedures to improve traffic control safety within the nighttime work zone. These practices and procedures range from the design considerations outlined by the Manual on Uniform Traffic Control Devices (MUTCD) to safety management techniques highlighted by the Construction Industry Institute (CII). Supervisors and workers were asked to indicate, based on their experience, five from a list of safety strategies that could improve traffic control safety. This list included (1) increased cone/drum taper lengths, (2) routine maintenance of traffic control devices, (3) decreased cone/drum distances, (4) inspection of traffic control devices prior to use, (5) increase of on-site law enforcement, (6) review of traffic control plans, (7) review of incident management plans, (8) proper training: traffic control set-up & breakdown, (9) increase public awareness, and (10) other. The total number of responses to each strategy were reviewed to determine if there were specific traffic control strategies which both entities felt were important for improved nighttime safety. The supervisors and workers were also asked questions regarding the implementation of the aforementioned safety strategies, which provided further insight into improvements of the important safety practices recommended by supervisors and workers.

4.2.3.1. Assessment of Responses from Supervisors

The supervisors who participated in the survey were either directly (in their roles as Certified Worksite Traffic Supervisors) or indirectly (in their roles as Department of Transportation Supervisors) involved with the work zone traffic control for both construction and maintenance operations. A total of 24 supervisors participated in the survey, of which 22 were involved in construction operations and two were involved in maintenance operations. The average age of the supervisors who participated in the survey was 40.9 years, and their experience in construction averaged 16.1 years. The supervisors averaged 6.2 years experience in nighttime work. The supervisors' frequency of nighttime work shifts varied between always working nights (five out of 24 respondents), monthly (one out of 24 respondents), to three-four times per year (six out of 24 respondents), to rarely working nights (11 out of 24 respondents), and no answer (one out of 24 respondents). Thus, the supervisors in the survey had considerable experience in both daytime and nighttime work.

The corresponding safety strategies and their percentages are shown in Figure 4.3. The results indicated that developing ways to further alert road users of the traffic control zone was important in planning. The supervisors also felt that including law enforcement for future projects was necessary to mitigate work zone traffic speeds. Providing both the supervisor and the worker with proper traffic control training was also among the most often chosen safety mitigation strategies. Among the safety strategies that yielded the lowest importance were review of traffic control plans, decreased cone and drum distances within the activity area, review of incident management plans, and others. The other responses included requiring law enforcement to enforce the speed limits and replacing cones with drums.

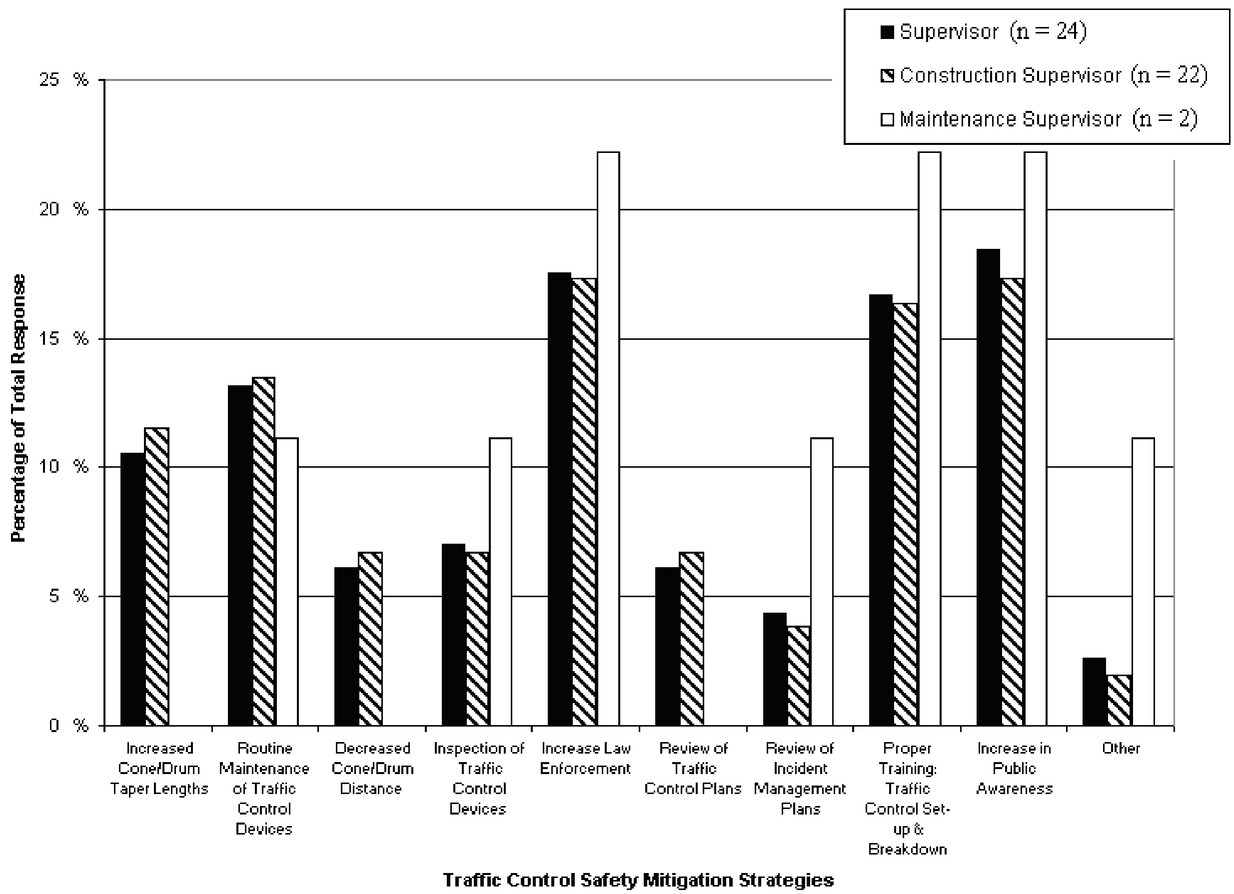


Figure 4.3 Supervisor Comparison of Important Traffic Control Safety Mitigation Strategies for Improved Nighttime Work Zone Safety

The results from the supervisor assessment were then compared with survey questions which addressed the current implementation of the safety practices. The results from the survey are shown in Table 4.9. The construction supervisors stated that some formal training was provided by the company regarding nighttime traffic control (six out of 22 respondents). Of the six respondents 100% found the training to be beneficial. The construction supervisors stated that formal training regarding nighttime traffic control was also received outside the company (six out of 22 respondents) either through another company or through the ATSSA. 83.33% of this group found the training to be beneficial. The construction supervisors stated some training was provided to their workers regarding proper traffic control setup and maintenance (19 out of 22 respondents). Some construction sites had law enforcement present to control traffic speeds (14 out of 22 respondents). Of these 14 respondents, 52.17% stated proper signage was provided to alert the general public that law enforcement was present.

Table 4.9 Supervisor Summary of Implemented Safety Practices

Safety Practice	Survey Question	Possible Answers	Construction Supervisor (n=22)	Maintenance Supervisor (n=2)
			Percent That Answered Yes	
Safety Training	Formal company training provided to the supervisor for nighttime traffic control.	YES/NO	27.27%	50.00%
	Formal company training beneficial.	YES/NO	100%	100.00%
	Formal training received outside the company for nighttime traffic control.	YES/NO	27.27%	-
	Formal outside training beneficial.	YES/NO	83.33%	-
	Traffic control setup and maintenance training provided to the worker.	YES/NO	86.36%	100.00%
Law Enforcement	Law enforcement on project to control speeding.	YES/NO	63.63%	-
Public Awareness	Proper signage alerting general public law enforcement is present.	YES/NO	52.17%	-

4.2.3.2. Assessment of Responses from Workers

A total of 61 workers participated in the survey, of which 38 were construction and 23 were maintenance. The average age of the workers was 36.6 years. Their experience in construction averaged 11 years. Moreover, the workers averaged 3.4 years in nighttime work. The workers' frequency of nighttime work shifts varied between always working nights (28 out of 61 respondents), monthly (five out of 61 respondents), to three-four times per year (11 out of 61 respondents), to rarely working nights (10 out of 61 respondents) and no answer (six out of 25 respondents). The workers also had considerable experience in both daytime and nighttime work. The workers were also asked if they had ever been involved in an accident during a nighttime operation. The response to this question was interesting in that 13.16% of the construction workers (five out of 38 respondents) and 21.74% of the maintenance workers (five out of 23 respondents) stated they had previously been involved either directly or indirectly in an accident. The worker responses to this assessment introduce not only work experiences but also their experiences in accident exposure.

The corresponding safety strategies and their percentages are shown in Figure 4.4. The results indicated that the workers were in agreement with the supervisors. The workers stated that developing ways to further alert road users of the traffic control zone was important in planning. The workers also felt that including law enforcement for future projects was necessary to mitigate speeding in work zones. Providing the worker with proper traffic control training was among the most often chosen safety mitigation strategies. Among the safety strategies that yielded the lowest importance were review of traffic control plans, decreased cone and drum distances within the activity area, review of incident management plans, and others. The other responses included requiring law enforcement to enforce the speed limits and replace the use of cones with drums.

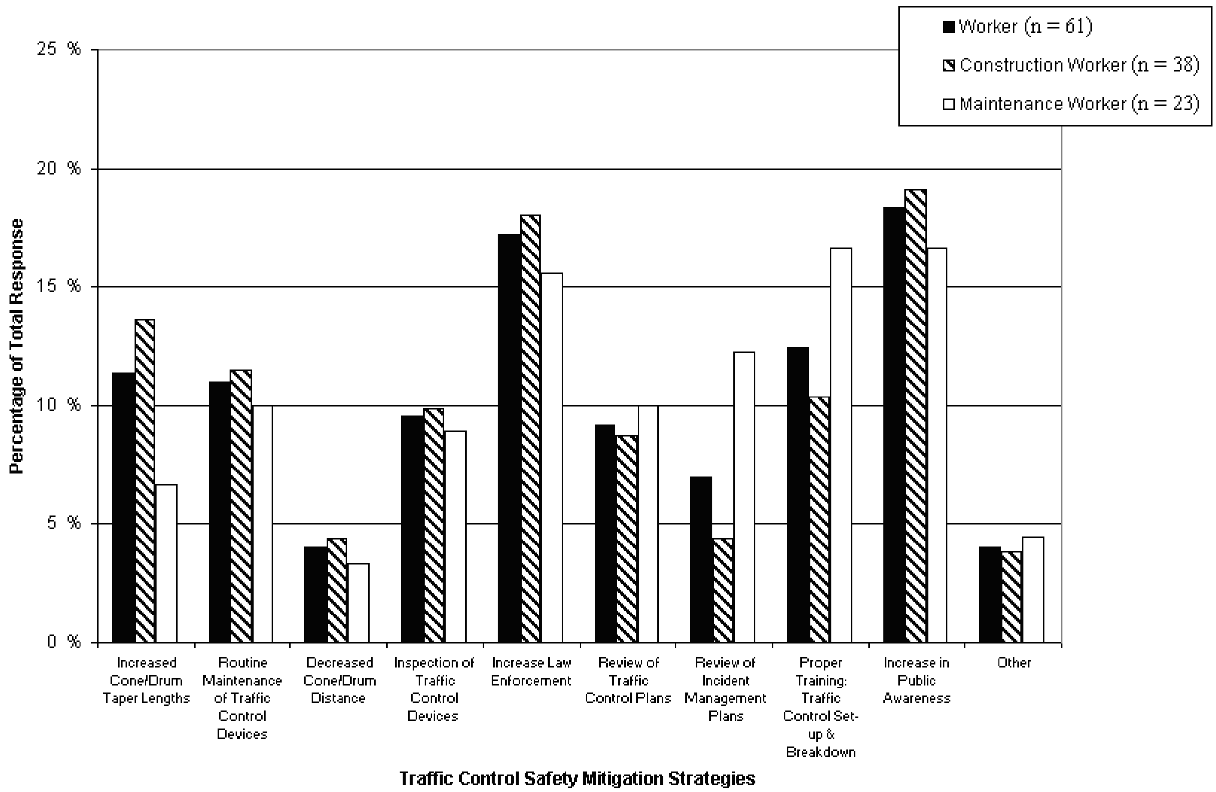


Figure 4.4 Worker Comparison of Important Traffic Control Safety Mitigation Strategies for Improved Nighttime Work Zone Safety

The results from the worker assessment were then compared with survey questions regarding the current implementation of the safety practices. The results from the survey are shown in Table 4.10. The results from the analyses of the surveys administered to workers indicated that some construction sites had law enforcement present to control traffic speeds (18 out of 38 respondents). The majority of the construction workers stated that adequate buffers were provided (33 out of 38 respondents) and proper maintenance was performed on the temporary traffic control (TTC) devices (36 out of 38 respondents). Although training was not among the most important safety practices requiring improvement, the construction workers stated that some training was provided regarding proper traffic control setup and maintenance (25 out of 38 respondents). The maintenance workers also stated no law enforcement was present during maintenance operations and that some traffic control training was provided (17 out of 23 respondents). Improving traffic control tapers and proper maintenance were not among the most important safety practices requiring improvement, and 19 of the 23 maintenance workers stated that adequate buffers were provided and 20 of the 23 maintenance workers stated that proper maintenance was received on the TTC devices.

Table 4.10 Worker Summary of Implemented Safety Practices

Safety Practice	Survey Question	Possible Answers	Construction Worker (n=38)	Maintenance Worker (n=23)
			Percent That Answered Yes	
Safety Training	Received traffic control setup and maintenance training.	YES/NO	65.79%	73.91%
Work Zone Buffers	Buffers provided are adequate.	YES/NO	86.84%	83.33%
Device Maintenance	Proper maintenance on TTC devices.	YES/NO	94.74%	86.96%
Law Enforcement	Law enforcement on project to control speeding.	YES/NO	47.37%	0.00%

4.2.3.3. Comparison of Supervisor and Worker Results

The results from the surveys administered to the supervisor and the worker were compared to examine whether there was an agreement among the respective entities regarding the viability of different traffic control strategies for improved safety performance. The supervisor and worker categories all agree, with the exception of the construction worker, that increased public awareness, increased law enforcement, and proper traffic control training are the most important safety practices for improved nighttime safety. The aforementioned results from the supervisor and worker comparison allowed for several conclusions:

1. The majority of supervisors authorized to make changes to the work zone traffic control were not receiving formal nighttime traffic control training.

2. The majority of construction supervisors who receive nighttime traffic control training were those who are Certified Worksite Traffic Supervisor's (CWTS) certified by the ATSSA.
3. The traffic control training was not always provided to the worker involved on both construction and maintenance operations.
4. Law enforcement was present on some construction sites, while law enforcement was never present during maintenance operations due issues such as highway agency funding.
5. The general public was not always aware that law enforcement was present on site.

4.3. Conclusion

The conclusions from this research are twofold: (1) traffic control planning by highway agencies and contractors impact the supervisors' and the workers' perceptions of safety, and (2) there is a significant difference between the supervisors' and the workers' perceptions of safety practices and the safety practices implemented by the highway agencies and the contractors.

An assessment of similar nighttime construction projects identified safety practices and procedures used in nighttime traffic control planning. The results from the formal interviews with Indiana contractors and INDOT personnel indicated that contractors are becoming more involved in traffic control planning. If an INDOT design engineer determines that the standard drawings and specifications meet the project conditions, the onus is on the contractor to adequately plan the work zone traffic control. The training and experience of those involved in the traffic control planning vary among contractors, which impacts considerations for nighttime planning. While not every contractor or highway agency employee receives traffic control training, those involved in design should be made aware of the additional references for nighttime work (e.g., FHWA documentation and the National Work Zone Safety Information Clearinghouse). Therefore, the highway agency should provide the additional information to both their employees and contractors.

Multiple linear regression analysis identified the significant factors that had the largest influence on the supervisors' and the workers' perceptions of safety. The general supervisor model indicated that traffic control design was the most influential factor. The general worker and construction worker models indicated that traffic control design, worker visibility, lighting, and training were the most influential factors. Comparison of the supervisor and worker models showed that traffic control design had the largest impact on the overall perception of safety. The analysis indicated that highway agencies and contractors should focus their planning efforts on temporary traffic control design, while continuing to provide the same level of consideration for traffic control maintenance, worker visibility, lighting, and training.

The analyses of the surveys distributed to the supervisor and the worker indicated the importance for improved traffic control training during construction and maintenance operations. The majority of supervisors involved in general traffic control supervision responded that they had received no formal training. These supervisors provide traffic control training to the workers. Therefore, to improve the supervisors' and the workers' perceptions of safety training, highway agencies and contractors must provide adequate information and training to the supervisors involved in traffic control operations.

Increased law enforcement and public awareness were also among the most important traffic control strategies for improved nighttime safety indicated by the supervisors and the workers. The supervisor and the worker surveys showed that law enforcement was either not implemented or required improvement by alerting the general public of the presence of law enforcement and ensuring that law enforcement is enforcing speeds. While law enforcement cannot be present on every nighttime operation, special considerations must be made on a project-by-project basis to include law enforcement or speed control methods for improved nighttime traffic control safety.

4.3.1 Limitations

The data analysis used and the conclusions drawn from this thesis provide highway agencies and contractors with insight into how evaluating safety perception can improve nighttime traffic control planning. However there are some limitations, which include the limited number of projects, the small number of survey respondents, the limited location of survey respondents, the inclusion of the general public's perspective, and the difficulty in the practical validation of the supervisor and worker regression models.

A restriction to this portion of the study was the limited number of projects used during project comparison. The initial intent was to evaluate traffic control planning procedures by administering a survey to designers involved in construction operations. A zero response rate was received for the survey; consequently, formal interviews were conducted to assess safety practices and procedures. There were only five nighttime projects in Indiana with similar project conditions available for assessment, three of which were performed by the same contractor. Thus, the conclusions drawn from this assessment are specific to contractors who perform nighttime work in Indiana.

Another restriction was the limited number of survey respondents. The responses received from the supervisor and worker surveys allowed for a general supervisor model, a general worker model, and a construction worker model during multiple regression analysis. The number of completed construction supervisor surveys was not large enough for analysis (19 respondents). Although the maintenance supervisor and worker sample sizes were complete sample sizes for Indiana, the completed number of surveys (two supervisor respondents and 16 worker respondents) was also not large enough for multiple regression analysis. Developing the additional models is important since traffic control strategies vary depending on the project conditions. For example, long-term stationary construction projects tend to have permanent barriers in the activity area protecting the road users and the workers, while projects with shorter durations use temporary devices (e.g., cones and drums) in the activity area. Thus the impact of traffic control design on the supervisors' and the workers' perceptions of safety could vary between construction and maintenance projects.

The location of the survey respondents is another limitation. The supervisor and the worker survey responses were from Indiana and Illinois. The conclusions made from the analyses are not necessarily representative of other regions in the United States. Traffic control considerations could vary depending on the amount of nighttime work within that region. For example, in regions where nighttime work is performed on a more frequent basis, the use of nighttime considerations in planning and implementation could be greater than in regions which are less experienced and performed less work at night.

The general public is also affected by the implemented traffic control planning safety practices and procedures. The supervisors and workers both stated that increasing public awareness of the traffic control zone was important for improved safety. Moreover, the majority of work zone incidents and fatalities involve road users. The conclusions made do not account for the safety perception of the general public.

The results from supervisor and worker models have not been validated. Validation would require surveying the safety perceptions of the supervisors and the workers on various nighttime construction and maintenance projects where the important safety factors are implemented and where each model's safety score is maximized. The average safety score could then be compared to the respective model to determine the accuracy of the model.

4.3.2. Recommendations for Future Work

This portion of the study investigated the impacts of safety practices and safety perception for nighttime traffic control. While the conclusions provide insight for improved highway agency and contractor planning for nighttime work, further research is required. The following recommendations extend beyond the limitations to this portion of the study and address issues which require further investigation:

The multiple linear regression analysis indicated that safety training had a negative impact on the supervisors' and the workers' perceptions of safety. The assessment of safety strategies for improved nighttime safety indicated proper traffic control training was one of the most important strategies, but this strategy has been inconsistently implemented. The results from the two analyses indicated further evaluation is required to determine the effectiveness of safety training strategies for both the supervisor and the worker.

The presence of law enforcement was significant for improving the safety perception for the worker regression analyses and the assessment of traffic control safety strategies. The Indiana Department of Transportation allocates funds to provide law enforcement in construction work zones. While law enforcement is not always present on every site, one contractor stated that his company includes law enforcement costs in their bid as a general pay item. Further evaluation regarding methods for contracting law enforcement and the impact of law enforcement on nighttime construction and maintenance work zones should be considered. In addition to on-site law enforcement, there are other methods of speed control. A comparison of implementing various speed control methods (e.g., variable speed limit signs) with law enforcement for nighttime work should also be evaluated.

The results from the traffic control strategy assessment identified public awareness to be an important strategy which could improve safety. Increased public awareness can range from portable changeable message signs and arrow panels to intelligent transportation system technologies. Therefore, investigating the effectiveness of these devices and their influence on the general public during nighttime operations will provide highway agencies and contractors with additional ways to improve nighttime traffic control planning.

Some of the explanatory variables identified in the regression analysis yielded parameter estimate signs which were contradictory to assumptions of safety practice. Additional statistical analyses were performed to determine if the model had an effect on the respective explanatory variables. The analyses included simple regression (to determine if the effects were correlated with other variables) and interaction plots (to determine if the sign changed at different levels). It is important to note that, while not considered in this study, there are additional measures to examine serious multicollinearity and should be considered in future analyses similar to that prescribed in this study. Ridge Regression is one method which modifies least squares to allow for more accurate biased estimators of regression coefficients (Kutner 2005). Further examination of the biased and unbiased estimators might offer additional explanation for parameter estimate signs that are contradictory to original assumptions.

The supervisor and worker models were developed based on questions identified through an extensive literature review. The majority of the questions asked of the supervisor and worker related to whether or not the safety factor was present at the specific work site. Future research should include questions that incorporate the perception of safety (e.g., 1 = unsafe to 5 = most safe) felt by the respective entity (i.e., supervisor and worker) when the safety factor is present. The model can then indicate the relationship between implemented safety factor and the overall safety score as the perception is improved.

CHAPTER 5. EVALUATION AND ASSESSMENT OF NIGHTTIME SPEED CONTROL

The previous chapter evaluated nighttime safety issues as they relate specifically to traffic control planning. The results provided insight into ways to improve traffic control on nighttime work zones. The analysis prescribed in this chapter supplements the previous chapter and investigates nighttime safety issues as they relate to speed control. The research steps as they relate to the research framework for this portion of the study are illustrated in Figure 5.1.

