FINAL REPORT

Nighttime Construction: Evaluation of Worker Safety Issues

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16. Abstract

The objective of this research study was to identify and measure the effects of nighttime construction conditions on worker safety and to investigate the performance of different high-visibility garments worn by construction personnel on highway projects under different lighting and weather conditions. After a comprehensive review of the literature, an analysis of Illinois accident records was conducted to identify the type, frequency, severity, and share of accidents caused by worker visibility problems in construction work zones. Three surveys were administrated to IDOT operations personnel, resident engineers, and contractors involved in nighttime construction to identify safety concerns on the part of these participants and to compare the results. The questionnaire investigated issues associated with the risk of workers being involved in accidents with the driving public and with equipment operating in the work zone, the efficiency of high-visibility garments, the effects of visibility problems on various critical factors, sources of high-visibility garments, fabric/material preferences, local practices, and high-visibility garment selection criteria. A comprehensive list of manufacturers and distributors of high-visibility garments was compiled. A survey was administered to DOTs other than IDOT that make use of high-visibility garments in nighttime construction. Based on the findings of the surveys, a set of six high-visibility garments was selected for testing. The findings of a series of tests run on these six vests conducted under different work, lighting, and weather conditions, indicated that the safety vest recently adopted for use by IDOT performs best.

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EXECUTIVE SUMMARY

Many state agencies including IDOT are shifting towards nighttime construction. Nighttime construction mitigates the impact of construction operations on the traveling public, shortens the duration of construction operations and reduces interruptions to construction activities. But nighttime construction operations may be more hazardous for both drivers and construction personnel because of visibility problems at nighttime.

In this research study, the effects of nighttime construction conditions on worker safety were investigated by studying the statistics provided by the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS) and by seeking the experiences of DOT personnel across the nation; the types of high-visibility garments used by construction workers and IDOT personnel on Illinois highway projects as well as those used in other states were surveyed; and finally, the performance of six high-visibility vests were investigated not in a laboratory setting but on actual construction/maintenance sites that involved different lighting, traffic, and weather conditions. Potential users' perceptions concerning the performance of these six safety vests were also collected by mean of a questionnaire survey.

The study shows that safety does not seem to be any more of a problem in nighttime than in daytime works. Most nighttime accidents involve workers struck by through traffic inside the work area as well as workers struck by construction equipment inside the work area. The main reason for nighttime accidents is perceived to be the condition of vehicle

operators with poor lighting condition being the second most common reason. It appears that investigating visibility issues associated with safety garments at nighttime is justified.

IDOT operations personnel, resident engineers, and contractors involved in nighttime construction operations in Illinois within the past five years were surveyed. An additional survey was conducted of transportation personnel in the other 49 DOTs in the nation using the same survey instrument. Finally, a list of manufacturers and distributors of safety vests in the U.S. was compiled. Based on the information collected, the following commonly used six safety vests were picked for field testing:

IODT Standard Vest
IDOT LED Vest
Head Lite Roadstar 200 Vest
Iron Horse Texas Style Vest
Chami Design Washington Style Vest
Safetyline Minnesota Style Vest

A field evaluation was conducted to measure the performance of the safety garments selected. A test setup was devised and a procedure called LUMINA was developed to electronically analyze the data collected and to produce an example movie of the tests. The field evaluation included different lighting, weather and location conditions. A survey of potential users of high visibility safety garments was also conducted to investigate (a) 360° visibility, (b) conspicuity against the background, (c) the brightness of the retro-reflective material, (d) the configuration of the vests (pockets, zipper, etc.), and (e) the overall perceived effectiveness.

Consolidated results obtained from the field tests that measured mean luminance values of the front faces and sides of the six safety vests and the perception of potential users of these vests indicated that the "Head Lite Roadstar 200" vest and the "Safetyline Minnesota Style" vest are significantly superior to the other four vests. It appears therefore that IDOT's decision to make the “Head Lite Roadstar 200” vest mandatory in future highway construction/maintenance works performed in Illinois is justified particularly since the information obtained in the surveys indicated that Illinois respondents are less satisfied with the nighttime performance of the safety garments currently in use on their work areas than respondents from other DOTs.