The intent of this portion of the study is to gather the perspective of Midwest transportation agency personnel on speed control, collect speed data from active nighttime work zones in Indiana, and conduct a statistical analysis to identify the factors (including observed speed control efforts) that significantly affect the mean and standard deviation of vehicle speeds in work zones. The chapter focuses on speed control on interstate nighttime construction and maintenance projects due to their high speed limits and frequent use of speed control. In developing an interrelated statistical model of mean speeds and standard deviations of speeds, new evidence is provided on the relative effectiveness of various speed control methods adding to the growing literature on this topic.

5.1. Methodology

The following section identifies the speed control methods used on nighttime work zones in Indiana and other Midwestern states. This section also describes the data collection process performed to evaluate these speed control methods.

5.1.1. Identification of Speed Control Measures Used on Nighttime Work Zones in Indiana and Other Midwestern States

Many methods of speed control have been studied in work zones throughout the United States. However, many of these are not regularly used on nighttime projects in Indiana and the Midwestern States. A formal telephone interview questionnaire was conducted in July of 2007 with Indiana Department of Transportation (INDOT) and other Midwestern DOT personnel to determine the types of speed control in use on nighttime work zones. Data about speed control measures currently used on daytime and nighttime work zones were collected for each state, along with their perceived effectiveness.

Data were collected regarding the following speed control methods: regulatory speed limit signs, recommended or advisory speed limit signs, work zone speed limit signs, police enforcement, speed display monitors, changeable message signs, variable speed limit or advisory system, rumble strips, double or increased fines, Wizard CB Alert System, and narrowed lane widths. Those interviewed were also asked if any other speed control methods that were not included in the aforementioned list, were in use by their agency or company. For each speed control method, data were collected on the daytime and nighttime use in construction and maintenance work zones. The interviewee was also asked to choose the two speed control methods they felt to be the most effective in reducing speeds and speed variance on nighttime construction and maintenance projects. Those interviewed were also asked to comment about the roadway type and project type on which each speed control method is typically used. Finally, the interviewee was asked what time during the night speeding is the biggest problem and where in the work zone speeding is of most concern. Twenty-five interviews were completed with employees from fourteen transportation agencies. The questionnaire is attached in Appendix I.

The questionnaire found that the most commonly used speed control methods on daytime projects were regulatory speed limits, double/increased fines, and police enforcement. The number of responses for each speed control method is depicted in Figure 5.2.

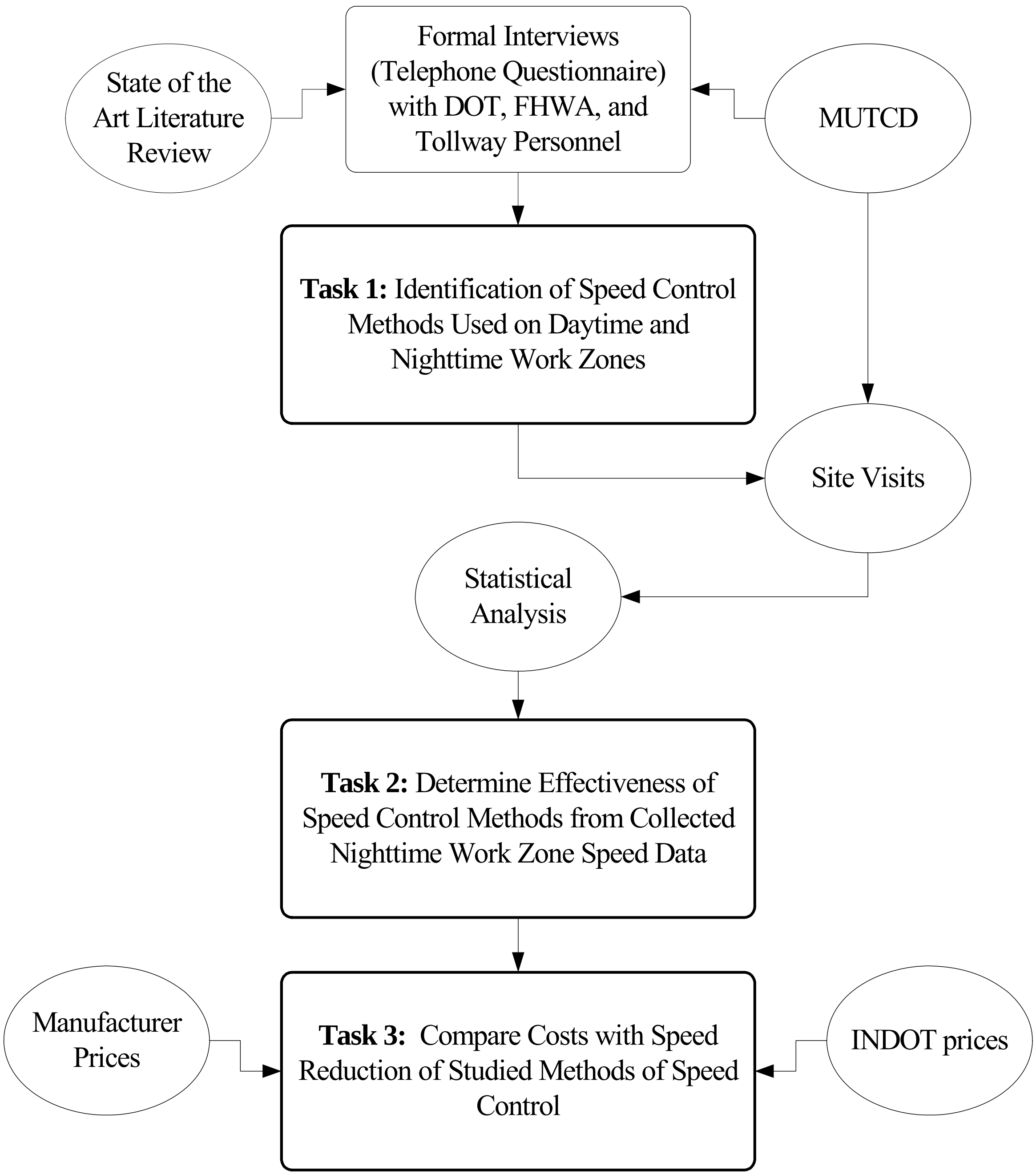


Figure 5.1 Research Tasks in Relation to the Research Framework → Speed Control

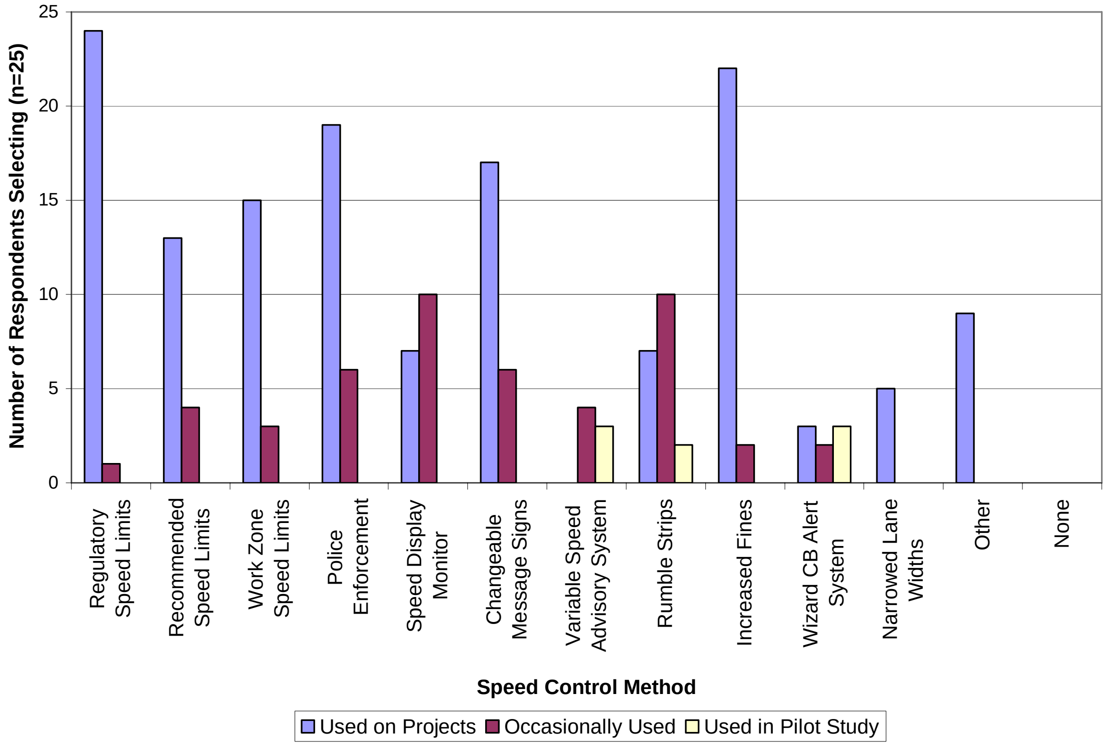


Figure 5.2 Speed Control Method Usage in Work Zones on Daytime Projects

The most commonly used speed control methods on nighttime projects were regulatory speed limits, double/increased fines, and police enforcement. No pilot studies were conducted on nighttime projects. Figure 5.3 shows the number of responses for each speed control method.

The interviewee was next asked to choose the two speed control methods they felt to be the most effective in reducing speeds and speed variance on nighttime construction and maintenance projects. The speed control methods believed to be the most effective at night were police enforcement and regulatory speed limits. Police enforcement was selected more than twice as often as any other method of speed control. Four of the individuals interviewed felt that none of the speed control methods were effective in lowering speeds through nighttime work zones. Figure 5.4 shows the responses received.

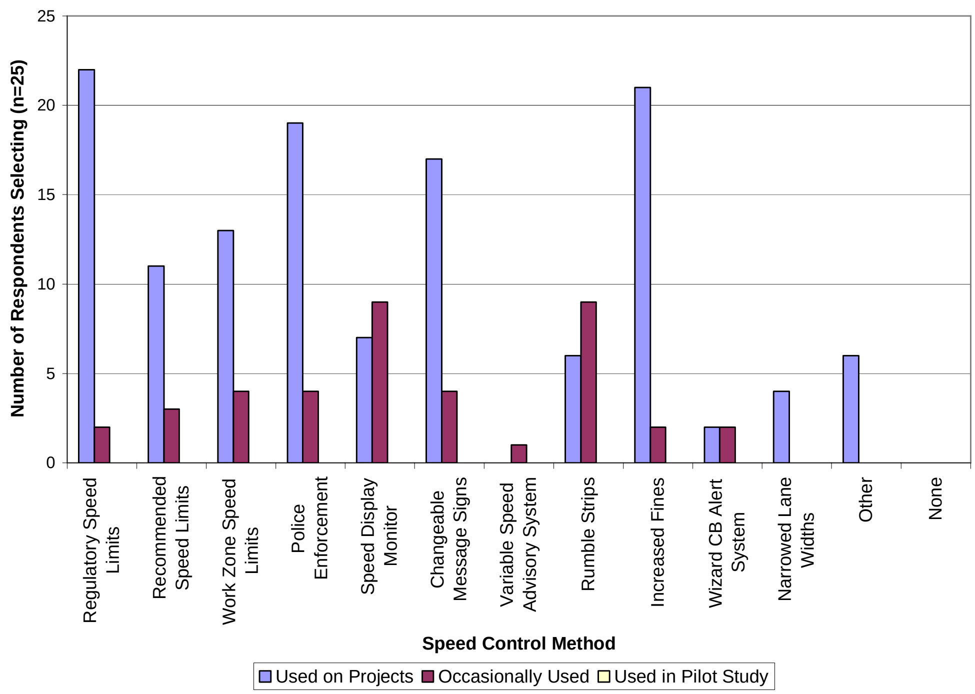


Figure 5.3 Control Method Usage in Work Zones on Nighttime Projects

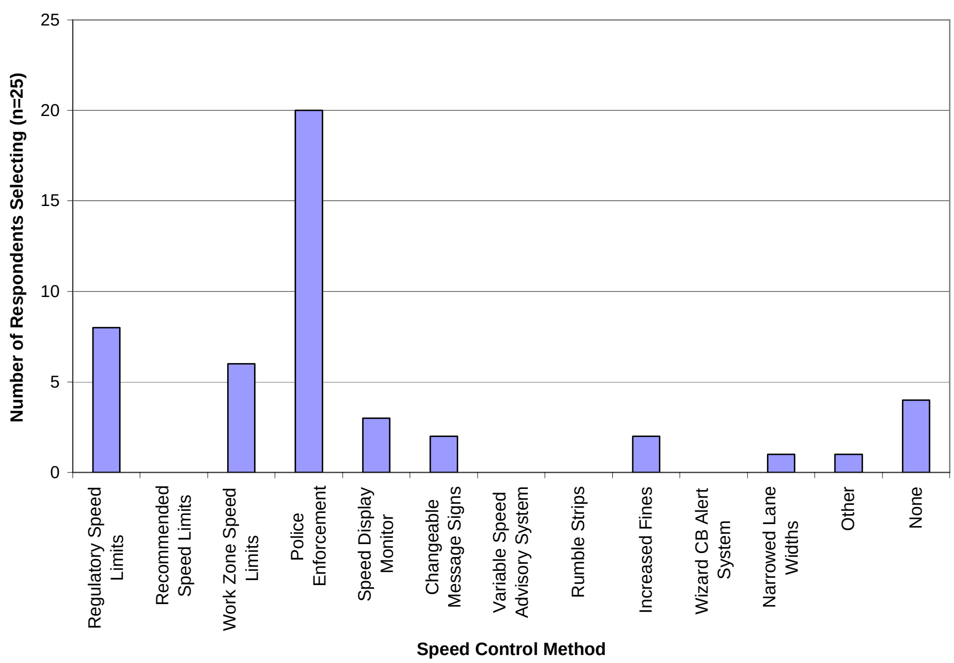


Figure 5.4 Perceptions of Most Effective Nighttime Speed Control Methods: Transportation Agency Personnel

Those interviewed were also asked where in the work zone is speeding of most concern. The Manual on Uniform Traffic Control Devices (MUTCD) broke down work zones into the following sections: (1) advance warning area, (2) transition area, (3) activity area, and (4) termination area. The active work zone or workspace is where the construction equipment is located and the actual work is taking place. The sections within the work zone where nighttime speeding was found to be of most concern were the active work zone and the transition area. Figure 5.5 shows the breakdown of responses.

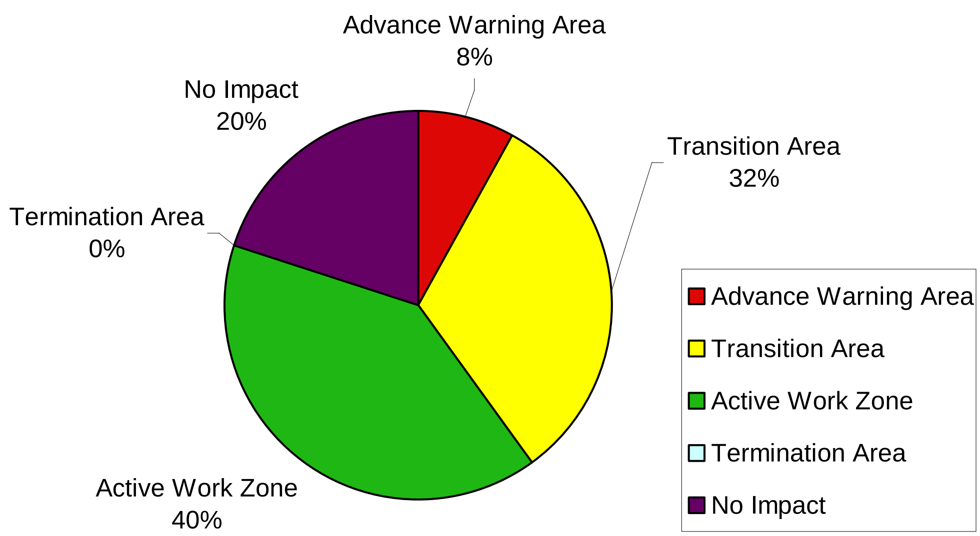


Figure 5.5 Location in the Work Zone Where Speeding is of Most Concern

Overall, it was found that the currently used speed control methods on nighttime projects in the Indiana are regulatory speed limit signs, work site speed limit signs, changeable message signs, police enforcement, and rumble strips. These five methods of speed control will be evaluated for their effectiveness in reducing speeds and speed variance in nighttime construction and maintenance work zones in Indiana.

5.1.2. Data Collection of Speed Control Methods

Site visits were made to nighttime construction and maintenance work zones in Indiana to collect the data necessary to evaluate each method of speed control. The study focused on interstate projects with free flowing traffic conditions due to their high speed limits and frequent use of speed control. Information about daytime and nighttime interstate construction projects was obtained from the Indiana Department of Transportation Work Zone Manager, Todd Shields. Each individual site visit was coordinated with the INDOT Project Superintendent. For this study, free flow vehicles were defined as those having headways of four seconds or more.

Eight site visits were made to Indiana interstate construction and maintenance work zones for nighttime data collection. These site visits were made between July and November of 2006. All projects visited had a least one lane closed for construction or maintenance activities. Original speed limits varied from 50 to 70 mph. A work zone speed limit of 45 mph was posted in all construction projects visited. The maintenance project visited did not have a posted work zone speed limit. Figure 5.6 shows a sketch of the work zone setup for Site Visit 1. Table 5.1 lists the specific characteristics of each of the site visits made.

Upon arrival to the project site, the research personnel drove through the length of the work zone, marking down the locations of signs, changeable message signs, rumble strips, and police enforcement. The researcher’s vehicle was parked behind the construction equipment so as to appear as part of the work zone but not interfere with construction activity. The researcher’s vehicle was equipped with a flashing light to comply with safety regulations. This also aided in blending in with the INDOT and contractor vehicles within the work zone, which were also equipped with flashing lights.

Speeds and distances were collected using a handheld laser gun. A handheld laser gun was used instead of a radar gun to reduce the amount of warning time for vehicles equipped with radar detectors. For each vehicle, the speed, vehicle type (car/van/SUV/pickup, single-unit truck, semi-truck, other) were recorded. For purposes of the analysis of mean speed and the standard deviation of speed, speeds were grouped into ten-minute intervals. The following were recorded for each ten-minute interval: time period, flow rate (veh/hr/lane), distance between data collection point and nearest construction vehicle (in feet), distance between data collection point and police enforcement (in feet), and the number of vehicles queued (the number of vehicles trailing a slower lead vehicle).

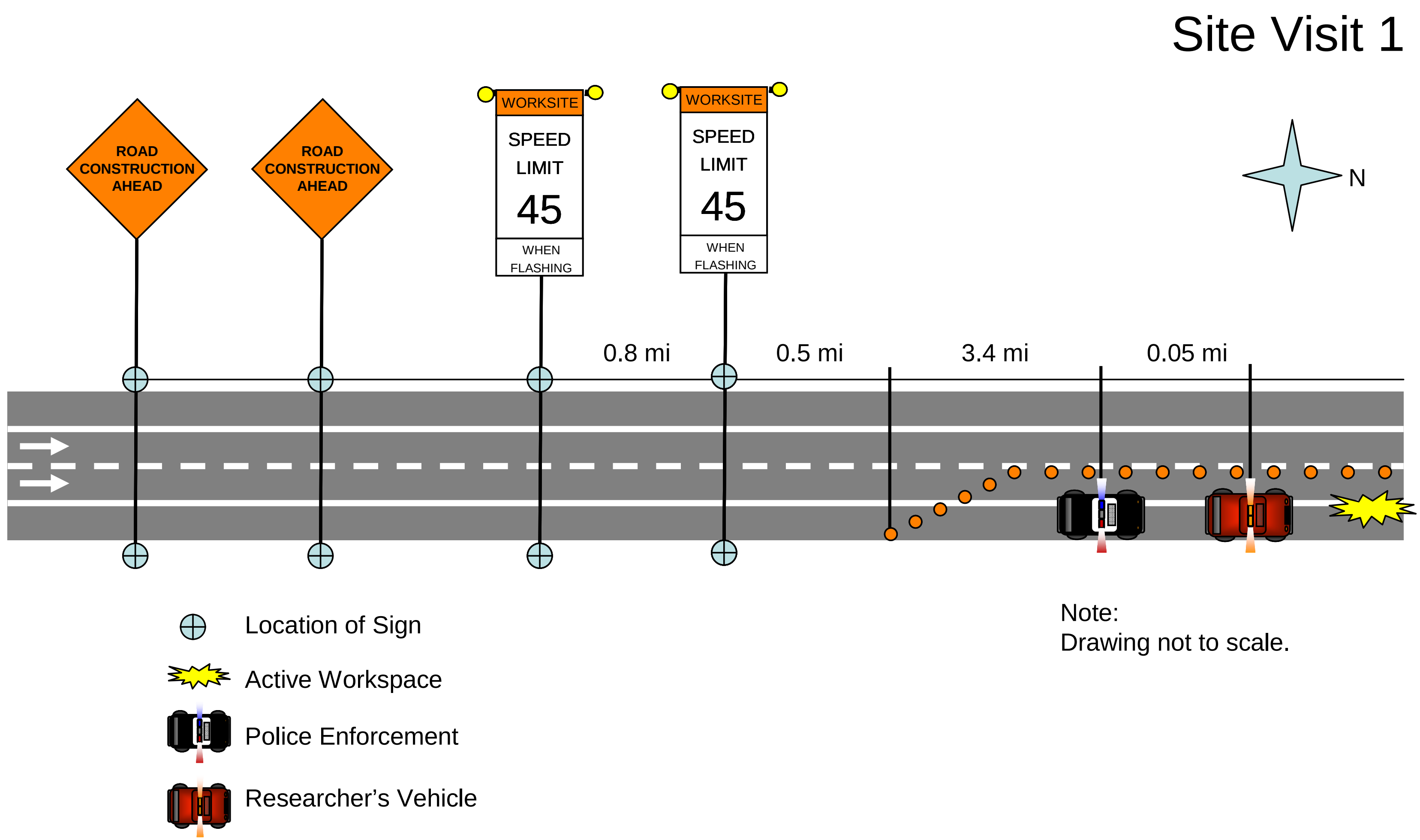


Figure 5.6 Site Visit 1 Work Zone Sketch

Table 5.1 Construction and Maintenance Site Visits

Site Visit	Date	Road	Location	INDOT Contract	Lanes Open/ Lanes	Orig. Speed Limit	Work Zone Speed Limit	Worksite Speed Limit Signs	CMS	Police	Rumble Strips	Data Points
1	7/28/06	I-69	Near Muncie on I-69 NB at exit 41	R-28097	1/2	70 mph	45 mph	4	0	1	No	377
2	7/31/06	I-465	Near IND airport on I-465 NB at Kentucky Ave exit	R-28256	1/3	55 mph	45 mph	2	2	0	No	436
3	8/1/06	I-70	Near Plainfield on I-70 EB at SR267 exit	R-28214	2/3	65 mph	45 mph	3	1	0	No	175
4	8/29/06	I-70	Near Plainfield on I-70 EB at SR 267 exit	R-28214	1/2	65 mph	45 mph	4	1	0	No	375
5	9/18/06	I-70	Near US231 interchange	R-28272	1/2	70 mph	45 mph	5	2	0	Yes	194
6	9/21/06	I-465	Between US31 and US421	RS-28258	2/3	55 mph	45 mph	2	1	1	No	589
7	11/2/06	I-65	South of Lafayette between mile markers 165-152	R-29140	1/2	70 mph	45 mph	3	0	0	No	196
8	11/14/06	I-65	Downtown Indianapolis	Maint.	1/3	50 mph	-	0	1	0	No	649

5.1.3. Data Analysis: Methodological Approach

Understanding the relationship between the mean of vehicle spot speeds and their variance is important since both mean speed and speed variance can affect the likelihood of an accident. Previous research by Boyle and Mannering (2004) studied the mean and the standard deviation of individual driver speeds over one-kilometer sections of highway. They estimated mean speed and the standard deviation of speed as a simultaneous equations system using three-stage least squares. Their findings showed that, for individual drivers (in addition to a multitude of other explanatory variables relating to roadway geometrics, driver socioeconomics, and so on) increases in the standard deviation of speed tended to decrease mean speed and that increases in mean speed tended to decrease the standard deviation of speed. However, because the data in this study was composed of the spot speeds of numerous drivers as opposed to the continuous collection of speeds for individual drivers (as was done by Boyle and Mannering), a model structure developed did not have mean speed and the standard deviation of speed directly related to one another (with mean speed appearing in the equation for the standard deviation of speed and the standard deviation of speed appearing in the equation for mean speed). Instead in a model structure the mean speed and the standard deviation are indirectly related to each other through disturbance-term correlation (i.e., unobserved factors that affect mean speed will also affect speed deviation). Thus, the proposed model system takes on the following form,

$$MS_i = \beta_i Z + \alpha_i X + \varepsilon_i \qquad (1)$$

$$SD_i = \lambda_i Z + \omega_i X + \upsilon_i \qquad (2)$$

where: MS_i is the mean speed (in mph) for time interval i; SD_i is measured standard deviation of spot speeds in time interval i (in mph); Z is a vector of site-specific characteristics; X is a vector of vehicle-specific characteristics; β_i , α_i, λ_i and ω_i are vectors of estimable parameters; and ε_i and υ_i are disturbance terms capturing unobserved characteristics.

Ordinary least squares (OLS) may be thought of as one approach to estimating Equations 1 and 2. However, because both mean speed and the standard deviation of speed are calculated for the same ten-minute interval within a particular nighttime work zone, they are likely to share unobserved characteristics. Although ordinary least squares estimation will yield unbiased and consistent estimates for these equations when estimated separately, because the correlation of the disturbances (resulting from shared unobserved characteristics) would not be considered the parameter estimates will not be efficient. Efficient parameter estimates can be obtained by considering the contemporaneous correlation of disturbances ε_i and υ_i and viewing the equations as seemingly unrelated (Washington 2003, Mannering 2007) as first proposed by Zellner (1962). Estimation of seemingly unrelated equations is accomplished using generalized least squares (GLS). Ordinary least squares assumes that disturbances have equal variance and are not correlated – so when using seemingly unrelated regression, GLS is used to relax these OLS assumptions (*11*). Recall that under ordinary least squares assumptions the resulting parameters are estimated as,

$$\hat{\beta} = \left(X^T X \right)^{-1} X^T Y , \tag{3}$$

where $\hat{\beta}$ is a $p \times 1$ column vector (where p is the number of coefficients), X is an $n \times p$ matrix of data (where n is the number of observations), X^T is the transpose of X, and Y is an $n \times 1$ column vector. Generalized least squares generalizes this expression by using a matrix that considers the correlation among equation error terms (Ω), so Equation 3 is rewritten as,

$$\hat{\beta} = \left(X^T \Omega^{-1} X \right)^{-1} X^T \Omega^{-1} Y . \tag{4}$$

In seemingly unrelated regression estimation, Ω is estimated from initial ordinary least squares estimates of individual equations (*11*).

5.2. Data Analysis

The data analysis performed in this portion of the study is three-fold. The first analysis is a comparison of spot speed data for each site visit and summary statistics of the data set. The second analysis uses seemingly unrelated regression estimation (SURE) to estimate the model system presented previously in Equations 1 and 2 and compares the results with ordinary least squares estimation of Equation 1 by conducting a likelihood ratio test. The final analysis compares the costs of the speed control methods included in the study. The following sections discuss the results from the individual analyses.

5.2.1. Data

In total, 2,994 vehicle speeds were collected at the eight site visits. An example of the spot-speed distribution for one of the work zone sites is presented in Figure 5.7.

A comparison of the average, minimum, maximum, and 85th percentile speeds for each of the eight site visits is shown in Table 5.2. The average speed through the work zones ranged from 38.3 mph on Site Visit 8 to 49.1 mph on Site Visit 3. The 85th percentile speeds ranged from 44.0 mph to 54.7 mph. Six of the eight site visits had an 85th percentile speed within 5 mph of the speed limit. However, five of the site visits recorded speeds more than 20 mph greater than the work zone speed limit. With a better understanding of the speed relationships on each site visit, a preliminary statistical analysis model was developed.

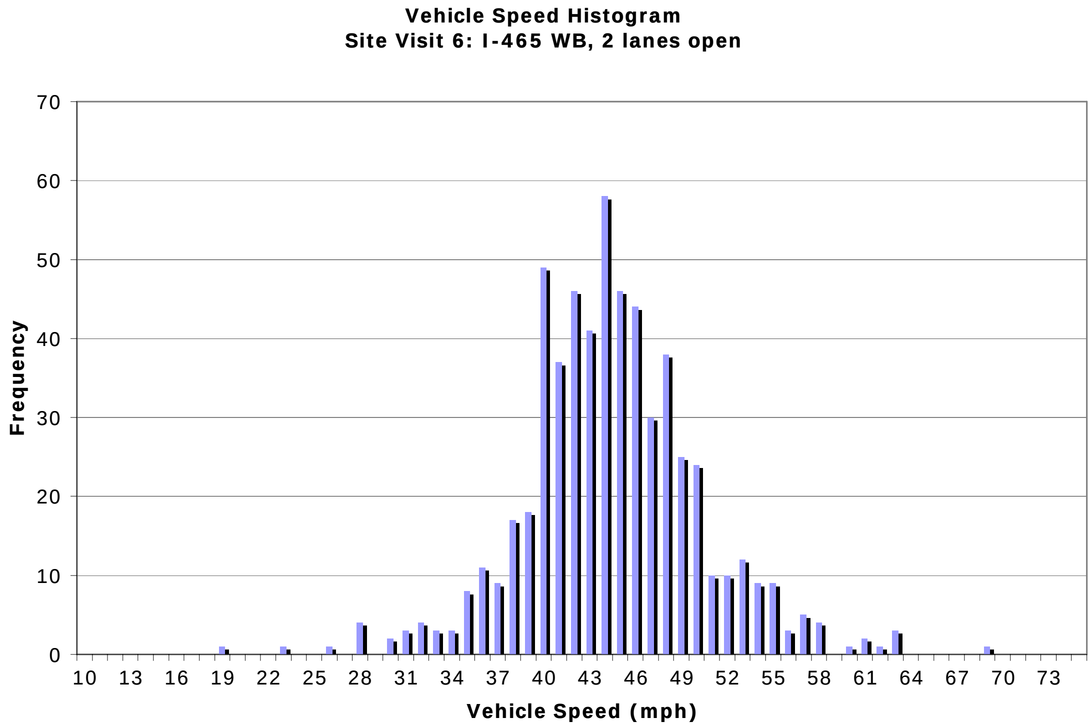


Figure 5.7 Sample Histogram of Spot Speeds at Site 6 (see Table 1 for a site description)

Table 5.2 Spot Speed Comparisons

Site Visit	Posted Speed Limit (mph)	Average Speed (mph)	Minimum Speed (mph)	Maximum Speed (mph)	85th Percentile Speed (mph)
1	45	40.0	11.0	71.0	48.2
2	45	45.8	10.0	68.0	51.7
3	45	49.1	39.0	67.0	54.7
4	45	43.1	17.0	61.0	48.9
5	45	45.9	35.0	61.0	49.1
6	45	44.4	19.0	69.0	49.2
7	45	44.6	15.0	75.0	49.4
8	50	38.3	13.0	58.0	44.0

The original data of 2,994 individual vehicle speeds were reduced to 86 ten-minute intervals for statistical modeling of mean speeds and speed standard deviations. Some of these ten-minute intervals could not be used due to a major change in the speed control present. An example is when a police officer left the work zone or changed his location within the work zone during a ten-minute time interval. Once these intervals were removed, 78 ten-minute intervals were left in the data set.

Table 5.3 presents summary statistics for these data. This table shows that data were collected between 9:30 pm and 3:30 am with 26.9% of the ten-minute intervals occurring before midnight and 15.4% occurring after 2:00 am. The average ten-minute average speed is 42.27 mph with a standard deviation of 5.83 mph. The average vehicle composition during the ten-minute intervals was 38.6% cars and pickups, 3.0% single-unit trucks, 57.6% semi-trucks, and 0.8% other vehicle type. All of the site visits took place on interstate work zones where the high percentage of semi-trucks was expected. Police enforcement was present in 14.1% of the ten-minute intervals when data were collected. Work zone speed limit signs were located within the activity area on 15.4% of the ten-minute intervals.

Rumble strips were only present on one of the work zones visited, Site Visit 5. This did not provide sufficient information on the effect of rumble strips on work zone speeds to include in the model. Therefore, the data points from Site Visit 5 were removed from the data set and a model was estimated from the remaining seven site visits.

Table 5.3 Sample Statistics for Ten-Minute Intervals (standard deviation in parentheses)

Variable	Values
Range of time periods in ten-minute increments	9:30 pm to 3:30 am
Range of time period indicators: ten-minute intervals before or after midnight. Example: -2 - 11:40 pm -1 - 11:50 pm 0 - 12:00 am 1 - 12:10 am 2 - 12:20 am	-15 to 20
Percent of ten-minute intervals collected before midnight	26.9%
Percent of ten-minute intervals collected after 2:00 am	15.4%
Average of ten-minute interval speeds (mph)	42.27 (5.83)
Average of standard deviation of ten-minute interval speeds	5.28 (1.45)
Percent vehicle type: car/pickup	38.6%
Percent vehicle type: single unit truck	3.0%
Percent vehicle type: semi truck	57.6%
Percent vehicle type: other	0.8%
Average number of vehicles queued during the ten-minute interval	44.67 (45.80)
Average distance behind nearest construction vehicle (ft)	318.62 (364.64)
Average distance in front of police vehicle (ft)	35.04 (87.04)
Average original speed limit of road section (mph)	61.79 (8.30)
Average speed limit posted in work zone (mph)	46.09 (2.08)
Percent of ten-minute intervals with police presence	14.1%
Average number of work site speed limit signs for ten-minute intervals	2.72 (1.70)
Number of changeable message signs for ten-minute intervals	0.97 (0.74)
Percent of ten-minute intervals with rumble strips	11.5%
Average number of open lanes for ten-minute intervals	1.09 (0.29)
Average flow rate (vehicles/hour/lane) for ten-minute intervals	471.77 (291.05)
Average distance from work zone speed limit sign to the first cone/barrel in taper (mi)	0.47 (0.41)
Percent of ten-minute intervals with a work zone speed limit sign within the work zone	15.4%

5.2.2. Seemingly Unrelated Regression Estimation

Seemingly unrelated regression estimation was used to estimate the model system presented previously in Equations 1 and 2. Table 5.4 gives the parameter estimates and model goodness-of-fit measures for mean speed (Equation 1 of the equation system). The table shows that the included variables are of plausible sign and statistically significant (all parameters estimated in the model are significantly different from zero with over 95% confidence). The adjusted R^2 value is 0.78.

Work zones that had two lanes opened (as opposed to one) had mean speeds that were 8.34 mph faster (recall that 5 of our 7 work zones had just one lane open and the other two had 2 lanes open). This means that drivers were less likely to slow down when multiple lanes were open through the work zone, presumably due to the additional maneuvering freedom afforded by the additional lane.

Work zones where the original speed limit was greater than 60 mph were found to have mean speeds that were 4.33 mph faster than works zones with original speed limits below 60 mph. Recall from Table 1 that site visits were made to work zones with original speed limits of 50 mph, 55 mph, 65 mph, and 70 mph. This shows that the magnitude of the difference between the original speed limit and work zone speed limit (set to 45 mph for all work zones except one which retained its initial 50 mph speed limit) is an important consideration.

As shown in Table 5.4, police enforcement was found to decrease the mean speed through the work zone by 5.26 mph. This value is consistent with prior research on the effectiveness of police enforcement. For example, Noel et. al. (1988) found that police enforcement in work zones decreased average speeds by 5.1 mph, and Benekohol et. al. (1992) found that the mean speeds of passenger cars and trucks were reduced by roughly 4 mph and 5 mph, respectively, in the presence of police enforcement.

Table 5.4. Seemingly Unrelated Regression Estimation Results for Mean Speed (mph)

Variable	**Estimated coefficient**	**t-statistic**
Constant	46.26	11.38
Lanes open indicator (1 if two lanes are open, 0 if one lane is open)	8.34	5.39
Speed limit indicator (1 if the original speed limit of the roadway is greater than 60 mph, 0 otherwise)	4.33	3.61
Police presence indicator (1 if police enforcement is present, 0 otherwise)	-5.26	-4.14
Distance from work zone speed limit sign to first cone or barrel in taper (in miles)	4.61	5.37
Percent of semi trucks in the traffic stream	-0.112	-4.74
Total traffic flow (vehicles/hour/lane)	-0.00742	-3.50
Before/after midnight time-period indicator Example: -2 for time periods beginning at 11:40 p.m.; -1 for 11:50 p.m.; 0 for midnight; 1 for 12:10 a.m.; 2 for 12:20 a.m., etc.	0.357	3.42
Number of observations		69
Adjusted R^2		0.78
Log-likelihood at zero		-221.34
Log-likelihood at convergence		-161.53

The longer the distance in miles from the work zone speed limit sign to the first cone or barrel in the taper, the higher the mean work zone speed. For each mile of distance between the work zone speed-limit sign and the beginning of the taper the mean speed through the work zone increased by 4.61 mph. This means that each additional tenth of a mile of distance between the work zone speed limit signs and the taper caused an increase in average speed through the work zone of almost 0.5 mph. This is very important to consider when creating a traffic-control plan for a work zone. It is important to note that this distance varied between 0 miles and 1.3 miles among the seven sites considered. Because the longest distance between signs and the taper observed was 1.3 miles, extreme caution should be exercised when using the results presented herein on work zones with this distance greater than 1.3 miles.

Higher percentages of semi-trucks in the traffic flow was found to result in lower mean work zone speeds as expected. The parameter estimate for this variable suggests that a 100% composition of semi-trucks would result in an average speed 11.2 mph slower than if there were no semi-trucks in the traffic flow, and each 1% increase in the composition of semi-trucks would result in a decrease in the mean speed of 0.1 mph. This shows that semi trucks generally drive at lower speeds through work zones and may also be having a speed-calming effect on other vehicles.

Total traffic flow was also found to significantly decrease mean speeds. The parameter estimate shows that for each additional 100 vehicles per lane per hour that pass through the work zone, the average speed decreases by 0.74 mph.

Finally, the indicator variable for the ten-minute time interval in which the data were collected (centered around midnight where its value is equal to 0) was also found to have a statistically significant impact on mean vehicle speeds. The model shows that for each ten-minute interval after midnight there is an increase in average speed of 0.36 mph. For example, data collected at 12:30 a.m. will have an average speed 1.08 mph faster than data collected at midnight (three times 0.36 mph). Data collected at 11:40 p.m. will have an average speed of 0.72 mph slower than data collected at midnight (two times 0.36 mph). This shows traffic speeds gradually increase with time during nighttime projects. This finding must be viewed in light of the data, which is limited to collection between 9:30 a.m. to 3:30 a.m., so extensions to times beyond this interval would be problematic.

Many variables were found insignificant in the mean-speed model. For example, it was speculated that the average speed would increase with the distance away from the active workspace. Because most of the work zones visited were paving operations, this distance often changed from one time interval to the next throughout the site visit as equipment moved forward. However, this distance was not statistically significant. Also, the number of work zone speed limit signs and the number of changeable message signs were found to be statistically insignificant in reducing the mean speed through the work zone. These findings may be related to our limited data – with only seven work zones visited, the amount of variance in the speed control measures across sites is limited.

The seemingly unrelated regression estimation results for the standard deviation of speed (Equation 2) are presented in Table 5.5. This table shows that most of the variables are significant at the 80% confidence level and above. The adjusted R^2 value is only 0.062 which reflects the rather large amount of variance in the speed standard deviation data Despite the low adjusted R^2 value, inclusion of this equation as part of the joint estimation of mean-speed and speed standard deviation significantly improves the parameter estimates of the mean-speed equation.

Table 5.5. Seemingly Unrelated Regression Estimation Results Standard Deviation of Speed (mph)

Variable	**Estimated coefficient**	**t-statistic**
Constant	3.25	1.50
Lanes open indicator (1 if two lanes are open, 0 if one lane is open)	1.12	1.4
Number of worksite speed limit signs	0.27	1.59
Percent of car-pickup-van-SUV in the traffic stream	0.013	1.21
Before midnight indicator (1 if data collected before midnight, 0 otherwise)	-1.45	-2.23
Number of vehicles queued	-0.19	-1.37
Total traffic flow (vehicles/hour/lane)	0.00453	1.95
Number of observations		69
Adjusted R^2		0.062
Log-likelihood at zero		-120.77
Log-likelihood at convergence		-111.70

Looking at the results in Table 5.5, work zones that had two lanes opened (as opposed to one) had speed standard deviations that were 1.12 mph faster. As was the case for the mean-speed parameter estimate, the additional lane allows greater speed-choice flexibility and this seems to increase the mean speed and spread of vehicle speeds.

The number of work zone speed limit signs was significant with each additional work zone speed limit sign increasing the standard deviation of speed by 0.27 mph. This increase in standard deviation may be caused by having only a portion of the driver population reacting to the signs while others do not.

The higher the percentage of personal vehicles (cars, pickup trucks, vans and SUVs) in the traffic flow, the higher the standard deviation of speed. The parameter estimate indicates that a 100% composition of personal vehicles would result in a speed variance 1.32 mph higher than if there were no personal vehicles in the traffic flow. The diversity in vehicle types and drivers in the personal-vehicle category are the likely source of this finding.

Parameter estimates show that time intervals before midnight had a 1.45 mph lower standard deviation than those after midnight. This reflects the higher standard deviation in speed after midnight. It is also interesting that this simple indicator variable fits the speed standard deviation data better than the more involved time-period indicator variable used in the mean-speed model.

The number of vehicles queued during the ten-minute interval was found, as expected, to reduce the standard deviation of speed. Recall that a queued vehicle is defined as one that trails a lead vehicle by less than 4 seconds – the idea being that the driver's choice of speed in a queued vehicle is potentially restricted by the lead vehicle. The parameter estimate shows that for each additional 100 vehicles queued during the time interval, the speed variance decreased by 2 mph. As one would expect, as the number of queued vehicles increases, vehicles were less able to drive much above or below the average speed of traffic. With slower vehicles causing queues, the standard deviation of vehicle speed is reduced.

Finally, total traffic flow was found to increase the standard deviation of speed (for each additional 100 vehicles per lane the standard deviation of speed increases by 0.45 mph). This might seem counterintuitive at first because one would expect that as the roadway becomes more congested the standard deviations of spot speeds would decline. But with the data in nighttime work zones, total traffic flows do not exceed 1000 veh/hr/lane and are often well below this value. Thus the flows per lane per hour are well below congested conditions. It appears this variable is capturing greater diversity in the driver population as flow increases and, because queued vehicles are already taken into account in another variable, this diversity leads to greater standard deviation.

To provide some evidence that seemingly unrelated regression estimation is improving parameter estimates relative to ordinary least squares estimation of Equation 1, a likelihood ratio test was conducted. The test statistic is, $X^2 = -2[LL(\beta_{OLS}) - LL(\beta_{SURE})]$ where $LL(\beta_{OLS})$ is the log likelihood at convergence of Equation 1 estimated by ordinary least squares and $LL(\beta_{SURE})$ is the log likelihood at convergence of Equation 1 estimated by seemingly unrelated regression. This test statistic is χ^2 distributed and, with $LL(\beta_{OLS})$ = -165.79 and $LL(\beta_{SURE})$ = -161.53, our estimates show that the hypothesis that OLS and SURE estimates are the same with over 99.5% confidence can be rejected, suggesting seemingly unrelated regression is significantly improving model estimates.

5.2.3. Cost Comparison

The final step in evaluating the effectiveness of the studied speed control methods is a simple cost comparison. The effects on mean speed found in the SURE model are shown in Table 5.6. An approximate cost per day for work zone speed limit signs and changeable message signs was compiled using INDOT bid tabulation figures for the projects on which site visits were made (INDOT 2007). Work zone speed limit signs were bid as the cost per sign. Daily set up and take down of the signs throughout the duration of the project were included in this price. To calculate the cost per day of each work zone speed limit sign the unit price was divided by duration of the project. While the early start date of the project was not included in the bid results, the number of days was included as a quantity for bid items priced per day. This duration was used to calculate the cost per day of each sign. Changeable message signs were bid as cost per day. The cost per day of work zone speed limit signs and changeable message signs was calculated for each project visited and then averaged. The cost for rumble strips was not determined as the project using rumble strips was bid as a lump sum contract.

The cost per hour of police enforcement was obtained from Pat McCarty, a Supervisor in the Work Zone Safety Section of INDOT who was able to provide additional insight into the billing process for work zone police enforcement. Volunteer off-duty lower ranked police officers are paid $30 per hour for work zone enforcement. If there are no volunteers, higher ranked off-duty officers are used for work zone enforcement and are paid up to $47 per hour. Additionally, vehicle usage is compensated at $0.40 per mile for up to 30 minutes of travel time to and from the project. There is no price differentiation between day and night work zone police enforcement (Pat McCarty, communication, March, 2007).

The Memorandum of Understanding (MOU) created between INDOT and the Indiana State Police Department is used to designate responsibilities between both parties for police enforcement on work zones. Each year, the MOU contains a list of construction work zones to receive extra patrols. The project list is compiled by INDOT by gathering a list of projects that need police enforcement from each district office. The projects are evaluated on the safety of the road and given a rank. The projects are then sorted by rank and priority is given to the projects needing police enforcement (Pat McCarty, communication, March, 2007).