Nighttime Construction: Evaluation of Worker Safety Issues

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The research team gratefully acknowledges the valuable input of the project Technical Review Panel (TRP) all through the research. The project TRP was chaired by James A. Schoenherr (IDOT Bureau of Operations) and was composed of Roger L. Driskell (IDOT Bureau of Design and Environment), Dennis A. Huckaba (IDOT Bureau of Operations), Randy J. Jackson (IDOT Bureau of Construction), Kevin McLaury (Federal Highway Administration), and Mike Staggs (Federal Highway Administration). The help received from David Lippert (IDOT) in distributing the questionnaires to departments of transportation of other states than Illinois was very much appreciated. The contribution to the success of the research of the many respondents to the many surveys conducted through this research was significant. They included IDOT operations personnel, IDOT resident engineers, contractors involved in nighttime construction, transportation personnel in other states, and the graduate students in the Construction Engineering and Management Program at IIT. Last but not least, the research team thanks Professors Steven Hanna and Dianne Kay (SIUE) for their continuous support, patience and understanding relative to project accounting and finances.

Nighttime Construction: Evaluation of Worker Safety Issues

1. INTRODUCTION

1.1 Research Background

Increased traffic volumes especially in urban areas are approaching the design capacity of many facilities. Heavy traffic and congestion last all day long. Any repair, maintenance, renovation or rehabilitation work conducted during the day on these roadways disrupts traffic and adds to congestions and delays. That is why planning construction and maintenance work at nighttime appears to be an attractive solution since traffic flow at night is minimal. Many State Agencies including IDOT are shifting towards nighttime construction. For example, Florida Department of Transportation (FDOT) has determined that nighttime work is one major solution to the problem of traffic congestion associated with highway maintenance (Layfield 1988).

In addition to the advantage of mitigating the impact of construction operations on the traveling public, nighttime construction has been observed to provide other obvious advantages, such as shortening the duration of construction operations and reduced interruptions to construction activities. However, nighttime construction has also disadvantages compared to daytime construction. One major disadvantage is that nighttime construction operations may be more hazardous for both drivers and construction personnel because of visibility problems at nighttime. Furthermore, statistics show that a higher percentage of nighttime drivers are impaired by drugs, alcohol, fatigue, or age-related vision impairments. Also, nighttime workers operate in an environment that may affect safety due to lighting and human factors.

The research on nighttime construction is very limited. Only few studies provide a comprehensive approach and valuable information (Ellis and Kumar 1993). It is generally expected that nighttime construction would cost more than daytime construction due to lighting cost, extra compensation for workers, and higher cost for materials. But Ellis and Kumar's (1993) studies conclude that total project cost is less for work conducted at night as compared with work conducted during the day, but there is no significant difference between the productivity values for daytime and nighttime projects. The main reason for the discrepancy may be due to the limited availability of accurate information for nighttime construction. When those studies were conducted, nighttime construction was still under experimentation.

Highway work zone safety has been a high-priority issue for traffic engineering professionals and has been widely studied (Wang et al. 1996, Ha and Nemeth 1995). Studies show that crash rates in work zones are higher than those on comparable highway sections without work zones (Pal and Sinha 1996). As nighttime construction is getting more popular in many states, more data are becoming available to support this type of study. Research is needed to identify and measure the effects of nighttime construction conditions on worker visibility. Research is also needed to investigate new/innovative technologies such as high-visibility garments and to evaluate the performance of these technologies under a variety of typical lighting and weather conditions for typical nighttime construction operations.

While the main problem in daytime is one of conspicuity, at night luminance becomes very important as color becomes of less importance (unless standardized to have recognition meaning). Most aspects of visibility depend on providing more luminance contrast to the observer than otherwise available. An effective means for increasing the detectability of a construction worker at night is some form of retroreflector that has the following characteristics: (a) is sufficiently bright as positioned on the worker to provide conspicuity or noticeability at distances of interest, (b) provides this conspicuity from all directions whether the worker is in motion or not (360^{o} protection), (c) furnishes recognition clues that the object sighted is a human being, that is a construction worker and not an inanimate object or vehicle, (d) reveals the motion of the construction worker as much as possible but is not totally dependent on its effect, and (e) if the high visibility materials are properly selected and located on the construction worker, it is not always necessary to use large areas of retroreflectivity to meet these requirements (ASTM F 923-00). This study will concentrate on measuring the luminance of high-visibility vests used in nighttime construction.