Table 5.6 Cost Comparison of Speed Control Methods

Speed Control Technique	Effect on Mean Speed	Approximate Cost to INDOT
Work Zone Speed Limit Sign	Increase of 4.614 mph for each additional mile distance between signs and the start of the taper.	$3.70/day
Changeable Message Sign	No significant effect on mean speed found.	$36.40/day
Police Enforcement	Mean speed decreases by 5.260 mph when police are present.	$30/hr - $47/hr plus $0.40/mile
Rumble Strips	Additional site visits needed.	-

Work zone speed limit signs are less expensive than changeable message signs and police enforcement. Due to the correlation between the number of signs and the original speed limit of the roadway, the effects of the number of signs on mean speed could not be found significant. However, an increase in the distance between work zone speed limit signs and the work zone was found to increase mean speeds. Changeable message signs, while more expensive than work zone speed limit signs, are already being used on many nighttime work zones but were not found to affect mean speeds. Various messages may improve their effectiveness. Police enforcement was found to reduce mean speeds by 5.26 mph. It also was the most expensive method of speed control in the study. The INDOT practice of using police enforcement on high risk projects should be continued.

5.3. Conclusion

The goals of this research were to demonstrate a methodology and provide some additional insight into the nighttime speed control strategies that may help to improve safety for workers and the traveling public. Data were collected from July to November 2006 on work zone characteristics and vehicle speeds on seven Indiana nighttime work zones that deployed a variety of speed control methods. Seemingly unrelated regression estimation (SURE) was used to simultaneously model mean speed and speed standard deviation. The model estimation results show that the number of open lanes, original speed limit of the road section, distance from the work zone speed limit signs to the beginning of the work zone taper, and the passing of time through the night – all resulted in higher mean speeds through the work zone. In contrast, police enforcement, percentage of semi trucks, and flow rate all decreased the mean speed. The estimation results for the model of the standard deviation of speed indicated that the number of open lanes, number of worksite speed limit signs, percentage of personal vehicles and traffic flow all increased the standard deviation of spot speeds through the work zone. Whereas observing speeds before midnight and a higher number of queued vehicles decreased the standard deviation of speed.

5.3.1 Limitations

The number of worksites visited limited the ability of the research team to assess many of the possible speed control strategies in nighttime work zones. This was further complicated by the fact that some of the work zone projects employed multiple speed control methods – making it statistically difficult to distinguish the individual effect of each speed control method on mean speed and speed standard deviation due to multicollinearity. However, even with our limited data, it was possible to statistically quantify the effectiveness of police enforcement and the distance between speed control signs and the active work zone in terms of reducing work zone speeds. Gathering additional data and applying the seemingly unrelated regression estimation approach would be a fruitful direction for future research and lead to additional insights on work zone speed control effectiveness. Specifically, additional data could allow assessing various flashing light options on construction speed-limit signs, the effect of varying the location and number of the speed-limit signs based on the length of the work zone, the effect of varying the placement of the signs based on the location of the active workspace within the work zone, and a multitude of other factors aimed at reducing speeds in nighttime work zones.

5.3.2. Recommendations for Future Work

This portion of the study investigated the effects of speed control methods on mean speed and the standard deviation of speed in nighttime work zones. While the conclusions provide insight for improved speed control strategies for nighttime work, further research is required. The following recommendations extend beyond the limitations of this study and address issues which require further investigation.

The SURE analysis indicated that the methods of speed control were correlated with each other and with the original speed limit of the roadway. The majority of work zones visited employed a combination of speed control methods. Thus, determining the effectiveness of the individual speed control measures was difficult. Future studies should attempt to separate out speed control methods to test each individually while keeping all other work zone characteristics the same.

Changeable message signs were not found to be significant for lowering mean speeds or speed variance in this study. On the work zones visited, changeable message signs were used as informational devices, not as speed control. Messages such as “Work Zone Ahead” and “Right

Lane Closed, Merge Left" were seen. However, prior studies did find changeable message signs effective in influencing speeds when messages were geared towards speed reduction. Further evaluation regarding changeable message signs as a speed control method on nighttime projects should be considered as they are already currently used in nighttime work zones. A comparison of speed reduction for various messages should also be evaluated.

The work zones visited varied in length from under one mile to twenty-one miles. This distance was not included in the model as the exact work zone length was not known on some of the projects. Also, the location of the active workspace within the work zone often changed as many of the projects were paving operations. The effect of the location of the active workspace on speed was also not a part of the model. In addition, the complexity of the work zone as observed by drivers may affect speeds. Some level of complexity may in fact reduce speeds without adding additional danger. The effect of the length of the work zone, the location of the active workspace within the work zone, and the complexity of the work zone on speeds should also be investigated, as speed control strategies should be tailored to the characteristics of the work zone.

Finally, in this study work zone speed limit signs were not shown to reduce mean speeds through nighttime work zones. All but one work zone visited used work zone speed limit signs, however, the number of signs varied. The SURE model attempted to determine the effect of each additional work zone speed limit sign on speed. This was inconclusive as the number of signs was highly correlated with the original speed limit of the roadway. Future examinations should include a before and after study of work zone speed limit signs on maintenance projects. Currently in Indiana, maintenance projects are the only work zones that are consistently without work zone speed limit signs where a before and after study could safely be conducted. Further research should also study additional work zone speed limit sign characteristics to maximize their effectiveness in reducing speeds. These include the following: (1) testing various flashing lights on top of the sign, (2) varying the location and number of the signs based on the length of the work zone, and (3) varying the placement of the signs based on the location of the active workspace within the work zone.

CHAPTER 6. EVALUATION OF CURRENT HIGH-VISIBILITY PPE PRACTICES AND DIFFERENT TYPES OF HIGH-VISIBILITY PPE

In order to evaluate current high-visibility PPE practices, the perspectives of owners, workers and general contractors was gathered. A testing procedure was developed and the perspectives of drivers were obtained to compare the visibility regarding the visibility of different types of safety garments.

The research methodology of this portion of the study consisted of three stages. The initial stage was the basis for the subsequent stages and included the identification of factors that determine the effectiveness of PPE and the identification of available and currently used PPE and PPE implementation practices. This stage was accomplished through a literature review and site visits to nighttime construction and maintenance projects. The second stage of consisted of the data collection process which was divided into two phases: (1) surveys deployed to owners, workers, and general contractors for evaluating current high-visibility practices in nighttime work zones and (2) videos of different high-visibility personal protective equipment were recorded in a simulated nighttime work zone and then shown to drivers who rated and compared the visibility of the garments. The final stage included a descriptive and statistical analysis of the data collected.

6.1 Data Collection

The data collection activity consisted of two phases. During the first phase, surveys were distributed to the owners, workers, and general contractors for the nighttime construction projects. The second phase involved an experimental procedure and a survey that was distributed to highway drivers.

6.1.1 Owner, Worker, and General Contractor Survey

The first phase of the survey data collection process consisted of three different questionnaires distributed to the owners (INDOT), workers, and general contractors for the nighttime construction and maintenance projects. The purpose of these surveys was to obtain their perspectives regarding PPE implementation procedures and current high-visibility PPE practices and effectiveness for improving worker visibility.

The three surveys were distributed between October 2006 and March 2007 through the U.S. mail, e-mail, INDOT staff meetings, and site visits. Tables 6.1, 6.2, and 6.3 show the rates of response to the surveys by owners, workers, and general contractors, respectively.

Table 6.1 Owners' Response Rate by DOT Personnel Category

Description	**Responses Received**	**Rate of Response**
INDOT Safety Directors	8	100%
INDOT Supervisory Personnel	2	100%
Midwest Work Zone Roundtable	2	13%
Total	12	

Table 6.2 Workers' Response Rate by Work Performed

Description	**Responses Received**	**Rate of Response**
INDOT Workers	56	29%
Construction Workers	13	37%
Total	69	

Table 6.3 General Contractors' Response Rate by State

Description	**Responses Received**	**Rate of Response**
Indiana	10	53%
Illinois	4	100%
Minnesota	0	0%
Michigan	0	0%
Kentucky	0	0%
Ohio	0	0%
Montana	1	100%
Total	15	

6.1.2 Drivers' Survey

The second phase of the survey data collection was divided into two main tasks. Videos of different high-visibility safety garment assemblies were prepared in a simulated work zone, which was then shown to automobile drivers who were asked to compare the visibility of the different PPE assemblies.

After two were controlled environments done to perfect the testing procedure, a simulated maintenance work zone (Figure 6.1) was set-up on interstate I-74 in southeast Indianapolis between Exits 96 and 99 was used. During the test, a worker wore the high-visibility garments and was videotaped in the active work zone area while performing two different tasks in two positions: position 1 and position 2. Figure 6.2 is a photograph showing the position chosen from site visit #8 (maintenance project). In position 1, the worker is facing to the traffic and in position 2, the worker is facing away from the traffic.

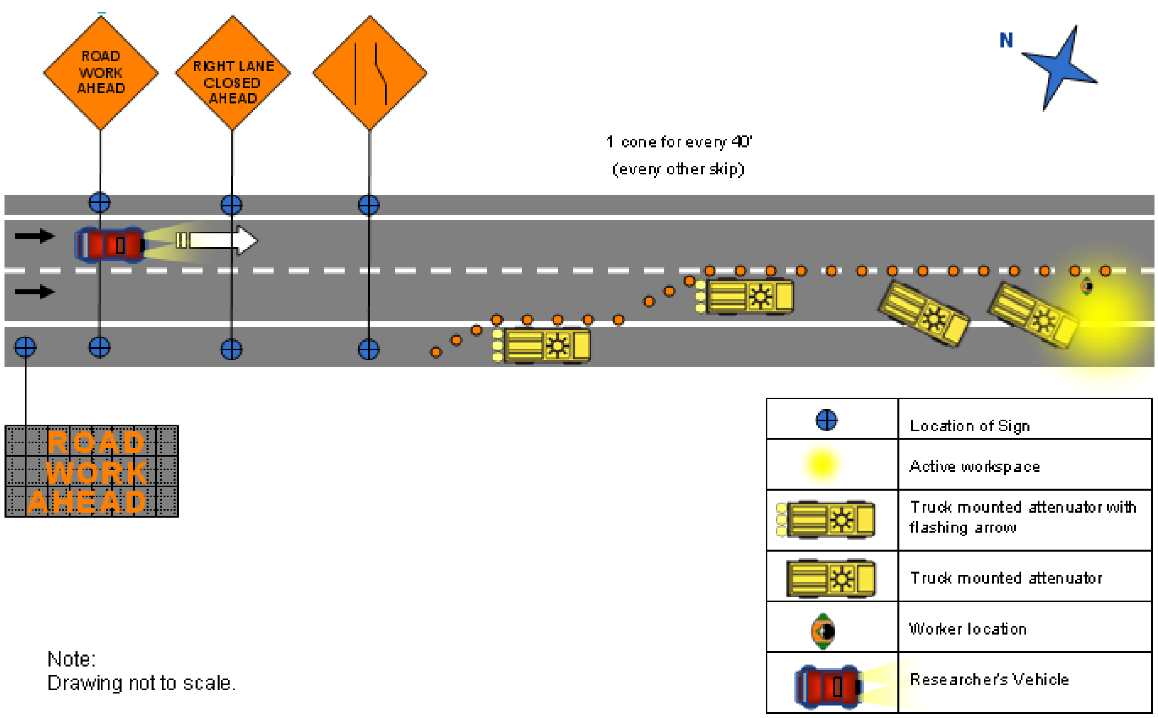


Figure 6.1 Test Layout for Data Collection – Phase II

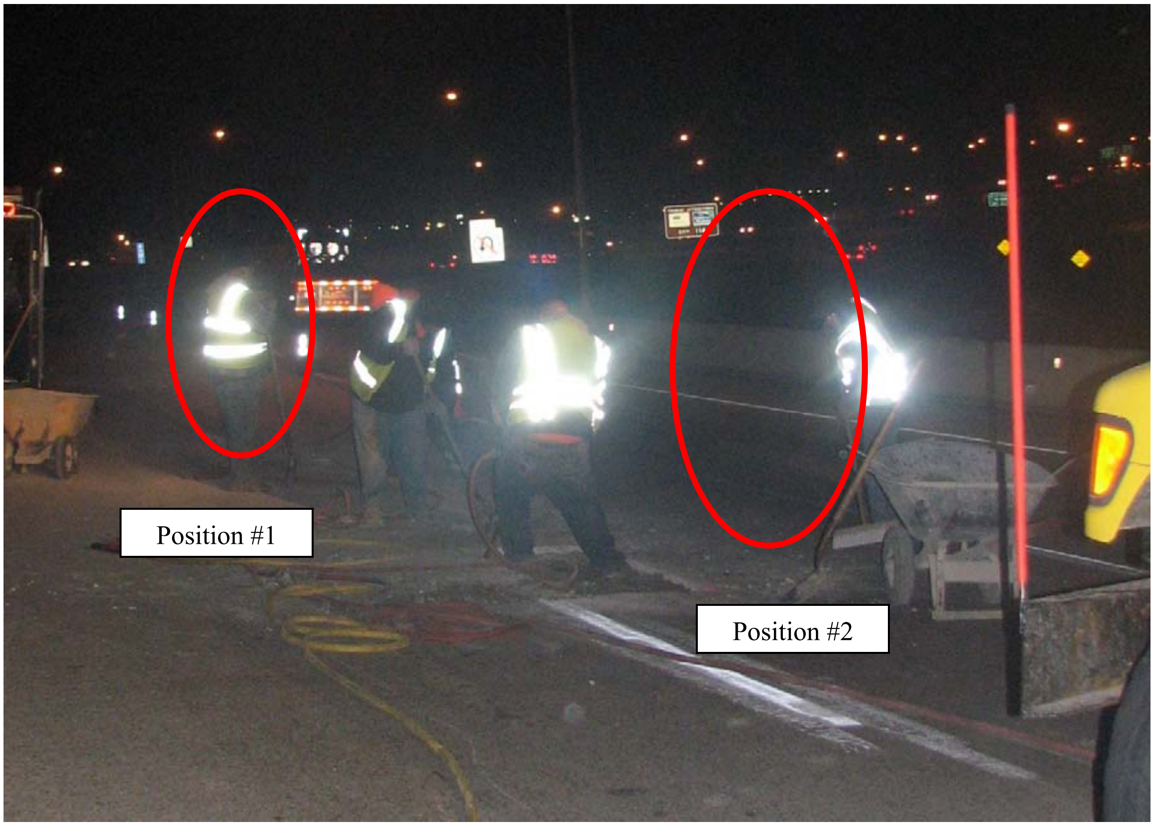


Figure 6.2 Photograph of positions used in testing (photo taken during Site Visit #8, I-65 Downtown Indianapolis, on November 14, 2006)

Fourteen different types of high-visibility PPE, described in Table 6.4, were considered in this study, all of which were yellow-green in color with white retroreflective material. Multiple coefficient of retroreflection (R_A) measurements were taken for each high-visibility PPE using a 930C retroreflectometer. The measurements were taken at an angle of incidence of 2 degrees, which was used to simulate the observation angle of the driver, and -4 degrees, which was used to simulate the entrance angle of the illumination.

Fifteen clothing assemblies were created by combining two or more high visibility items. The high-visibility PPE assemblies all meet the minimum requirements for Performance Classes 2 or 3 of the ANSI/ISEA 107-2004. Table 6.5 describes the different assemblies worn by the workers and Figures 6.3 through 6.17 show the assemblies.

Table 6.4 Description of high-visibility PPE used

Item	PPE	Performance Class	Amount of Retroreflective Material (in^2/front face)
1	INDOT Safety Vest	II	132
2	Short Sleeves Safety Vest	III	149
3	OccuLux Hi-Viz Breathable Safety Pants	E	96
4	High-visibility Headgear	Headwear	0
5	Arm and knee bands	-	42
6	Self-illuminated Vest	II	136
7	High Visibility T-shirt	II	101
8	Mesh Vest	II	112
9	Crew neck sweatshirt	II	100
10	Hooded Sweatshirt	III	158
11	High-visibility windbreaker	III	158
12	High-visibility 5-in-1 winter coat	III	226
13	Reversible high-visibility rain jacket	III	126
14	Rain suit (jacket and pant)	III	285

Table 6.5 PPE Assemblies

Assembly	High Visibility PPE Item													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
a (control)	✓			✓										
b	✓			✓	✓									
c	✓		✓	✓										
d		✓	✓	✓										
e		✓		✓										
f				✓	✓		✓							
g				✓			✓							
h				✓		✓								
i				✓				✓						
j				✓					✓					
k				✓						✓				
l				✓							✓			
m				✓								✓		
n				✓									✓	
o				✓										✓

Legend:

▲→ White retroreflective material; **O**→ orange fabric; ★ → lime-green fabric;
●→retroreflective bands; ■→ lime green high-visibility pants; ◆→ black fabric; ✚→ LED

a) Front View b) Back View

Figure 6.3 High-Visibility PPE Assembly *a*

a) Front View b) Back View

Figure 6.4 High-Visibility PPE Assembly *b*

a) Front View b) Back View

Figure 6.5 High-Visibility PPE Assembly *c*

a) Front View b) Back View

Figure 6.6 High-Visibility PPE Assembly *d*

a) Front View b) Back View

Figure 6.7 High-Visibility PPE Assembly *e*

a) Front View b) Back View

Figure 6.8 High-Visibility PPE Assembly *f*

a) Front View b) Back View

Figure 6.9 High-Visibility PPE Assembly *g*

a) Front View b) Back View

Figure 6.10 High-Visibility PPE Assembly *h*

a) Front View b) Back View

Figure 6.11 High-Visibility PPE Assembly *i*

a) Front View b) Back View

Figure 6.12 High-Visibility PPE Assembly *j*

a) Front View b) Back View

Figure 6.13 High-Visibility PPE Assembly *k*

a) Front View b) Back View

Figure 6.14 High-Visibility PPE Assembly *l*

a) Front View b) Back View

Figure 6.15 High-Visibility PPE Assembly *m*

a) Front View b) Back View

Figure 6.16 High-Visibility PPE Assembly *n*

a) Front View b) Back View

Figure 6.17 High-Visibility PPE Assembly *o*

Once the experimental set-up was assembled in the controlled and simulated work zones, a video camera was mounted on the dashboard inside a passenger automobile. The research team passed multiple times through the open lane of the work zone and recorded the approach view of the worker. A video was made for each assembly in both worker positions for a total of 30. The videos were recorded at 45 mph, which is the posted work zone speed limit on Indiana's interstates. The purpose of this set-up was to obtain an image similar to that seen by drivers while passing through the work zone.

Since lighting can be a significant factor in the conspicuity of high-visibility apparel, the amount of light in the active work zone was measured in candles and lux using an electronic light meter. The measures were taken to obtain a range of representative lighting levels in the work zone when the test automobile was passing at an average of approximately 1,000 feet and 180 feet before the testing assembly

Data was collected in this second phase from 148 questionnaires distributed in April 2006 to different groups of Civil Engineering students at Purdue University, West Lafayette, Indiana. Each video was approximately seven seconds long and showed the last portion of the work zone. Immediately after watching a pair of videos, the subjects were asked to compare the visibility of the high-visibility safety garments they saw regarding which of the two assemblies shown in the videos were the most visible or if there was no difference among their visibility. In order to rank the difference among the assemblies in the videos, after each pair-wise comparison the subject rated the difference in visibility using the following scale: 1-small, 3-mediun, and 5-big. The majority of the respondents were between 21 and 22 years old. Eighty-four percent (84%) of the respondents were male and 16% of the respondents were female.

6.2 Data Analysis

The data from each collection phase was analyzed. For the first phase, a descriptive analysis was completed, and a statistical analysis was conducted for the second phase. A binary probit model with random effects was developed in an effort to represent the data.

6.2.1 Data Analysis for Survey Distributed to Owners, Workers, and General Contractors

In the first phase of the data collection, the data were evaluated using graphic, tabular, and summary statistics descriptions. For part of the analysis, the responses of the owners, workers, and general contractors were combined to compare their perspectives and to determine consensus opinions.

The respondents were asked about the types of PPE commonly used in nighttime construction operations. Figure 6.18 shows the number of responses for each PPE. The majority of the respondents said that high-visibility hardhats, protection for hands, eyes, and feet protection and high visibility safety vests are commonly used. A few respondents said that high-visibility Performance Class III garments, such as sleeved safety vests, are used. Miller (2007) found that the average vehicle speeds in nighttime operations vary from 10 mph to 75 mph, and a literature review revealed that for speeds greater than 50 mph, Performance Class III should be used.

Regular and effective training is necessary to ensure that the workers are making the best use of the PPE for their safety and for the durability of the PPE. The respondents were asked to give their perspective on the effectiveness of the PPE training. More than 56% of the workers strongly agreed that PPE training is effective. However, 28% were either neutral or believed that PPE training was ineffective. The majority of all the groups surveyed agreed that training is effective.

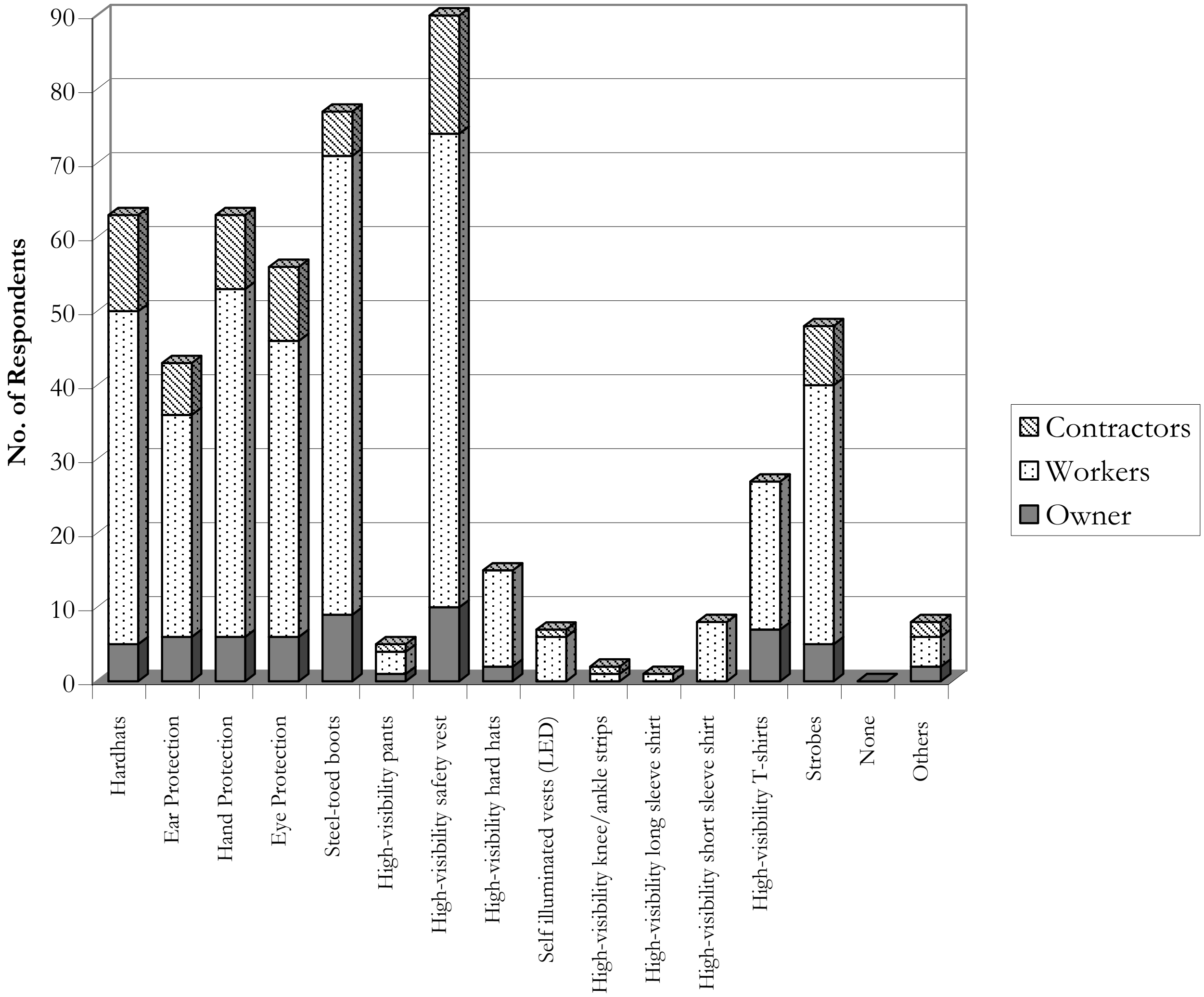


Figure 6.18 PPE usage in nighttime construction and maintenance operations

Workers are expected to receive safety training when they are hired. It was found that 16% of the workers surveyed did not receive this training. The majority of the workers said that they received orientation on how to use a PPE and which PPE is applicable for a certain type of work. However, only a few said they received training on when to dispose of the PPE. If workers are not well trained in this area, they could continue using PPE that does not provide the full protection for which it was designed.

From those workers who responded the survey, 79% said they received on-going training on PPE. The majority of this proportion of workers said this training is received daily, whereas more than 50% of the respondents said this training is biweekly or at longer intervals of time.

Approximately 70% of the general contractors and workers said they received on-going training regarding PPE.

As stated in Chapter 2, the OSHA 10-hour General Industry Outreach Training includes a section on PPE, which covers examples of PPE, establishing a PPE program, and training requirements. The workers were asked whether they had completed the 10-hour or 30-hour OSHA training. As shown in Figure 6.19, the majority of the respondents had not taken either of the OSHA trainings.

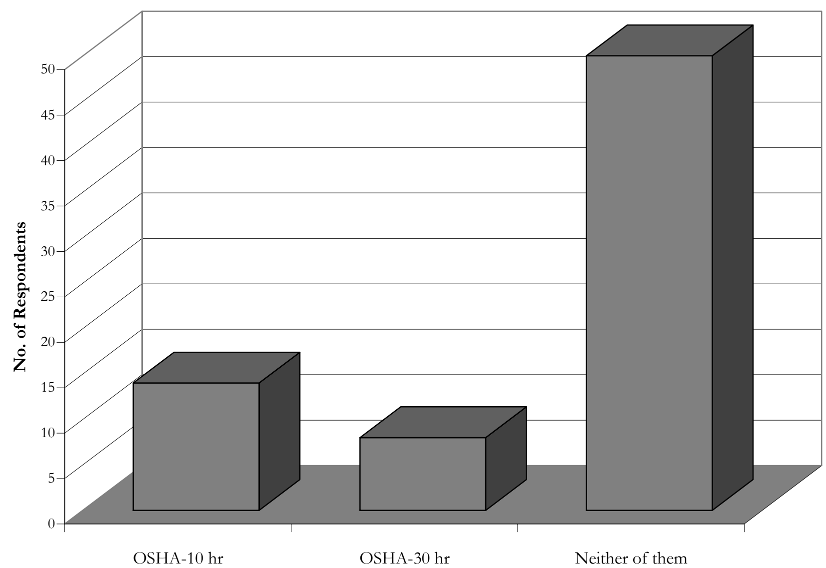


Figure 6.19 OSHA training taken by workers

In addition to providing effective training to workers, it is vital to verify that the workers understand the safety procedures regarding the use of PPE. Forty three percent of the general contractors and 45% of the owners said they do not have such strategies. In addition, 33% of the general contractors and 10% of the owners said they do not have strategies to ensure that the worker is using the PPE; and 38% of the general contractors have experienced resistance regarding PPE use. General contractors and owners need to develop strategies to ensure that workers understand the training and are correctly using the PPE. The plan should also emphasize the importance of using the PPE. If this knowledge does not motivate the worker, non-monetary rewarding incentives could be used, such as the selection of "the safest employee of the month."

All of the general contractors surveyed said they have a written safety program that addresses PPE and have a designated person on a project to ensure that safety procedures are followed. This person is usually the safety manager or the superintendent. The majority of the general contractors indicated that the safety manager or the superintendent is in charge of deciding which PPE will be purchased and used for a specific type of work. Workers were also asked who is responsible for choosing the PPE that will be used for a specific type of work and 36% of the respondents said the foreman is responsible, and 28% said they use the same PPE they already have.

The proper sizing of safety garment must be considered when analyzing PPE practices because doing so increases the durability of the garment (Zeiger 2001), ensures that the garment will perform as designed, and ensures that the equipment itself does not cause discomfort or pose a further hazard (WSIB 2003). The workers and general contractors were asked how the sizes of the garments were chosen. As shown in Figure 6.20, the majority of the workers said they were chosen based on experience while the general contractors' answers were equally distributed among (1) past experience, (2) size chart and (3) other methods such as buying various sizes and workers' feedback. In addition, the majority of the workers (89%) and general contractors (80%) said that all workers use the same type of safety garment while engaging in a project activity.

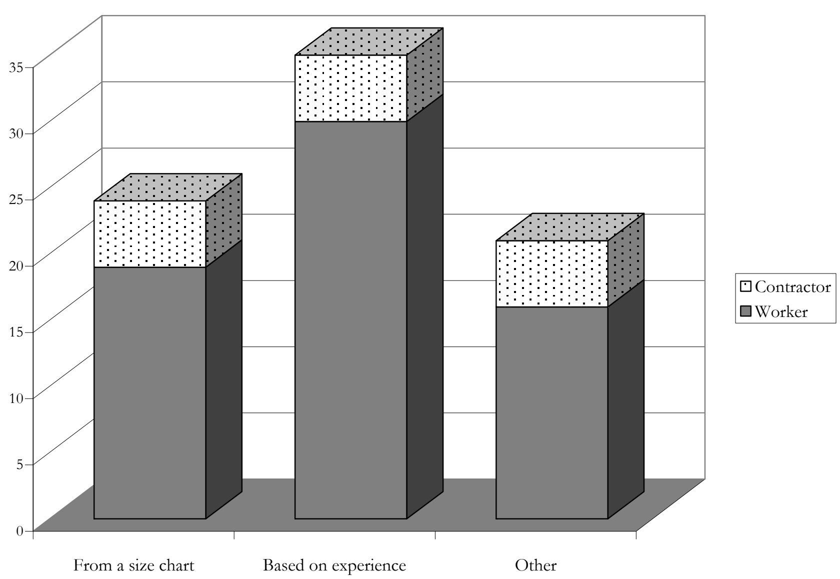


Figure 6.20 Selection of garment size

Other results from the surveys related to PPE selection and management can be summarized as follows:

- 73% of the owners do not require contractors to use a specific type of PPE.
- 88% of the workers said they have pre-activity safety meetings that discuss PPE.
- 89% of the workers said all workers use the same high-visibility garment on the same project.
- 90% of the workers said they have not used a high-visibility vest with sleeves or safety pants.
- 93% of the workers said they use a safety garment that is assigned for their exclusive use, which agrees with the responses of the contractors.
- 98% of the workers receive PPE training in safety meetings.
- 100% of the workers attend safety meetings.
- OSHA regulations are the primary standards used by general contractors to regulate PPE.
- Fourteen out of the 15 representatives of construction companies who completed the survey said they are familiar with ANSI/ISEA 107-2004.

The subjects were asked to rate the importance of some of these characteristics when choosing a safety garment. As shown in Table 6.6, the owners, workers, and general contractors gave the smallest importance score to the cost of the PPE. However, as can be anticipated, owners and general contractors gave more importance to this attribute than the workers. For the owner, the most important attributes to consider when choosing a high-visibility PPE were that it should allow unrestricted movement and that it should not prompt the worker to take unnecessary risks. Of major importance to the worker was that the PPE allows comfortable movement. For the general contractor, the quantity of retroreflective material was the most important characteristic that should be considered when choosing a safety garment.

Table 6.6 Comparisons of responses of owners, workers, and general contractors regarding the importance of different high-visibility PPE characteristics

High-Visibility PPE	Owner	Worker	General Contractor	Average
Lightweight	4.25	4.28	4.06	4.2
Durability	4.31	4.25	4.38	4.3
Allows comfortable movement	4.46	**4.58****	4.63	4.6
Breathable fabric	4.31	4.32	4.38	4.3
Color	4.54	4.42	4.63	4.5
Quantity of retroreflective material	4.85	4.39	**4.88****	4.7
Retroreflective pattern	4.38	4.11	4.38	4.3
Cost	**3.85***	**2.79***	**3.63***	3.4
Clearly identifies wearer as a person	4.85	4.53	4.69	4.7
Visible through the full range of body motions	4.62	4.34	4.56	4.5
Allows unrestricted movement for performance of any task	**4.92****	4.54	4.75	4.7
Does not prompt the worker to take unnecessary risks	**4.92****	4.22	4.56	4.6

* Less important
** Most Important

The owners, workers, and general contractors were asked in the surveys to assess the effectiveness of the currently used high-visibility PPE by rating based on factors identified in the literature review. As shown in Table 6.7, the lowest average scores were 2.69, 2.33, and 2.81 for owners, workers, and general contractors respectively and showed a consensus low score for "work is performed without safety concerns." These scores are between the "disagree" and "neutral" choices and were predictable for nighttime construction operations. For the owner and worker, the highest scores were given to "PPE training is effective." For the general contractor, the highest score was given to "clearly identifies the worker as a person."

Table 6.7 Comparisons of the average of answers of owners, workers and general contractors regarding the effectiveness of currently used safety garment.

High-Visibility PPE	Owner	Worker	General Contractor	Average
Currently used PPE is effective to ensure nighttime construction safety	3.62	3.26	3.94	3.6
Work is done without safety concerns	**2.69***	**2.33***	**2.81***	2.6
The worker feels comfortable	3.25	3.22	3.94	3.5
PPE training is effective	**3.83****	**3.81****	3.88	3.8
Clearly identifies the worker as a person	3.69	3.43	**4.13****	3.8
Makes the worker visible through the full range of body motions	3.31	3.25	4	3.5
Is of safe design and construction for the work to be performed	3.77	3.42	3.94	3.7
Does not give a false sense of security	3.77	3.68	3.5	3.7

*Smallest score
** Largest scores

The subjects were also asked to rate the performance of the high visibility PPE as far as improving worker visibility. The majority of the owners and workers said the PPE performance was good, while the majority of the general contractors said the effectiveness was between good and excellent. As shown in Figure 6.21, when all the answers of the three groups surveyed are combined, the majority of the respondents (46%) felt that the currently used overall effectiveness was good, 7% of the respondents felt it was excellent, and 23% of the respondents believed the PPE performance was less than good.

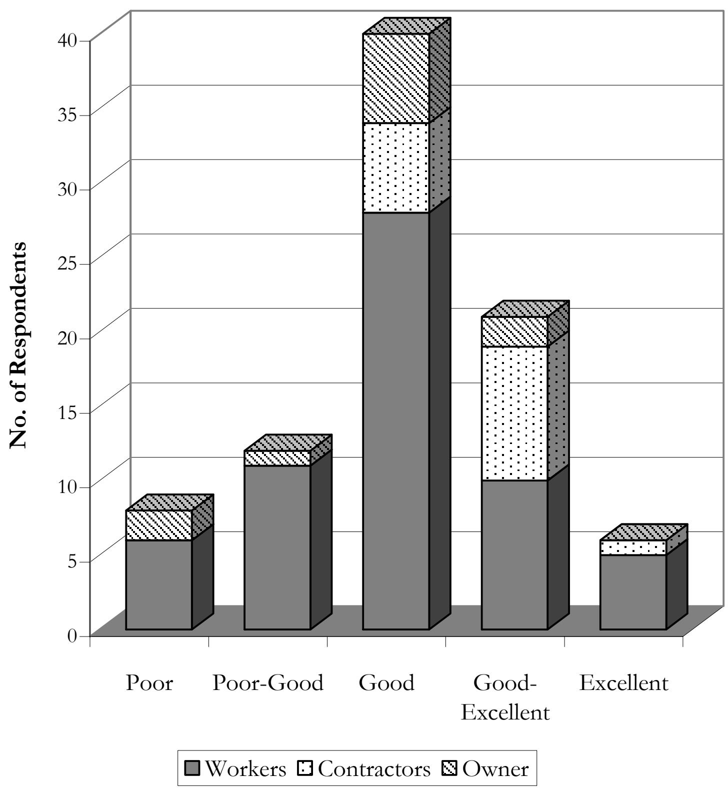


Figure 6.21 Perspectives on performance of currently used high-visibility PPE

In order to know what other types of PPE could be considered for use in nighttime projects, the owners, workers, and general contractors were asked to rate the effectiveness of different types of high-visibility PPE. As shown in Table 6.8, retroreflective knee/ankle bands received the average smallest effectiveness score for each group surveyed, and the average highest score was received by safety vests.

Table 6.8 Comparisons of answers of owners, workers, and general contractors for the effectiveness of different types of high-visibility PPE

High-Visibility PPE	Owner	Worker	General Contractor	Average
Pants	3.63	3.14	3.19	3.3
Safety Vests	**4.60****	**4.26****	**4.50****	4.5
Hard Hats	4.13	3.52	3.31	3.7
Self-Illuminated garments	3.14	3.77	3.00	3.3
Knee/ankle strips	**2.80***	**2.76***	**2.38***	2.6
Long Sleeve shirts	3.33	3.27	3.19	3.3
Short Sleeve shirts	3.57	3.64	3.19	3.5
T-shirts	4.00	3.81	3.13	3.6
Strobes	4.12	4.09	3.88	4.0

* Least effective
** Most effective

6.2.2 Data Analysis for Survey Distributed to Drivers

The data obtained from the drivers' survey, was preliminarily analyzed using graphic, tabular, and summary statistics. From this analysis it was then determined that data that would be modeled.

The data consisted of 148 questionnaires distributed to three different groups of Purdue undergraduate students taking civil engineering classes. Each group made a different pair-wise comparison between the different videos. The first comparison consisted of the evaluation of each of the assemblies in both positions studied. The second and third comparisons were between all the assemblies and the INDOT safety vest in positions 1 and 2, respectively. The video of the INDOT safety vest assembly was shown first in both these comparisons. Table 6.9 describes the data samples.

Table 6.9 Description of data samples

Sample	Pair-wise comparison	No. of subjects
Sample #1	Position 1 vs. Position 2	30
Sample #2	INDOT safety vest vs. Assembly X* Position 1	58
Sample #3	INDOT safety vest vs. Assembly X Position 2	60
Total		148

When passing through a work zone, the majority of the respondents indicated they drive at higher speeds than the typically posted 45 mph speed limit. The mean speed according to the drivers was 52 miles per hour with a standard deviation of 6.66 miles per hour. Figure 6.22 shows the distribution of these speeds. An increase in speed considerably reduces the distance available to reach a complete stop once the driver recognizes a worker. A few drivers said their speed would vary depending on whether they see activity or workers in the work zone.

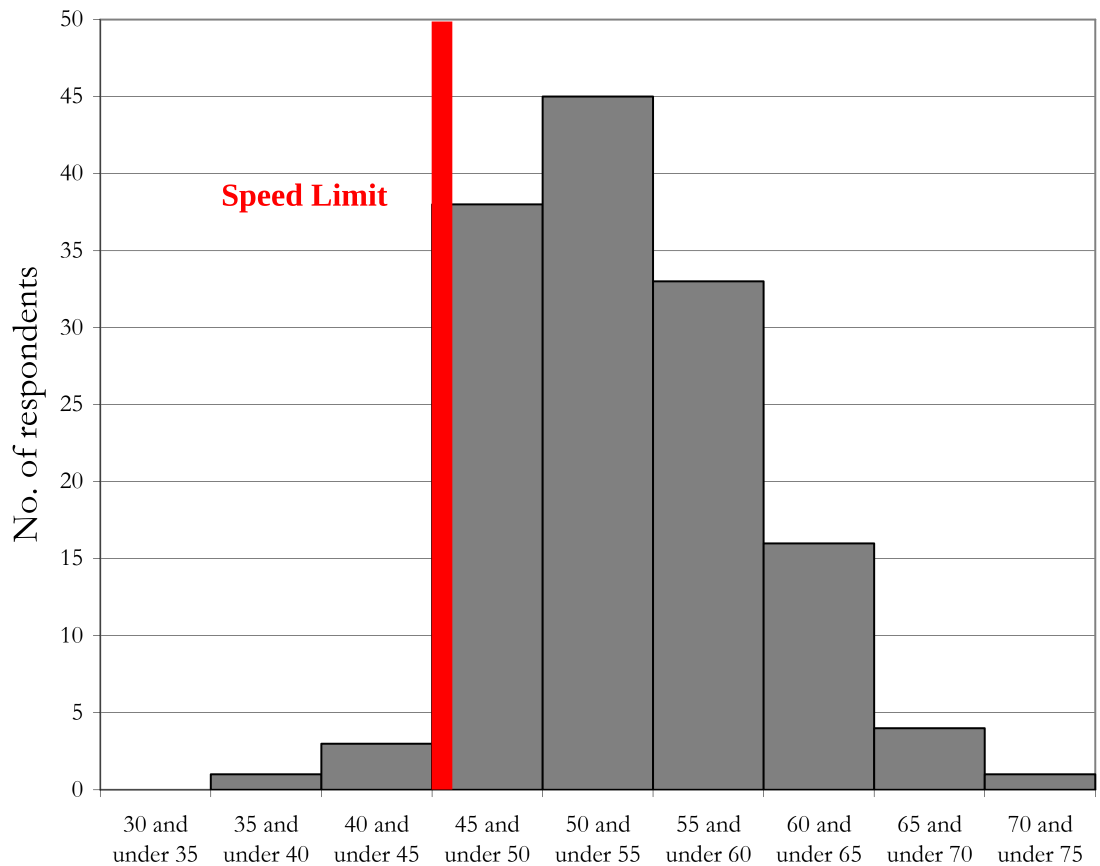


Figure 6.22 Speeds of drivers through a nighttime work zone when the speed limit is 45mph

6.2.2.1 Evaluation of Comparisons between the High-Visibility Assemblies

The first assessment consisted of the pair-wise comparison of a safety garment in different positions (positions 1 and 2). The results for the position comparisons for each assembly are shown in Figure 6.23. In some cases, such as Assembly *f* and *m* (see Figures 6.15

and 6.18), the majority of the respondents thought that the position did not affect the visibility of the garments. However, the majority of the drivers believed that there was difference in visibility between the positions for most of the assemblies. For a majority of the comparisons, the mean of the degree of difference was minimal, at less than 1.5.

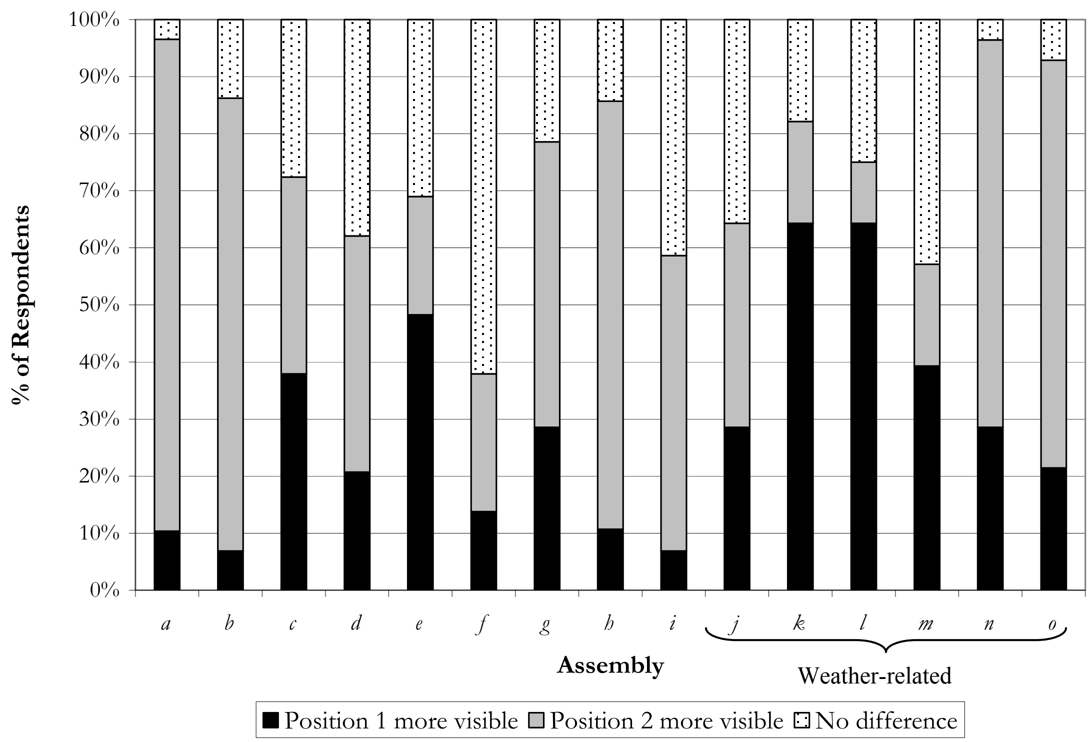


Figure 6.23 Position comparisons for each assembly

The high-visibility PPE currently used by INDOT is a yellow green mesh vest with a four-inch wide fluorescent orange strip with two strips of reflective silver material. This safety vest was used as the standard for comparisons in the driver visibility evaluations. When evaluating the comparisons between the INDOT safety vest and a second assembly (Assembly X) in positions 1 and 2, the distribution of the comparisons was similar for both positions for most of the assemblies, except assemblies *e* and *h*. These results suggest that the positions evaluated affected the visibility of a garment, but did not affect which garment was more visible when comparing INDOT safety vest with Assembly X.