It should be noted that a comprehensive study has not yet been conducted in Illinois to compare high-visibility garments being marketed by various manufacturers and being used by various state agencies. Construction operations are severely affected by weather and lighting conditions as well as local practices such as experience and culture of contractors and transportation agencies. In conclusion, a comprehensive study that evaluates safety issues in nighttime construction operations is needed in Illinois to provide IDOT with appropriate information for making decisions conducive to better visibility of workers in nighttime construction and therefore to fewer accidents.

1.2 Objectives and Scope

The objectives of this research study are:

- To measure the effects of nighttime vs. daytime construction on worker safety.
- To survey the types of high-visibility garments used by construction workers and IDOT personnel on Illinois highway projects as well as those used in other states.
- To investigate the performance of different high-visibility garments worn by construction workers on highway projects under different lighting and weather conditions.

1.3 Organization of the Report

This research is presented in seven chapters. An introduction to the subject of worker safety in nighttime construction, and the objectives and scope of the research are presented in Chapter 1.

Chapter 2 covers a comprehensive review of the literature on work zone safety garments. The implications of good safety measures on project performance factors are also examined in this chapter.

The analysis of fatal accidents in work zones in Illinois is presented in Chapter 3. Here, a comparison of daytime vs. nighttime accidents is conducted using d-statistical data provided by FARS.

Chapter 4 describes the methodology used in the study.

Chapter 5 includes the evaluation of the safety garment surveys administered to IDOT operation personnel, resident engineers, contractors and to departments of transportation in states other than Illinois.

Chapter 6 reports the findings of the site measurements and of the questionnaire surveys. In this chapter, descriptive statistics and comparison tests of the data obtained from field measurements and site questionnaires are presented and discussed. Chapter 7 provides the conclusion of this research.

2. LITERATURE SURVEY

2.1 Introduction

Highway and street construction and/or maintenance workers are exposed to the risk of fatality or serious non-fatal injury. More than 100 workers are killed and over 20,000 are injured in highway and street construction sites every year (Pratt et al. 2001). Construction worker safety issues in nighttime construction need to be considered in the context of the visibility of safety clothing and the work zone safety conditions (Birch 1998). The best way to improve safety is to identify potential dangerous situations and to take preventive action to avoid the occurrences. It is feasible to eliminate the hazards that can cause accidents in nighttime construction operations.

High-visibility safety garments serve an important role in the protection of construction workers and personnel who operate on highway construction sites. Many accidents are attributed to inadequate visibility and detectability of the highway construction worker at night.

The results of an investigation about fatal accidents in highway work zones in Illinois are reported in Chapter 3. The Illinois accident records indicate that a total of 406 fatalities occurred in highway construction work zones in the period of 1996-2000, 207 of which happened at nighttime (http://www.fars.nhtsa.dot.gov). By using data mining techniques, patterns have been found in the fatalities data when these data are analyzed with respect to type of fatality (workers or other victims), visibility dependent factors such as light and weather conditions. Lighting is of course a crucial factor and is only indirectly incorporated into this research since lighting is not the main focus of this research.

The *Manual of Uniform Traffic Control Devices* (MUTCD 2000) regulates the color of a safety garment: "For daytime work, the flagger's vest, shirt, or jacket shall be orange, yellow, strong yellow green or fluorescent versions of these colors." The MUTCD recommends a minimum sight distance for workers active in nighttime operations. The 2000 revision of the Manual covers high-visibility clothing in its Chapters 6D and 6E and states that workers exposed to traffic should be attired in bright, highly visible clothing similar to that of flaggers.

The British standard BS EN 471 (1994) establishes minimum areas of high-visibility material for three levels of performance: 0.8 m^2, 0.5 m^2, and 0.14 m^2 for Class 3, Class 2, and Class 1 respectively. Class 3 would be used for work-zone applications. The standard states "Class 3 garments offer greater conspicuity against most urban and rural backgrounds than Class 2 garments which in turn are significantly superior to Class 1 garments." BS EN 471 (1994) also includes specifications for the following three colors: fluorescent yellow, fluorescent orange-red, and fluorescent red.