After each pair-wise comparison, the drivers were asked to rate the degree of difference in visibility between the garments, with (1) being little difference and (5) being significant difference. Table 6.10 shows the frequency at which drivers chose each rating for position 1 and

2. The assemblies ranked in the first three places (*d*, *c*, and *b* in that order) were the same three assemblies for both positions evaluated. Assembly *g* was also ranked third in position 2. Assembly *c* is a Performance Class III safety garment with high-visibility long pants, Assembly *b* is the INDOT safety vest with safety pants, and Assembly *c* is the INDOT safety vest with retroreflective bands. Table 6.11 shows the assemblies

Table 6.10 Degree of difference – position 1 and 2

	Assembly	% of Respondents*	Frequency of Responses: Degree of Difference**					Mean	Ranking***
			1	2	3	4	5		
Position 1	***b***	**62%**	4	21	9	2	0	2.3	3
	c	**88%**	4	10	21	11	5	3.1	2
	d	**90%**	0	5	25	18	4	3.4	1
	e	**48%**	9	10	7	1	1	2.1	4
	f	**36%**	8	6	7	0	0	2.0	5
	g	**50%**	11	10	7	1	0	1.9	6
	h	**29%**	5	9	3	0	0	1.9	6
	i	**24%**	4	4	6	0	0	2.1	4
Position 2	***b***	**68%**	9	11	17	4	0	2.4	3
	c	**75%**	5	16	16	8	0	2.6	2
	d	**83%**	5	9	18	14	4	3.1	1
	e	**47%**	11	5	8	4	0	2.2	4
	f	**40%**	8	6	9	1	0	2.1	6
	g	**80%**	12	13	14	9	0	2.4	3
	h	**40%**	8	10	4	1	1	2.0	5
	i	**37%**	8	9	4	1	0	1.9	6

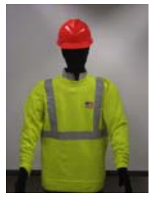
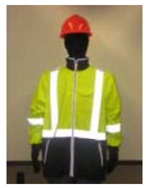
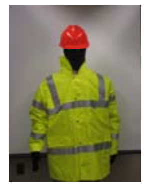
* % of respondents that chose Assembly X as the most visible
** 1=little difference, 5= Big Difference
*** 1=most visible, 6=least visible

Table 6.11 Assemblies ranked in the first, second and third positions for positions 1 and 2

1	2	3
		
Assembly *d* Safety vest with short sleeves + pants	Assembly *c* INDOT safety vest + safety pants	Assembly *b* INDOT safety vest + arm/ankle band

The driver's survey included three pair-wise comparisons between different types of weather-related safety garments: (1) two sweatshirts (assemblies *j* and *k*), (2) two coats (assemblies *l* and *m*), and (3) two rain coats (assemblies *n* and *o*). Table 6.12 shows the weather-related assemblies that were compared. Figure 6.24 shows the comparison of PPE for different weather conditions. The results were very similar for each weather-related PPE type (sweatshirts, coats, and rain coats) in each position. When comparing the sweatshirts, assembly *k* was believed to be the most visible by the majority of the respondents. The majority of the respondents indicated no difference in the visibility of the two coats evaluated. However, of the respondents who found a difference, the majority believed that assembly *l* was more visible. For the comparison of rain coats, the majority of the respondents believed that assembly *o* was more visible.

Table 6.12 Comparisons made for weather-related high-visibility PPE assemblies

Weather-Related Assemblies		
Sweatshirts		
	Assembly *j* Crew neck	Assembly *k* Hooded
Coats		
	Assembly *l* Windbreaker Coat	Assembly *m* 5-in-1 Coat
Rain Garment		
	Assembly *n* Rain jacket	Assembly *o* Rain suit

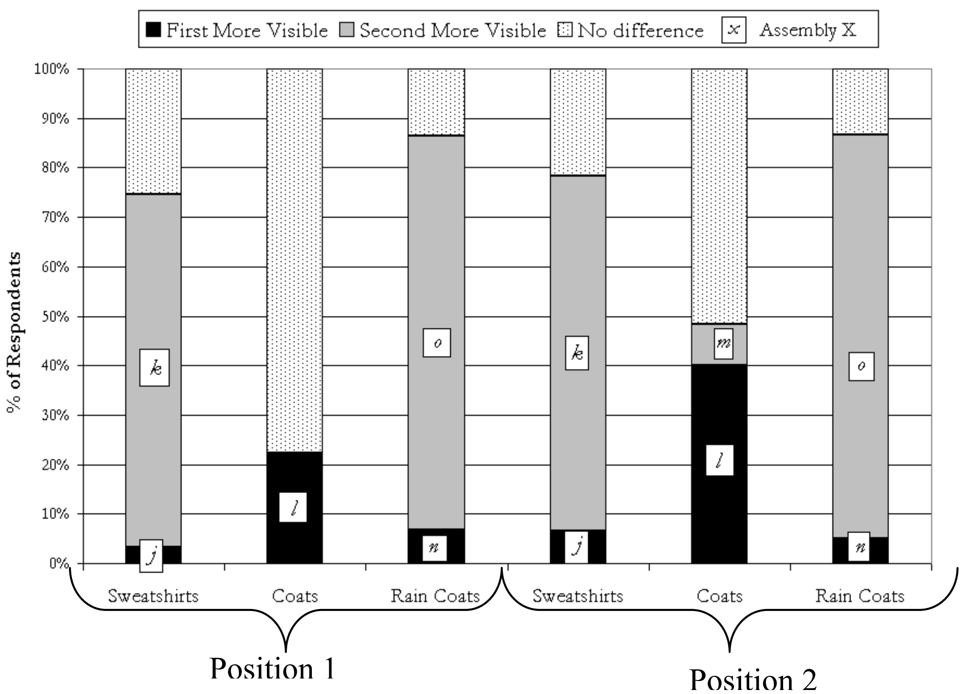


Figure 6.24 Position comparison for weather-related PPE

6.2.2.2 Binary Probit Model with Random Effects

A binary probit model considers two discrete outcomes denoted as (1) or (2); in this case (1) the INDOT safety garment is more visible and (2), Assembly X is more visible. Following Washington et. al. (2003), the formulation for the binary probit model is derived from a simple linear function Z_{in} that determines discrete outcome i for observation n,

$$Z_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{6.1}$$

where β_i is a vector of estimable parameters for discrete outcome i, and X_{in} is a vector of observable characteristics that determine discrete outcomes for observation n. These parameters determine the discrete response for the observation and in this case are related to the characteristics of the assembly, the driver, the video and the display room. The addition of the disturbance term ε_{in} emerges because of the possibility that for instance: (1) variables have been omitted, (2) the form of Eq. 6.1 may not be linear, or (3) variations in β_i are not accounted for (Washington et al. 2003).

If the probability of observation n to have a discrete outcome I is denoted by $P_n(i)$, with I being all possible outcomes for observation n, and ($i \in I$) then,

$$P_n(i) = P(Z_{in} \geq Z_{In}) \ \forall \ I \neq i\ . \tag{6.2}$$

Combining Eq. 6.1 and Eq. 6.2,

$$P_n(i) = P(\beta_i X_n - \beta_I X_n \geq \varepsilon_{In} - \varepsilon_{in}) \ \forall \ I \neq i. \tag{6.3}$$

Washington et al. (2003) state that probit models arise when the disturbance term ε_{In} in Eq. 6.3 is assumed to be normally distributed, resulting in Equation 6.4, which estimates the probability of outcome 1 occurring for observation n:

$$P_n(1) = P(\beta_1 X_{1n} - \beta_2 X_{2n} \geq \varepsilon_{2n} - \varepsilon_{1n}) \tag{6.4}$$

In this equation, ε_{1n} and ε_{2n} are normally distributed with mean = 0, variances σ^2_1 and σ^2_2 respectively, and the covariance is σ_{12}. When there are normally distributed variates, the addition or subtraction of two normal variates also produces a normally distributed variate (Washington et al. 2003)

Each of the responses from the survey subjects resulted in multiple comparisons that will likely share unobserved effects that can result in the underestimation of the standard errors of the model's parameters. This can result in inflated *t* statistics, potentially misleading levels of significance, and potential biases in parameter estimates. These problems can be addressed with a random effects model which includes a normally distributed individual-specific error term (φ_i) to account for random error within each individual (Shafizadeh and Mannering 2006) in addition to the traditional disturbance term of each observation. In this case, Equation 6.1 becomes,

$$Z_{in} \mid \varphi_i = \beta_i X_{in} + \varepsilon_{in} + \sigma_\varphi \varphi_i \tag{6.7}$$

where φ_i is normally distributed with the mean zero and the variance one, and the term σ_φ is an estimable parameter. The development of an estimable model from this equation follows that from Equations 6.2 to 6.6 above. Please note that if σ_φ is not significantly different from zero, the random effects are not significant in the model; and if it is significantly different from zero, then the random effects are significant.

A binary probit model was developed to predict which variables determine whether it is more or less likely that the INDOT safety vest was not chosen as the more visible garment. More details about the development of the model can be found in Valentin (2007). The following independent variables were considered for the analysis: Assembly X–related characteristics, drivers' characteristics, site-related characteristics, and display room characteristics. Table 6.13 shows the variables considered in the development of the binary probit model.

The descriptive statistics for the variables found to be significant in the binary probit model are presented in Table 6.14, and the estimation results for the model are presented in Table 6.15. The model provides information on how the characteristics of the assembly, driver, and site are associated with the perceived visibility of the garments. The table shows that the parameters estimated are statistically significant (all parameters estimated in the model are significantly different from zero with over 90% confidence). The adjusted R^2 value is 0.45. A positive sign in the coefficient means that an increase in the value of the variable or a value of 1 for the indicator variables will make Assembly X more likely to be chosen as the more visible PPE.

Table 6.13 Variables considered in the analysis

Characteristics of Assembly X
Retroreflectivity main garment (mean) (cd/lx/m^2)
Retroreflectivity main garment (variance) (cd/lx/m^2)
Retroreflectivity the main garment (standard deviation) (cd/lx/m^2)
Retroreflectivity secondary garment (mean)(cd/lx/m^2)
Retroreflectivity secondary garments (variance)(cd/lx/m^2)
Retroreflectivity secondary garment (standard deviation)(cd/lx/m^2)
Width retroreflective strips (primary-(in^2))
Amount of retroreflective material main garment (in^2)
Amount of retroreflective material secondary garment (in^2)
Total retroreflective material (in^2)
Amount of background material primary garment (in^2)
Amount of background material secondary (in^2)
Total background material (in^2)
Orange fabric (in^2)
LEDs (1) yes, (2) no
Retroreflective borders (1) yes, (2) no
Orange borders (1) yes, (2) no
Fabric Type (1)mesh (2)polyester (3)cotton

Characteristics of the site
Lux at 180 feet
Lux at 1000 feet

Characteristics of the driver
Driver's age
Driver's gender: (1)male, (2) female
Are you currently? (1) Not affiliated with Purdue (2) Purdue undergraduate (3) Purdue graduate (4) Purdue faculty (5) Purdue staff (other than faculty/TA/RA)
Are you a licensed driver? (1) Yes, (2) No
If you are licensed to drive, how many years have you had a license?
Do you wear glasses/contact lenses? (1) Yes, (2) No
How frequently do you drive at night? (1) Daily, (2) Weekly, (3) Monthly, (4) 3-4 Times a Year, (5) Never, (6) Unsure
How frequently do you encounter a nighttime work zone on highways? (1) Daily, (2) Weekly, (3) Monthly, (4) 3-4 Times a Year, (5) Never, (6) Unsure
If the speed limit in a nighttime work zone is 45mph, how fast would you drive?
What color is the best for improving worker visibility? (1)orange,(2)yellow green, (3) yellow, (4)pink, (5)other

Characteristics related to the display room
Distance from the driver to the point the video was displayed: (1) near – first 4 rows,(2) moderate - middle 3 rows (3) far – last 4 rows.
Side of the room where the driver was seated. (1)left, (2) right

Table 6.14 Statistics for variables found to be significant in random effects binary probit model estimations*

Independent Variable	**Symbol**	**Mean**	**Standard Deviation**	**Minimum /Maximum**
Characteristics Related to Drivers				
Frequency driving at night (1 if daily or weekly, 0 otherwise)	*freqn*	0.92	.26	0/1
Characteristics Related to Assembly X				
Mean of retroreflectivity (cd/lx*m^2) of the main garment	*mmean*	448.75	38.77	410.3/554.4
Variance of retroreflectivity (cd/lx*m^2) of the main garment	*mvar*	119.60	198.71	31.50/679.40
Variance of retroreflectivity (cd/lx*m^2) of the secondary garment	*svar*	262.27	225.72	0/530
Characteristic Related to Site				
Amount of light (lux) at 180 feet	*lux*	6.00	5.61	0/18.45

Table 6.15 Random effects binary probit model of perceived visibility of high-visibility garments*

Independent Variable	**Symbol**	**Estimated Coefficient**	***t* statistic**
Constant		-8.910	-2.620
Characteristics Related to Drivers			
Frequency driving at night (1 if daily or weekly, 0 otherwise)	*freqn*	2.190	1.248
Characteristics Related to Assembly X			
Mean of retroreflectivity (cd/lx*m^2) of the main garment	*mmean*	0.012	2.142
Variance of retroreflectivity (cd/lx*m^2) of the main garment	*mvar*	0.001	1.439
Variance of the retroreflectivity (cd/lx*m^2) of the secondary garment	*svar*	-0.003	-1.401
Characteristics related to site			
Amount of light (lux) at 180 feet	*lux*	1.170	3.179
Model Parameters			
Random effect (Hausman test) parameter σ	φ_i	0.651	3.955
Number of observations	325		
Initial log-likelihood	-132.518		
Log likelihood at convergence	-67.540		
ρ^2	0.49		
Adjusted ρ^2	0.45		

*Dependent variable are zeros (INDOT safety vest) and ones (Assembly X).

The drivers made multiple comparisons that are likely to share unobserved effects. The significance of the random effects parameter (σ), with a t statistic of 3.955 indicates that the random effects element of the model is warranted.

Individuals who drive more frequently at night were found to be less likely to choose the INDOT safety vest as the most visible. This finding may indicate that a frequent driver may get used to seeing the INDOT safety garment in a work zone different garment may captures their attention more effectively. Further, it suggests that high-visibility garments should be changed periodically.

The garment-related characteristics were also found to be significant. Higher values in the mean and variance of Assembly X's retroreflectivity indicate that it is less likely for a driver to choose the INDOT safety vest as the more visible PPE. These findings suggest that garments with lower intensities and a lower variance of retroreflectivity cause the workers to blend into the work zone with inanimate objects, making them less visible to drivers.

However, lower values in the mean of the retroreflectivity of the secondary garment indicate that it is more likely that respondents will choose the INDOT safety vest as the more visible PPE. This finding may reflect that the combination of high retroreflectivity values in the primary and secondary garment is not effective, and differences in the values are needed to make the worker more visible and detectable.

As expected, the lighting at the site was a very significant variable. The higher the intensity of light, the more likely it was that the driver did not choose the INDOT safety vest as the more visible garment. Changes in lighting can be produced by the headlights of passing vehicles and by changes in weather conditions. Greater amounts of lux could mean that more vehicles are passing through the work zone at that time.

6.3 Conclusion

The survey distributed to owners, workers, and general contractors was focused on obtaining their perspectives on current PPE practices in order to improve these practices. Characteristics related to the comfort of the worker were rated as very important when choosing a safety garment. For this reason, the sizes of the garments should be chosen based on a size chart provided by the manufacturer or supplier of the garments. Proper sizing will provide not only more comfort to the worker, but also will result in longer durability and better performance of the garment.

When the subjects were asked about the importance of different factors when choosing PPE, the quantity of retroreflective material on the garment obtained one of the highest scores. Owners and general contractors should consider using Performance Class III garments for nighttime construction operations. For some projects, the performance standards obtained by Class III garments will be higher than those required, but for most projects it will be appropriate. The training procedures can be improved by requiring at least the 10-hour OSHA training. In addition, training workers how to maintain the PPE will increase its useful life, resulting in savings for the owner and/or the general contractor.

From the binary probit model, the characteristics found to increase the likelihood of not choosing the INDOT safety vest as more visible were: the amount of light (lux); the variance of retroreflectivity (cd/lx*m^2) of the main garment; the mean of retroreflectivity (cd/lx*m^2) of the main garment; and the frequency at which the respondents drive at night. The findings of the model reflect that the variance of the retroreflectivity of the secondary high-visibility PPE increased the likelihood of choosing the INDOT safety vest as more visible. This finding suggests that to improve the visibility of current PPE garments there should be differences in the values of retroreflectivity between the primary and secondary high-visibility PPE. In addition, the garments should be changed or rotated with other garments periodically to prevent reduction in their effectiveness.

Overall, Assemblies *d*, *c,* and *b* were ranked as the most visible PPE. Assemblies *d* and *c* are assemblies comprised of the currently used INDOT safety vest and an additional garment. The currently used INDOT safety vest could be improved by adding other PPE items. Different weather-related assemblies also were compared, and it was found that the majority of the respondents believed there was no difference in the visibility of the coats assessed. For the sweatshirts, Assembly *k* (which has retroreflective strips on the arms) was believed to be the most visible by the majority of the respondents. When the raincoats were compared, Assembly *o* (which has high-visibility pants) was found to be more visible.

6.5.1 Limitations of the Research

The results of this portion of the study could be expanded by overcoming the following limitations in the research:

There was a low response to the surveys of the owners and general contractors. A descriptive analysis of the data was possible, but the data were not sufficient for a statistical analysis. A model could be developed predicting how the perspectives of the owners, workers, and general contractors vary according to characteristics such as the type of training received, the project conditions, position within the organization, etc.

Another limitation of the study was that the driver survey considered only one environment. The videos were developed in one simulated nighttime maintenance work zone. Even though the work zone was identical to a real work zone, it would be beneficial to study the differences in the surrounding environments, factors encountered in real work zones such as various workers at the same time, and variability in work zone characteristics such as the type of project and the length of the work zone. In addition, the results from this analysis have not been implemented on-site to validate the binary probit model with random effects.

Another restriction of the project was the lack of variability in the characteristics of the drivers. Variability in characteristics such as the age of the driver and years of driving experience could affect the results of the analysis. In addition, other socio-economic variables could be considered, such as annual income, miles traveled per year, and miles traveled at night through work zones.

6.5.2 Recommendations for Future Research

The effect of the complexity of the surrounding environment and retroreflective patterns of the garments should be investigated. Application of the procedure in different real projects taking into consideration various workers working at the same time should be done. In addition, even when the majority of owners, workers, and general contractors indicated that yellow-green was the most effective color for improving visibility, different colors could be tested to see if there is any significant difference among them. This study also found, through descriptive analysis, that the positions analyzed did not have considerable influence when drivers chose the more visible garment. However, future studies could consider other positions, such as the worker kneeling down or walking. Future studies of high-visibility PPE should try to address these factors because they can impact the detection and conspicuity of the worker.

The analysis of the perspectives of the owners, workers, and general contractors consisted only of a descriptive analysis of the data. With a larger sample size, a model could be developed that can predict how the perspectives of the owners, workers, and general contractors regarding the effectiveness of current PPE practices vary according to characteristics such as the type of training received, the project conditions, the respondent's position in the organization, or the type of garment currently used. In addition, this research summarized the results of the degree of difference regarding the perceived visibility by drivers. Since the degree of difference was ordered from 1 to 5, an ordered probit model could be considered for the analysis.

This study found that variability in the retroreflectivity of the safety garment is important in improving worker visibility. In addition, through site visits, it was found that some of the project workers were using different types of safety garments. The effects of using different types of safety garments while performing the same task on the same project should be evaluated.

Finally, the videos used for the driver survey were created using a stationary camera mounted on the dashboard of a passenger automobile. An eye tracking camera can be used to create the videos, which can be shown to drivers individually to simulate in a more realistic way what the drivers actually sees when passing trough a work zone. Speeds could be increased by playing the video faster in order to determine whether higher speeds have an effect on the visibility of the garments. Further, future research therefore should consider semi-trucks in the analysis as Miller (2007) found that the percent of semi-trucks traveling in a nighttime work zone ranges from 16% to 97% of the traffic. The results of accidents when a semi-truck is involved can be very severe, and when the retroreflectivity of the safety garments was measured, it was found that for the angle of incidence generated by a semi-truck, the measurements were lower than for an automobile.

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APPENDIX

Appendix A. Survey Distributed to Owners

<u>Evaluation of Cost for Safety Planning in Nighttime Construction</u>

Questionnaire – Focus on Perspectives of Owners

Introduction:
Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime construction projects. In this case, the key players are: (i) The owners of the constructed projects, (ii) the contractors and (iii) the workers.

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards owners. The purpose is to identify the most effective safety mitigation techniques to ensure worker safety.

The questionnaire will take about 15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Safety Mitigation Techniques
B. On-Site Safety Perceptions
C. Cost of Various Techniques

In addition to these questions you will be asked to provide some basic project information.

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

3. Project Characteristics

Please fill in the following information regarding the project:

Project location: (Town, County, State, Roadway Number)	
Name of project:	
Project activities performed during the hours of darkness: (Please Circle)	Excavation, Paving, Grading, Surfacing, Maintenance, Other(Please Specify)
What is the size of the work zone area?	______ (ft^2)
Total number of workers on the project?	______ No. of Workers
Number of shifts on the project? Select one option and fill in the time frame of the shift(e.g. 6pm -4am)	1 2 3 Time Frame: ______ ______ ______
Number of workers per shift? (Please specify number of workers associated with each shift):	______ Shift 1 ______ Shift 2 ______ Shift 3
How many supervisors are there on each shift?(please specify number associated with which shift)	______ Shift 1 ______ Shift 2 ______ Shift 3
How many lanes in each direction?	1 2 3 4
Will there be any lane closures during this project?	______ Yes ______ No If yes, how many lanes will be closed, 1 2 3 4
Will the lane closures be only at night?	______ Yes _______ No

4. Safety Mitigation Strategies
Please check the appropriate answer and/or fill in comments.

1) What is the frequency of safety meetings?

_____Beg. Of Project _____Daily _____Weekly ______Bi-Weekly ______ Never

2) Do workers attend toolbox meetings?

______Daily ______Weekly ______Bi-Weekly ______ Never

3) Do workers receive pre-activity safety meetings? (e.g. before excavation, etc.)

________ Yes, Before Activities _______ No, Only as Part of Hiring Orientation

4) Does the project require personnel to be certified in the OSHA 10-hr training?

______ Yes ______ No

5) Is structured safety training required of newly hired workers?

______ Yes ______ No

5.1) If yes, approximate amount of time? _________

6) Are formal inspections performed routinely?

_____Yes _____No

6.1) If yes, how often? ______Daily _______Weekly ______Monthly

7) Is there a formal document explaining the procedures to investigate accidents and near misses?

______ Yes ______No

8) Is there law enforcement on site to help mitigate traffic?

______Yes ______No

8.1) If yes, what type of law enforcement? ___________________________

9) Does the project follow the MUTCD for work zones?

______ Yes ______ No

10) On the project, who is authorized to make changes to the work zone set-up?

______Owner ______ Project Manager _____ Asst. Project Manager ______Worker

11) Are safety records used for evaluating contractors' or subcontractors pre-qualifications?

______Yes ______ No

11.1) If yes, which Records?

____

12) Do you require contractors to assign safety personnel in the field?

______ Yes ______ No _______Depends on the type of project

13) Does the project employ an alcohol and substance abuse program for workers?

______ Yes ______ No

14) Are workers required to wear Personal Protective Equipment (PPE)?

______ Yes ______ No

14.1) If yes, what type of PPE do they wear? (Check all that apply)

______ Safety Vests ______Hard Hats ______ Eye Protection

______ Ear Protection ______ Other (Please List) ______________

15) Are workers required to have PPE training?

______ Yes ______ No

16) What type of traffic planning strategy is employed?

____

____

17) Do you deploy traffic control devices on the project?

______ Yes ______ No

17.1) If yes, how many traffic control devices are on the project?

____

17.2) If yes, what type of traffic control devices do you deploy?

____

c. Cost Information

Please fill in the cost of the following items on the project. The cost of these items is for the entire project. Also, if the equipment is owned by INDOT, please give the purchase cost of the item.

Item	**Budgeted Cost**
Lighting:	**$________________**
Personal Protective Equipment:	**$________________**
Law Enforcement:	**$________________**
Traffic Control Devices: (Signs, Cones, ect):	**$________________**
Safety Training:	**$________________**
Shift Differential: (Cumulative Cost of Wage Increase on Project)	**$________________**
Alternative Mitigation Strategies: (Please list, then write costs)	
____________________________	**$________________**
____________________________	**$________________**
____________________________	**$________________**
____________________________	**$________________**

d. Relative Importance of Safety Practices
Please read the following safety techniques. Use a scale of 1 to 10; score each item as to how important you feel they are towards safety of your contractor and workers. For each item please pick ANY NUMBER between 1-10 (1-does not help safety on site, 5-contributes to safety on site, 10-Essential for safety)

a. Pre-Job Planning ________
b. Employee Safety Training ________
c. Safety Incentives Program ________
d. Substance and Alcohol Program ________
e. Proper Usage of Lighting ________
f. Role of Law Enforcement on Site ________
g. Use of Personal Protective Equipment (PPE) ________
h. Safety Meetings ________
i. Accident and near miss investigations ________
j. Traffic Control Plan ________

e. Additional Comments & Suggestions
In the space below please provide any additional comments regarding nighttime construction safety issues, mitigation strategies, and suggestions for ways to improve safety on project sites.

____
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Appendix B. Survey Distributed to General Contractors

<u>Evaluation of Cost for Safety Planning in Nighttime Construction</u>

Questionnaire – Focus on Perspectives of General Contractors

Introduction:
Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime construction projects. In this case, the key players are: (i) The owners of the constructed projects, (ii) the contractors and (iii) the workers.

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards contractors. The purpose is to identify the most effective safety mitigation techniques to ensure worker safety.

The questionnaire will take about 20 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Safety Mitigation Techniques
B. On-Site Safety Perceptions
C. Cost of Various Techniques

In addition to these questions you will be asked to provide some basic project information.

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

a. Company Information & Safety Techniques

Please fill in the following information about your company:

1) Indicate the size of your company (annual revenue in dollar amount, M=Million)

______<50M ______50-250M _____250-500M _____500-750M _____>750M

2) Approximate number of worked hours(in a year)? ________

3) Does the company have a written company safety program?

______ Yes ______ No

4) Does the company have a safety committee?

______ Yes ______ No

4.1) If yes, who is included in the safety committee?

____

5) Who is responsible for the safety aspects of your nighttime construction projects during the construction planning phase?

_____ Safety manager _______Superintendent _____ Personnel Department

______Foreman _______Depends on the type of Project

6) Are safety records criteria for subcontractors' pre-qualifications?

______ Yes ______ No

7) Does the company require personnel to be certified in OSHA 10-hr training?

______ Yes ______ No

8) Does the company unit, sub-district have an incentive program for safe work practices?

______ Yes ______ No

8.1) If yes, describe the program:

____

9) Does your company unit, sub-district use the practice of pre-work safety meetings? (e.g. before excavation, etc)

______ Yes ______ No

10) Does the company use the practice of toolbox meetings?

______ Yes ______ No

11) Does the company perform routinely formal jobsite inspections?

______ Yes ______ No

11.1) If yes, what is the frequency of your inspections?

______Daily ______Weekly ______Monthly ______Bi-Monthly ______Do not Know

12) Does the company have a formal document explaining the procedures to investigate accidents and near misses?

______ Yes ______ No

12.1) If yes, please provide basic details of the document?

____

____

13) Does the company think that investigations of accidents after occurrence will improve safety performance?

______ Yes ______ No

14) In your experience, with what frequency does the owner get involved in safety-related aspects of the project?

____<25% of the time ______25-50% ______50-75% _______>75%

15) On a scale of 1 through 5, how safe would you perceive your worksites are for the workers?

______ (1-Unsafe, 3 Somewhat Safe, 5-Completely Safe; Please pick between 1and 5)

b. General Company Information (For 2004, If 2004 is Unavailable use 2003)

Number of Night hours Worked:	________ hrs
Number of Day Hours Worked:	________ hrs
Lost Time Injury Rate :	________
Level of Recordable Injury Rates (RIR):	________
Current Experience Modification Rating (EMR):	________
Year of Data:	______ 2003 ______ 2004

c. Company Cost Information

Please indicate if your company accounts for this cost in your nighttime construction bidding and/or planning. If you account for the cost, please indicate the amount:

Category	Does your company account for this cost in the project budget?	Cost ($)
Lighting	______ Yes _______ No	$________
Personal Protective Equipment (PPE)	______ Yes _______ No	$________
Safety Training	______ Yes _______ No	$________
Safety Incentives	______ Yes _______ No	$________
Law Enforcement:	______ Yes _______ No	$________
Traffic Control Devices: (Signs, Cones, etc):	______ Yes _______ No	$________
Shift Differential: (Cumulative Cost of Wage Increase on Project)	______ Yes _______ No	$________
	______ Yes _______ No	
Alternative Mitigation Strategies:	___________ Strategy 1	$________
(Please List, then Write Costs)	___________ Strategy 2	$________
	___________ Strategy 3	$________
	___________ Strategy 4	$________

d. Relative Importance of Safety Practices

Please read the following safety techniques. Use a scale of 1 to 10; score each item as to how important you feel they are towards safety of your workers. For each item please pick ANY NUMBER between 1-10 (1-does not help safety on site, 5-contributes to safety on site, 10-essential for safety)

a. Pre-Job Planning ________
b. Employee Safety Training ________
c. Safety Incentives Program ________
d. Substance and Alcohol Program ________
e. Proper Usage of Lighting ________
f. Role of Law Enforcement on Site ________
g. Use of Personal Protective Equipment (PPE) ________
h. Safety Meetings ________
i. Accident and near miss investigations ________
j. Traffic Control Plan ________

e. Additional Comments & Suggestions

In the space below please provide any additional comments regarding nighttime construction safety issues, mitigation strategies, and suggestions for ways to improve safety on project sites.

Appendix C. Survey Distributed to Construction Workers on Nighttime Jobsites

Evaluation of Cost for Safety Planning in Nighttime Construction

Questionnaire – Focus on Perspectives of Workers

Introduction:
Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime construction projects. In this case, the key players are: (i) The owners of the constructed projects, (ii) the contractors and (iii) the workers.

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards workers. The purpose is to identify the most effective safety mitigation techniques to ensure worker safety.

The questionnaire will take about 15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Safety Mitigation Techniques
B. On-Site Safety Perceptions
C. Cost of Various Techniques

In addition to these questions you will be asked to provide some basic project information.

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

a. Safety Training Experience

Please check the answer that best describes your experience during nighttime construction work.

1) Have you received OSHA related safety training?

______ Yes ______ No

1.1) Have you received OSHA 10-hr training?

______ Yes ______ No

1.2) When was the last time you received safety training?

_____ 1 Month Ago ______ 3 Months Ago ______Over 6 Months Ago

_______Over a Year Ago _______Do Not Know

2) Do you attend pre-activity safety meetings? (e.g. before excavation)

______ Yes ______ No

3) If pre-work safety meetings are used, what is their frequency?

______Daily ______Weekly ______Monthly ______Do not Know

4) Were you required to take a mandatory drug test as part of your hiring requirements?

______ Yes ______ No

5) Do you know what Personal Protective Equipment is?

______ Yes ______ No

6) Have you been trained in proper use of Personal Protective Equipment?

______ Yes ______ No ______ Not Applicable

7) When was the last time you received Personal Protective Equipment Training?

_____ 1 Month Ago ______ 3 Months Ago ______Over 6 Months Ago

_______Not Applicable _______Do Not Know

8) Are you required to wear Personal Protective Equipment?

______ Yes ______ No

9) What type of Personal Protective Equipment do you wear, if any?

____

12) On a scale of 1-5, how safe does wearing PPE make you personally feel? ______

(1-unsafe, 3-contributes to my safety, 5-completely safe; Please pick between 1and 5)

13) Is the site lit well enough for you to feel safe while performing your work?

______ Yes ______ No

14) Does poor lighting make it hard to communicate with your supervisor?

_____ Yes ______ No

15) Are there traffic control devices on projects you work on?

______ Yes ______ No

16) Is there law enforcement on site to help mitigate traffic?

______ Yes ______ No

16.1) If you responded yes to the previous question, on a scale of 1 -5, how safe does law enforcement on site make you feel? _________ (1-unsafe, 3-contributes to my safety, 5-completely safe; Please pick between 1and 5)

17) Does your employer have a disciplinary action program for unsafe work practices?

______ Yes ______ No

18) Does your employer have a workers' safety incentive program?

______ Yes ______ No _______Never Implemented

19) Do you receive additional pay for working at night?

______ Yes ______ No _____ Do Not Know

20) Do you ever feel too tired to be driving home after your night shift?

______ Yes ______ No

21) Have you ever been involved in an accident during nighttime work?

______ Yes ______ No

22) Have you ever been injured while working in construction before this project?

______ Yes ______ No

23) In your experience, how often does your supervisor get directly involved in your personal safety?

______<25% of the time _______25-50% _______50-75% _______>75%

24) On a scale of 1 through 5, do you feel that your direct supervisor cares about your personal safety? ________ (1-does not care, 3-somewhat cares, 5-completely cares; Please pick between 1and 5)

25) In general, on a scale of 1 through 5, how safe do you feel while performing your job during nighttime hours? ________

(1-unsafe, 3-contributes to my safety, 5-completely safe; Please pick between 1and 5)

b. Causes of Unsafe Practices in Nighttime Construction

Based on your experience, please indicate what the three (3) principal causes of accidents and fatalities in night-time construction work. (Check ONLY 3)

1. Lack of Lighting ___________
2. Insufficient Personal Protective Equipment ___________
3. Misuse of Personal Protective Equipment ___________
4. Lack of Communication ___________
5. Lack of Proper Training ___________
6. Insufficient Traffic Control ___________
7. Workers' Irresponsibility ___________
8. Lack of Supervision ___________
9. General Public Irresponsibility ___________
10. Other ___________________ ___________

c. Relative Importance of Safety Practices

Please read the following distinct safety techniques. Using a scale of 1 to 10; score the items as to how important you feel they are towards your personal safety on nighttime construction projects. For each item please pick ANY NUMBER between 1-10 (1-does not help my personal safety, 5-contributes to my safety, 10-Is essential to my personal safety)

a. Pre-Job Planning ________
b. Employee Safety Training ________
c. Safety Incentives Program ________
d. Substance and Alcohol Program ________
e. Proper Usage of Lighting ________
f. Role of Law Enforcement on Site ________
g. Use of Personal Protective Equipment (PPE) ________
h. Safety Meetings ________
i. Accident and near miss investigations ________
j. Traffic Control Plan ________

d. Demographic Information (Voluntary)

Age:	___________
Gender:	______ Male _______ Female
Do you belong to a Labor Union:	______ Yes _______ No
Years of experience in construction:	___________ years
Number of nighttime projects Worked on:	______ Number _______ Unsure
How frequently do you work night shifts?	______ Always ______ Monthly ______ 3-4 Times a Year ______ Rarely ______ Never
Do you prefer to work at night or during the day?	______ Day _______ Night

e. Additional Comments & Suggestions

In the space below please provide any additional comments regarding nighttime construction safety issues, mitigation strategies, and suggestions for ways to improve safety on project sites.

Appendix D: Survey Distributed to Designers

Evaluation of Traffic Control Planning Procedures For Safety in Nighttime Construction

Questionnaire – Focus on Perspectives of Designers

Introduction:

Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime traffic control planning for construction and maintenance operations. In this case, the key players in the nighttime traffic control planning are:

(i) Designers: The management responsible the design of traffic control plan

(ii) Supervisors: The management responsible for executing and maintaining the traffic control plan

(iii) Workers: Those who work in and around the traffic control zone

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards designers. The purpose is to identify the most effective safety mitigation techniques to ensure worker safety.

The questionnaire will take about 15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Project Characteristics
B. Design Characteristics
C. Safety Mitigation Strategies
D. Cost Information
E. Relative Importance of Safety Practices
F. Additional Comments and Suggestions

Please note that all responses to the questions might not be available for the specific project, in which case please answer based upon your companies project standards.

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

a. Project Characteristics

Please fill in the following information regarding the project:

Company Name:

Project location:
(Town, County, State, Roadway Number)

Name of project:

Work Environment:	___ Urban ___ Suburban ___ Rural
Project type:	___ Maintenance ___ Construction ___ Both
Project activities performed during the hours of darkness:	___ Excavation ___ Paving ___ Grading ___ Surfacing Other(Please Specify):___________ _________________________________ _________________________________
Projected Project Duration:	_______ No. of Days
What is the size of the work zone area?	_______ (ft^2)
What is the work zone type?	___ Mobile ___ Non-Mobile
How many lanes are present in each direction?	1 2 3 4
Will there be any lane closures during this project?	_______ Yes _______ No If yes, how many lanes will be closed, 1 2 3 4
Will the lane closures be only at night?	_______ Yes _______ No

b. Design Characteristics

Please check the appropriate answer and/or fill in comments.

1) Are you a sub-contractor for the traffic control design of this project?

   ______ Yes ______ No

2) Are you working with other parties during the traffic control design phase of this project?

   ______ Yes ______ No

   2.1) If yes, which of the following parties?

   ______ DOT ______ Contractor ______Other (Please List) _______________

   ____

3) Is formal training required by your company as a necessary pre-requisite to nighttime traffic control design?

   ______ Yes ______ No

   3.1) If yes, did you find this training beneficial?

   ______ Yes ______ No

4) Have you ever had formal training in nighttime traffic control design?

   ______ Yes ______ No

   4.1) If yes, please describe your training.____________________________

   ____

   4.2) If yes, did you find this training beneficial?

   ______ Yes ______ No

5) On the project, which of the following traffic control strategies are used:

   ______ Queuing Analysis Software ______ Highway Capacity Manual (HCM)

   ______ Manual on Uniform Traffic Control Devices (MUTCD)

   ______ Other (Please List) _______________________________________

6) Does your company have guidelines for nighttime traffic control design?

   ______ Yes ______ No

   6.1) If yes, do you use them in your design?

   ______ Yes _____ Occasionally _____ No

   6.2) If yes, do you find these guidelines beneficial?

   ______ Yes ______ No

7) On the project, are there special considerations for nighttime traffic control (e.g., increased taper lengths, shorter distance between drums, increase in buffer zones, etc) (Please List) ____

____

8) Do you deploy traffic control devices on the project?

______ Yes ______ No

8.1) If yes, what type of traffic control devices do you deploy?

______ Variable Message Boards ______ Signs ______Drums

______ Drums w/ Lights ______Cones ______ Others (Please List)____________

8.2) If yes, are these traffic control devices inspected prior to use?

______ Yes ______ No

8.3) If yes, what is the frequency of inspection during use?

______Hourly ______Daily _______Weekly ______Monthly

9) Are Incident Management Plans required for this project?

______ Yes ______ No

9.1) If yes, who is responsible for the plan development?

______ DOT ______ Contractor ______Other (Please List) ________

9.2) If yes, are these plans reviewed with any of the following?

______ Law Enforcement ______ Emergency Response Systems

______ Fire Department ______ (Please List) _______________

10) Are formal inspections of the work zone performed routinely?

_____ Yes _____ No

10.1) If yes, how often?

______Hourly ______Daily _______Weekly ______Monthly

11) Is there a formal document explaining the procedures to investigate accidents and near misses?

______ Yes ______No

11.1) If yes, do these procedures require recorded documentation of the incident if it involves a worker?

______ Yes ______No

11.2) If yes, do these procedures require recorded documentation of the incident if it involves the general public?

______ Yes ______No

12) Is law enforcement required on site to help mitigate traffic?

______Yes ______No

12.1) If yes, what type of law enforcement? ____________________________

12.2) If yes, are there signs making the general public aware of the law enforcement?______Yes ______ No

13) On the project, who is responsible for executing and maintaining the traffic control plan?

______ Project Manager ______ Project Engineer ______ Superintendent

______Forman ______Worker

______Other (Please List) _____________________________________

14) On the project, are there others authorized to make changes to the work zone set-up?

______ Project Manager ______ Project Engineer ______ Superintendent

______Forman ______Worker

______Other (Please List) _______________________________________

c. Safety Mitigation Strategies

Please check the appropriate answer and/or fill in comments.

1) What is the frequency of safety meetings?

______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly

______ Never

2) Do workers receive pre-activity safety meetings? (e.g., before excavation, etc.)

_______Yes, Before Activities

_______ No, Only as Part of Hiring Orientation

3) Referring to Questions 1-2, at any of these meetings is the traffic control plan reviewed with the workers?

______ Yes ______ No

3.1) If yes, how often?

______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly ______Never

4) Referring to Questions 1-2, at any of these meetings is the incident management plan reviewed with the workers?

______ Yes ______ No

4.1) If yes, how often?

______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly ______Never

5) Does the project require personnel to be certified in the OSHA 10-hr training?

______ Yes ______ No

6) Is structured safety training required of newly hired workers?

______ Yes ______ No

6.1) If yes, approximate amount of time?_________________________

6.2) If yes, are the traffic control plans reviewed? ______ Yes ______ No

6.3) If yes, are the incident management plans reviewed?

______ Yes ______ No

7) Are safety records used for evaluating contractors' or subcontractors pre-qualifications?

______Yes ______ No

7.1) If yes, which Records?____

____

8) Do you require contractors to assign safety personnel in the field?

______ Yes ______ No _______Depends on the type of project

9) Are workers required to wear Personal Protective Equipment (PPE)?

______ Yes ______ No

9.1) If yes, what type of PPE do they wear? (Check all that apply)

______ Safety Vests ______Hard Hats ______ Eye Protection

______ Ear Protection ______ Other (Please List) ______________

10) Are workers required to have PPE training?

______ Yes ______ No

d. Cost Information

Please fill in the cost of the following items on the project. The cost of these items are for the entire project. Also, if the equipment is rented, please give the purchase cost of the item.

Item	**Budgeted Cost**
Total Project Cost: (Contract Amount)	$________________
Pre-Construction Planning Costs:	$________________
Lighting:	$________________
Personal Protective Equipment:	$________________
Law Enforcement:	$________________
Traffic Control Devices: (Variable Message Boards, Signs, Cones, Drums, etc):	$________________
Safety Training:	$________________
Alternative Mitigation Strategies: (Please list types of strategies with associated costs)	
______________________________	$________________
______________________________	$________________
______________________________	$________________
______________________________	$________________

e. Relative Importance of Safety Practices:
Please read the following safety techniques relating to project planning and implementation. Score each item as to how important you feel they are towards safety of your contractor and workers. For each item please pick ANY NUMBER between 1-5 (1-least effective in promoting on-site safety, 5-Essential for safety)

a.	Investigation and Documentation of Work Zone Incidents	1	2	3	4	5
b.	Traffic Control Plan	1	2	3	4	5
c.	Incident Management Plan	1	2	3	4	5
d.	Inspection of Traffic Control Plan	1	2	3	4	5
e.	Maintenance of Traffic Control Devicing Equipment	1	2	3	4	5
f.	Safety Meetings	1	2	3	4	5
g.	Proper Usage of Personal Protective Equipment (PPE)	1	2	3	4	5
h.	Role of Law Enforcement on Site	1	2	3	4	5
i.	Employee Safety Training	1	2	3	4	5
j.	Proper Usage of Lighting	1	2	3	4	5

f. Additional Comments & Suggestions
In the space below please provide any additional comments regarding nighttime construction traffic control design, mitigation strategies and suggestions for ways to improve safety on project.

____

Appendix E: Surveys Distributed to Supervisors

Evaluation of Traffic Control Planning Procedures For Safety in Nighttime Construction

Questionnaire – Focus on Perspectives of Supervisors

Introduction:
Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime traffic control planning for construction and maintenance operations. In this case, the key players in the nighttime traffic control planning are:

(iv) Designers: The management responsible the design of traffic control plan
(v) Supervisors: The management responsible for executing and maintaining the traffic control plan
(vi) Workers: Those who work in and around the traffic control zone

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards supervisors. The purpose is to identify the most effective safety mitigation techniques to ensure worker safety.