While the fourth standard AS/NZS 1906.4 (1997) out of AS/NZS 1906 series published by Australian and New Zealand agencies covers high-visibility materials to be used in the manufacture of safety garments, it does not specify a standard for high-visibility garments themselves. The standard for high visibility garments (AS/NZS 4602 (1999) was issued most likely based on the British Standard BS EN 471 (1994) *Specification for High-Visibility Warning Clothing*, which regulates the detailed standard for high-visibility garments. *High Performance Textiles* (Nov 1997) reports that an establishment at Bradford, UK is equipped to undertake tests in accordance with European standards such as BS EN ISO 105, AATCC, DIN and others to assess the conformance of high visibility clothing with BS EN 471.

Military Specification Safety Clothing, High Visibility (MIL-S-43753C 1998) classifies and specifies safety ensembles according to types and styles to provide high visibility to military police required to work in areas traversed by vehicles in both day and night conditions. It is different from other specifications in that it specifies the types and styles of the ensemble in great detail, while other standards generally don't specify this kind of detail. While the requirements in the military standards are not much different from BS EN 471 (1994), it is noteworthy that they encourage extensive quality assurance procedures, a feature that may be of value for safety garments used in construction work zones. For example, the separation of a piece and/or appendages of a garment is considered to be a serious flaw especially when it happens on a construction site because of the difficulty repairing and/or replacing the damaged garment on site.

ANSI/ISEA 107-1999 issued in June 1999 by the International Safety Equipment Association provides guidelines for high-visibility and reflective apparel including recommendations for the design, performance and use of vests, jackets, jumpsuits, trousers and harnesses. The safety garments are categorized into three classes I, II, III depending on the type of construction operation, the wearers that are involved, and the degree of exposure to traffic on a highway. A good interpretation of the classes is presented in an article by Bradley (2001) and on the 3M website (http://www.international.3m.com/intl/CA/english/centres/safety/personal-safety/standards.html).

The informative Appendix B (Conspicuity Classes Guideline) of the *American National Standard for High-Visibility Safety Apparel* (ANSI/ISEA 107-1999) states that several factors affect the conspicuity of safety garments, including (1) the speed of vehicle and moving equipment, (2) the level of complexity and/or confusion of background, (3) the level of separation of worker from work zone, (4) the level of attention scattering and/or diverting, (5) the level of inclement weather condition, and (6) the nearness of work to traffic. Furthermore, depending on the intermittence or continuous exposure to attention, a different Class needs to be applied in behalf of the worker. The standard indicates that different classes of safety garment need to be used based on the types of highway maintenance or construction operation. The standard also addresses indirectly the importance of the level of attention that a vehicle operator needs to pay based on the distribution of workers in the work zone. The one thing the standard does not consider is the side view of the garment while the front and rear visual requirements are specified. Because the number of night projects has increased, the new ANSI/ISEA-107 standard (1999) has supported work zone safety to encourage the usage of brighter and more visible safety garments. Though there is no requirement for incorporating light emitting devices, long-lasting message boards, and handheld flashers to create high-visibility, it is known that those devices increase detectability in nighttime work zones. Though the standard could drive up the costs for manufacturers and consumers, public benefit and improved worker safety are expected. Although the guidelines stated in ANSI/ISEA 107-1999 are not mandatory, it is in the worker's interest to follow them by taking into consideration the information presented in its Appendix B.

Several DOTs had developed their own standards before the ANSI/ISEA-107 standard was issued in 1999 because there was no standard that could bring consistency. Though the ANSI/ISEA standard is a good thing because standardization is helpful to manufacturers that are involved in mass production, reasonable localization need to be possible to meet a specific need in different states. It should be noted that a standard could not specify all the application details, since each construction location has its own operation environment such as background, lighting, and location setting. As a result, localizing the information provided by a standard need to be allowed. Furthermore, it should not be ignored that worker safety can be ensured not only by emphasizing the need to wear high-visibility clothing but also by incorporating high-visibility devices. Indeed, the brighter and more visible the work equipment and devices, the more attention is drawn to the workers. When reflective materials cannot provide sufficient illumination of the work zone, high-visibility equipment such as traffic batons and handheld flashers need to be incorporated.