The questionnaire will take about 15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Project Characteristics
B. Work Zone Safety
C. Ways to Improve Safety during Nighttime Construction Planning
D. Relative Importance of Safety Practices
E. Demographic Information (Voluntary)
F. Additional Comments and Suggestions

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

a. Project Characteristics
Please fill in the following information regarding the project:

Company Name:
Project location:
(Town, County, State, Roadway Number)
Name of project:

Work Environment:	___ Urban ___ Suburban ___ Rural
Project type:	___ Maintenance ___ Construction ___ Both
Project activities performed during the hours of darkness:	___ Excavation ___ Paving ___ Grading ___ Surfacing Other(Please Specify):__________ ______________________________
Projected Project Duration:	______ No. of Days
What is the size of the work zone area?	______ (ft^2)
What is the work zone type?	___ Mobile ___ Non-Mobile
Number of shifts on the project? Select one option and fill in the time frame of the shift (e.g., 6 p.m. – 4 a.m.)	1 2 3 Time Frame: ______ ______ ______
Number of workers per shift? (Please specify number of workers associated with each shift):	______ Shift 1 ______ Shift 2 ______ Shift 3

	Owner	**Contractor**
How many supervisors are there on each shift? (please specify number associated with which shift)	______ Shift 1 ______ Shift 2 ______ Shift 3	______ Shift 1 ______ Shift 2 ______ Shift 3

How many lanes are present in each direction? 1 2 3 4

Will there be any lane closures during this project?	______ Yes ______ No If yes, how many lanes will be closed, 1 2 3 4
Will the lane closures be only at night?	______ Yes ______ No

b. Work Zone Safety
Please check the appropriate answer and/or fill in comments.

1) What is the frequency of safety meetings?

   ______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly ______Never

2) Do workers receive pre-activity safety meetings? (e.g., before excavation, etc.)

   ________ Yes, Before Activities

   _______ No, Only as Part of Hiring Orientation

3) Referring to Questions 1-2, at any of these meetings is the traffic control plan reviewed with the workers?

   ______ Yes ______ No

   3.1) If yes, how often?

   ______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly ______Never

   3.2) If yes, are there procedures explaining proper traffic control set-up and maintenance?

   ______ Yes ______ No

4) Referring to Questions 1-2, at any of these meetings are steps reviewed with the workers in case of an accident or an emergency? (e.g., incident management plan)

   ______ Yes ______ No

   4.1) If yes, how often?

   ______Beg. Of Project ______Daily ______Weekly ______Bi-Weekly ______Never

5) Some companies require OSHA safety training, have you received this training?

   ______ Yes ______ No ______ Unsure

   5.1) Have you received OSHA 10-hr training?

   ______ Yes ______ No ______ Unsure

   5.2) When was the last time you received safety training?

______ 1 Month Ago ______ 3 Months Ago

______ Over 6 Months Ago _____ Over a Year Ago _____ Do Not Know

6) Is formal training required by your company as a necessary pre-requisite to nighttime traffic control design/set-up?

______ Yes ______ No

6.1) If yes, did you find this training beneficial?

______ Yes ______ No

7) Have you ever had formal training in nighttime traffic control design/work zone set-up?

______ Yes ______ No

7.1) If yes, please describe your training. _____________________________

7.2) If yes, did you find this training beneficial?

______ Yes ______ No

8) Does your company have guidelines for nighttime traffic control design/work zone set-up?

______ Yes ______ No

8.1) If yes, do you use them in your design/work zone set-up?

______ Yes _____ Occasionally _____ No

8.2) If yes, do you find these guidelines beneficial?

______ Yes ______ No

9) Are there traffic control devices on the projects you work on?

_____ Yes _____ No

10) On the project, are the traffic control devices operating properly and well-maintained?

_____ Yes _____ No

11) Are formal inspections of the work zone performed routinely?

_____ Yes _____ No

11.1) If yes, how often?

______Hourly ______Daily _______Weekly ______Monthly

12) Is there a formal document explaining the procedures to investigate accidents and near misses?

______ Yes ______No

12.1) If yes, do these procedures require recorded documentation of the incident if it involves a worker?

______ Yes ______No

12.2) If yes, do these procedures require recorded documentation of the incident if it involves the general public?

______ Yes ______No

13) Is law enforcement required on site to help control traffic?

______Yes ______No

13.1) If yes, what type of law enforcement? ___________________________

13.2) If yes, are there signs making the general public aware of the law enforcement?

______Yes ______ No

14) On the project, who is responsible for executing and maintaining the traffic control plan?

______ Project Manager ______ Project Engineer ______ Superintendent

______Forman ______Worker ______Other (Please List) ________

15) On the project, are there others authorized to make changes to the work zone set-up?

______ Project Manager ______ Project Engineer ______ Superintendent

______Forman ______Worker ______Other (Please List) ________

16) Do you feel safe with the work zone buffers provided to you?

_____ Yes _____ No

17) On a scale of 1-5, how safe do you feel working within the traffic control zone?________

(1-unsafe, 3-contributes to my safety, 5-completely safe, Please pick between 1 and 5)

18) Is the site lit properly lit for the work preformed?

_____ Yes _____ No

19) Have you ever been in an accident during a nighttime construction project?

_____ Yes _____ No

20) Does poor lighting make it hard to communicate with your workers?

_____ Yes _____ No

21) Is structured safety training required of newly hired workers?

_____Yes _____ No

21.1) If yes, approximate amount of time? ______________________________

21.2) If yes, are the traffic control plans reviewed? ______ Yes ______ No

21.3) If yes, are steps reviewed with the workers in case of an accident or an emergency? (e.g., incident management plans)

______ Yes ______ No

c. Ways to Improve Safety during Nighttime Construction Planning:
Based on your experience, please indicate which five (5) of the following would better improve work zone safety within the traffic control zone. (Check ONLY5)

1. Increased Cone/Drum Taper Lengths (Where Applicable)	________
2. Routine Maintenance of Traffic Control Devices	________
3. Decreased Cone/Drum Distances (Where Applicable)	________
4. Inspection of Traffic Control Devices Prior to Use	________
5. Increase of On Site Law Enforcement	________
6. Review of Traffic Control Plans (e.g., Where devices are placed, what are the work zone limits)	________
7. Review of Incident Management Plans (e.g., What to do in case of an accident)	________
8. Proper Training: Traffic Control Set-up & Breakdown	________
9. Increase in Public Awareness	________
10. Other____________________________	________

d. Relative Importance of Safety Practices:
Please read the following safety techniques relating to project planning and implementation. Score each item as to how important you feel they are towards your safety on nighttime construction projects. For each item please pick ANY NUMBER between 1-5 (1-least effective in promoting on-site safety, 5-Essential for safety)

a. Investigation and Documentation of Work Zone Incidents 1 2 3 4 5

b. Traffic Control Plan 1 2 3 4 5
(e.g., Where devices are placed, what are the work zone limits)

c. Incident Management Plan 1 2 3 4 5
(e.g., What to do in case of an accident)

d. Inspection of Traffic Control Plan 1 2 3 4 5

e. Maintenance of Traffic Control Devicing Equipment 1 2 3 4 5

f. Safety Meetings 1 2 3 4 5

g. Proper Usage of Personal Protective Equipment (PPE) 1 2 3 4 5

h. Role of Law Enforcement on Site 1 2 3 4 5

i. Employee Safety Training 1 2 3 4 5

j. Proper Usage of Lighting 1 2 3 4 5

e. Demographic Information (Voluntary)

Age:	______________________
Gender:	___ Male ___ Female
Experience in construction:	_______________ years
Experience in <u>nighttime</u> construction:	_______________ years
Number of nighttime project worked on:	___ Number ___ Unsure
Do you belong to a Labor Union:	___ Yes ___ No
How frequently do you work night shifts?	___ Always ___ Monthly ___ 3-4 Times a Year ___ Rarely ___ Never
Have you ever worked both daytime and nighttime shifts in one week?	___ Yes ___ No
Do you prefer to work at night or during the day?	___ Day ___ Night ___ No Difference

f. Additional Comments & Suggestions

In the space below please provide any additional comments regarding nighttime construction traffic control design, mitigation strategies and suggestions for ways to improve safety on project.

____
____
____
____
____

Appendix F: Survey Distributed to Workers

Evaluation of Traffic Control Planning Procedures For Safety in Nighttime Construction

Questionnaire – Focus on Perspectives of Workers

Introduction:
Purdue University is conducting a study investigating safety in nighttime construction operations. To accomplish the goals of this study, a survey is being conducted among the key players in nighttime traffic control planning for construction and maintenance operations. In this case, the key players in the nighttime traffic control planning are:

(i) Designers: The management responsible the design of traffic control plan
(ii) Supervisors: The management responsible for executing and maintaining the traffic control plan
(iii) Workers: Those who work in and around the traffic control zone

We are requesting you complete this survey which includes general questions about work/environment related aspects and specific questions related to safety. This questionnaire is specifically geared towards workers. The purpose is to identify the most effective ways to improve safety, in order to ensure safety of the worker.

The questionnaire will take about 15 minutes of your time to complete. The information collected will be kept confidential and it will only be used for academic purposes. Your participation in this survey is completely voluntary. It is the goal of this research to develop safety planning strategies to reduce the number of accidents that cause injuries and fatalities during nighttime construction operations. For this reason your cooperation is extremely vital to the success of this research.

Several questions will be presented in the following questionnaire in the following categories:

A. Project Characteristics
B. Work Zone Safety
C. Ways to Improve Safety during Nighttime Construction Planning
D. Relative Importance of Safety Practices
E. Demographic Information (Voluntary)
F. Additional Comments and Suggestions

Please return the completed survey to the following address:

Professor Dulcy M. Abraham
Purdue University
School of Civil Engineering
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

a. Project Characteristics
Please fill in the following information regarding the project:

Company Name:

Project location:
(Town, County, State, Roadway Number)

Project type:
___ Maintenance
___ Construction
___ Both

Project activities performed during the hours of darkness:
___ Excavation
___ Paving
___ Grading
___ Surfacing

Other(Please Specify):___________
____
____

b. Work Zone Safety
Please check the appropriate answer and/or fill in comments.

1) Some companies require OSHA safety training, have you ever received this training?

_______ Yes _______ No _______ Unsure

1.1) Have you received OSHA 10-hr training?

_______ Yes _______ No _______ Unsure

1.2) When was the last time you received safety training?

_______ 1 Month Ago _______ 3 Months Ago _______ Over 6 Months Ago

_______ Over a Year Ago _______ Do Not Know

2) Do you attend pre-activity safety meetings? (e.g., before excavation, etc.)

_______ Yes _______ No

2.1) If yes, is the traffic control plan and limits to the work zone reviewed?

_______ Yes _______ No

2.2) If yes, are there procedures explaining proper traffic control set-up and maintenance?

_______ Yes _______ No

2.3) If yes, is there review of an incident management plan in case of an accident or an emergency within the work zone?

______ Yes ______ No

3) Is law enforcement on site to help control traffic?

______ Yes ______ No

4) On a scale of 1-5, how safe do you feel when law enforcement is present? _______

(1-unsafe, 3-contributes to my safety, 5-completely safe, Please pick between 1 and 5)

5) Do you know what Personal Protective Equipment is?

______ Yes ______ No

6) Are you required to wear Personal Protective Equipment?

______ Yes ______ No

7) On a scale of 1-5, how safe does wearing PPE make you feel?_______

(1-unsafe, 3-contributes to my safety, 5-completely safe, Please pick between 1 and 5)

8) Do you wear the PPE?

______ Daily ______ Once per Week ______ Twice per Week

______ Once a Month ______ Never

9) Are there traffic control devices on the projects you work on?

_____ Yes _____ No

10) On the project, are the traffic control devices operating properly and well-maintained?

_____ Yes _____ No

11) Do you feel safe with the work zone buffers provided to you?

_____ Yes _____ No

12) On a scale of 1-5, how safe do you feel working within the traffic control zone?_______

(1-unsafe, 3-contributes to my safety, 5-completely safe, Please pick between 1 and 5)

13) Have you ever been in an accident during a nighttime construction project?

_____ Yes _____ No

14) Is the site lit well enough for you to feel safe while performing your work?

_____ Yes _____ No

15) Does poor lighting make it hard to communicate with your supervisor?

_____ Yes _____ No

c. Ways to Improve Safety during Nighttime Construction Planning:
Based on your experience, please indicate which five (5) of the following would better improve work zone safety within the traffic control zone. (Check ONLY5)

1. Increased Cone/Drum Taper Lengths (Where Applicable) ________
2. Routine Maintenance of Traffic Control Devices ________
3. Decreased Cone/Drum Distances (Where Applicable) ________
4. Inspection of Traffic Control Devices Prior to Use ________
5. Increase of On Site Law Enforcement ________
6. Review of Traffic Control Plans ________
   (i.e., Where devices are placed, what are the work zone limits)
7. Review of Incident Management Plans ________
   (i.e., What to do in case of an accident)
8. Proper Training: Traffic Control Set-up & Breakdown ________
9. Increase in Public Awareness ________
10. Other____________________________ ________

d. Relative Importance of Safety Practices:
Please read the following safety techniques relating to project planning and implementation. Score each item as to how important you feel they are towards your safety on nighttime construction projects. For each item please pick ANY NUMBER between 1-5 (1-least effective in promoting on-site safety, 5-Essential for safety)

a. Investigation and Documentation of Work Zone Incidents 1 2 3 4 5

b. Traffic Control Plan 1 2 3 4 5
(e.g., Where devices are placed, what are the work zone limits)

c. Incident Management Plan 1 2 3 4 5
(e.g., What to do in case of an accident)

d. Inspection of Traffic Control Plan 1 2 3 4 5

e. Maintenance of Traffic Control Devicing Equipment 1 2 3 4 5

f. Safety Meetings 1 2 3 4 5

g. Proper Usage of Personal Protective Equipment (PPE) 1 2 3 4 5

h. Role of Law Enforcement on Site 1 2 3 4 5

i. Employee Safety Training 1 2 3 4 5

j. Proper Usage of Lighting 1 2 3 4 5

e. Demographic Information (Voluntary)

Age:	____________________
Gender:	___ Male ___ Female
Experience in construction:	______________ years
Experience in <u>nighttime</u> construction:	______________ years
Number of nighttime project worked on:	___ Number ___ Unsure
Do you belong to a Labor Union:	___ Yes ___ No
How frequently do you work night shifts?	___ Always ___ Monthly ___ 3-4 Times a Year ___ Rarely ___ Never
Have you ever worked both daytime and nighttime shifts in one week?	___ Yes ___ No
Do you prefer to work at night or during the day?	___ Day ___ Night ___ No Difference

f. Additional Comments & Suggestions
In the space below please provide any additional comments regarding nighttime construction traffic control design, mitigation strategies and suggestions for ways to improve safety on project.

____
____
____
____
____

Appendix G: Formal Interview Questionnaire

Formal Interview Questions/Comments – Contractor

1. For the project what were the specific traffic control requirements by INDOT? What was the planning process used by your company to implement these requirements?

2. Who within your company made decisions regarding the project's traffic control?

3. Was the TTC subcontracted? What services did the subcontractor provide for the project?

4. Which INDOT documents did your company use during the TTC planning? In addition to the INDOT documents, were other DOT or FHWA documents referenced during TTC planning?

5. Which standard plan did your company use from INDOT? Reasons for this selection?

6. Were there any deviations from the standard plans? Did INDOT require deviations to be submitted for review? If so who within INDOT did the review?

7. Does your company have special considerations for nighttime work? (e.g., increased tapers, shorter drum/cone distances, increased buffers)

8. Does your company have special nighttime guidelines in safety planning? [OVERALL]

9. Are there additional comments specific to your project that you would like to add?

Appendix H: Summary of Formal Interview Results

Table H.1 Summary of Formal Interview Results

Project	Work Description	Project Complete	Contract Value	Traffic Control Contract Percentage	Traffic Control Pay Items
1	Asphalt Resurface	May 2006	$1,567,000	8.07%	Quality Adj., Temp Traffic Control Devices (109-08443) Temporary Pavement Marking Removable (801-06207) Construction Sign (801-06640) Flashing Arrow Sign (801-06710) Maintaining Traffic (801-06775) Temporary Worksite Flashing Light Sign (801-07117) Temporary Changeable Message Sign (801-07215)
2	Asphalt Resurface	April 2005	$896,442	2.21%	Temporary Pavement Marking (801-06207) Construction Sign (801-06640) Maintaining Traffic (801-06775)
3	Asphalt Resurface	Nov 2005	$2,815,900	1.74%	Same as Project 1 pay items.
4	Asphalt Resurface	Aug 2005	$1,599,490	3.78%	Temporary Worksite Speed Limit Sign (801-01093) Temporary Pavement Marking Removable (801-06207) Construction Sign (801-06640) Flashing Arrow Sign (801-06710) Maintaining Traffic (801-06775) Temporary Changeable Message Sign (801-07215)
5	Asphalt Resurface	Sept 2005	$3,874,004	1.50%%	Temporary Pavement Marking (801-06203) Temporary Pavement Marking Removable (801-06207) Construction Sign (801-06640) Maintaining Traffic (801-06775) Temporary Changeable Message Sign (801-07215)

Table H.1 Summary of Formal Interview Results (Continued)

Project	Traffic Restrictions/Lane Closures	Entity Involved in TTC Plan	Contractor Entities involved in TTC Selection (ATTSA Certified)	TTC Plan References
1	Single lane closure: 3 p.m. – 7 p.m. and 6 a.m. – 9 a.m. (M-F) Double lane closure: 6 a.m. – 10 p.m. (M-F) 9 a.m. – Midnight (Sat) Midnight – 10 p.m. (Sun)	Contractor X	Asphalt Manager (No)	1. INDOT Standard Drawings & Specifications. 2. Special Provisions.
2	Single lane closure 6 a.m. – 7 p.m. (M-F) Double lane closure 6 a.m. – 9 p.m. (M-F)	Contractor Y	Asphalt Manager (Yes)	1. INDOT Standard Drawings & Specifications. 2. Special Provisions. 3. INDOT Work Zone Safety Manual.
3	Southbound lanes 6 a.m. – 9 p.m. (M-F) Northbound lanes 3 p.m. – 7 p.m. (M-F)	Contractor X	Asphalt Manager (No)	Same as Project 1 references.
4	Mainline and Auxiliary Lanes: 6 a.m. – 7 p.m. (M-F) Approaches and Crossovers: Northbound 6 a.m. – 7 p.m. (M-F) Southbound 3 p.m. to 7 p.m. (M-F) Northbound lane 6 a.m. – 9 p.m. (M-F)	Contractor X	Asphalt Manager (No)	1. INDOT Standard Drawings & Specifications. 2. Special Provisions.
5	Mainline and Auxiliary Lanes: 6 a.m. – 7 p.m. (M-F) Approaches and Crossovers: Northbound 6 a.m. – 9 p.m. (M-F) Southbound 3 p.m. to 7 p.m. (M-F)	Contractor Z	Estimator (No) Asphalt Manager (Yes)	1. INDOT Standard Drawings & Specifications. 2. Special Provisions. 3. ATSSA “Guide to Temporary Traffic Control in Work Zones.”

Note: 1. Traffic restrictions and lane closure times noted in the table are the periods in which the contractor cannot perform work.
2. Restrictions and lane closures are determined by INDOT using their Lane Closure Policy.
3. Mainline is the primary road were work is performed. Auxiliary lane may exit or proceed along mainlines (i.e., on-ramp).
4. Approaches are intersecting roads along the mainline. Crossovers denote intersections for auxiliary lanes and approaches.

Table H.1 Summary of Formal Interview Results (Continued)

Project	TTC Plan	Deviation from Standards	Contractor Nighttime Work Considerations	TTC Plan Submission to INDOT	TTC Plan Review with INDOT	Additional TTC Requirements required by INDOT
1	INDOT Standard Drawing 801 TCLC 01	No	1. Police officer to mitigate traffic speeds. 2. Work zone speed limit signs. 3. Increased amount of barrels in the taper. 4. Decreased cone distances in the activity area.	No	Yes	1. CWTS ATSSA Certification. 2. Weekly Device Inspection Reports. 3. Certify Devices are compliant with NCHRP Report 350 crash test standards.
2	INDOT Work Zone Safety Plan: 1. Lane Closure on a Four Lane Undivided Road 2. Lane Closure on Divided Roadway or One Way Street	No	1. Flagmen used control traffic at intersections	No	Yes	
3	INDOT Standard Drawing 801 TCLC 01	No	1. Work zone speed limit signs. 2. Increased amount of barrels in the taper. 3. Decreased cone distances in the activity area.	No	Yes	
4	INDOT Standard Drawing 801 TCLC 01	No	Same as Project 3.	No	Yes	
5	INDOT Standard Drawing 801 TCLC 01	No	Same as Project 3.	No	Yes	

Appendix I: Formal Telephone Interview Questionnaire

<u>Formal Interview Questions/Comments</u>
Nighttime Construction & Maintenance Work Zone Speed Control

Demographic Information
Date of Interview: ______________________ Subject #:________________

Name: ____

Age: ____

Agency/Company: ____

Length of time with agency/company: _________________________________

Title of current position: ____

Length of time in current position: ____________________________________

Years of experience dealing with construction: ___________________________

Years of experience dealing with nighttime construction: ___________________

Speed Control

1) Which of the following are used by your agency/company as speed control methods in work zones on **daytime** construction/maintenance projects? (Yes, No, Sometimes)

- Regulatory speed limit signs posted
- Recommended speed limit signs posted
- Work zone speed signs (when lights flashing)
- Police enforcement
- Speed display monitor
- Changeable message signs
- Variable speed limit system
- Rumble strips
- Double fines
- Wizard CB alert system
- Narrowed lane widths
- Other: ____________
- None

2) Which of the following are used by your agency/company as speed control methods in work zones on **nighttime** construction/maintenance projects? (Yes, No, Sometimes)

- Regulatory speed limit signs posted
- Recommended speed limit signs posted
- Work zone speed signs (when lights flashing)
- Police enforcement
- Speed display monitor
- Changeable message signs
- Variable speed limit system
- Rumble strips
- Double fines
- Wizard CB alert system
- Narrowed lane widths
- Other: ____________
- None

3) Please choose the two speed control methods you feel to be the most effective in reducing speeds and speed variance on **nighttime** construction/maintenance projects.

4) What is the average estimated cost of each speed control method used day or night by your agency/company?

5) On which type of project is each speed control measure used by your agency/company? See options below.
Interstate (I), Rural highway (H), Urban (U)
Construction (C), Maintenance (M)

6) When is nighttime speeding the biggest problem for nighttime construction?
    - Weekdays
    - Weekends
    - Holidays
    - No difference

7) What time of night is speeding the biggest problem?
   - 6pm – 9pm
   - 9pm - midnight
   - Midnight – 3am
   - 3am - 6am
   - No difference

8) Where in the work zone is speeding of most concern?
   - Advance warning area (between first sign and active work zone)
   - Transition area (cone or barrel taper)
   - Active work zone
   - Termination area (between active work zone and last sign)

9) Do you have any additional comments on speed control for nighttime projects?

Speed Control Methods	(1) Used daytime	(2) Used nighttime	(3) Most effective @ night	(4) Average cost	(5) Project type
Regulatory speed limit signs posted					
Recommended speed limit signs posted					
Work zone speed signs (when lights flashing)					
Police enforcement					
Speed display monitor					
Changeable message signs					
Variable speed limit system					
Rumble strips					
Increased/double fines					
Wizard CB alert system					
Narrowed lane widths					
Other: __________					
None					