The *Standard Guide to Properties of High Visibility Materials Used to Improve Individual Safety* (ASTM Designation F 923-00) was issued by the American Society for Testing and Materials (ASTM) as a standard guideline for high-visibility clothing for nighttime and daytime. The guide provides general principles for the enhancement of anyone exposed to motor vehicles, including construction workers' and airport workers' visibility both at night and during the day. The guide covers not only the physical principles but also variables involved in the performance and selection of high visibility materials. Even though the guide examines the principles, it does not set minimum standards for the properties of high visibility materials. It describes the relation of successive aspects of visibility to corresponding responses of the observer on perception. The four elements of visual perception, which consist of detectability, conspicuity, reorganization, and localizability, are explained in distinct sequential phases that correspond to visibility information from the roadway.

National Institute for Occupational Safety and Health (NIOSH) presents a guideline including high-visibility apparel and illumination of the work zone. An extensive analysis is conducted of worker fatalities and injuries in highway work zones by comparing the accident rates between inside and outside work zones based on data obtained from the Bureau of Labor Statistics for the years 1992 to 1998 (Pratt et al. 2001). The study makes recommendations to reduce accidents in construction work zones, including the use of high-visibility garments and proper illumination among many others.

2.2 Previous Research

Retro-reflective materials are known to perform well when used in making worker safety garments for use in nighttime operations. There are however different colors and/or shapes that may perform better in different circumstances such as background contrast, and location settings.

Though MIL-S-43753C (1998) allows mesh type vests to be worn by military personnel, there are managerial difficulties associated with the use of mesh type vests in construction operations since it is not easy to control what the workers wear under the vest (*Safety Vest Task Force* 1999). Though safety devices such as barrels, cones, and barricades surrounding the work zone can augment worker safety, they were not considered in this research. Since workers such as flaggers that operate at the edge of the work zone are solely dependent on safety clothing for their personal safety, the flagger who is to be supplied with the most visible safety clothing was identified for testing in this research.

2.2.1 Worker Visibility Issues

The ASTM *Standard Guide to Properties of High Visibility Materials Used to Improve Individual Safety* (ASTM Designation F 923-00) provides extensive information about both daytime and nighttime visibility issues. While in daytime, with high light levels, the moment at which an object can be detected on the road relies on visual acuity, that is, on the ability of human vision to resolve small details, at nighttime, luminance contrast becomes more important. Therefore, visibility at nighttime depends on providing more efficient luminance contrast to the observer.

The main problem in daytime visibility is conspicuity caused by abundant distracting details, visual clutter, glare, and camouflage effects. The ASTM standard states that the problems of recognition and localization are alleviated in daytime due to the human ability of form recognition with a relatively slight variation in size (Section 12 in ASTM Standard).

Conspicuity is best improved by providing high color or luminance contrast. Object shape or outline contrast and highlighted motion promote conspicuity as well. High brightness alone helps only against certain dark backgrounds and may camouflage a person against light backgrounds. Also, according to the ASTM standard, bright-saturated colors not normally found in the environment such as vivid blues and greens tend to stand out even if not fluorescent, because they are not generally common in the daytime environment. Therefore, there seem to be many issues left to explore concerning background settings. On the other hand, a study conducted by Washington State DOT (*Safety Vest Task Force* 1999) reports that lime-green vests tend to fade rapidly to a soft gray white color, although it gives a very high initial visibility.

At nighttime, to increase the detectability of an object, some form of retro-reflective material should have the following characteristics: (1) It should be sufficiently bright as positioned on the worker to provide conspicuity or noticeability at distances of interest. (2) It should provide this conspicuity from all directions whether the construction worker is in motion or not (360-degree protection). The *Michigan Manual of Uniform Traffic Control Devices* (revised 2001) issued by the Michigan State Advisory Committee has a full section about 360-degree protection. (3) It should furnish recognition cues that the object sighted is a human being, that is, a construction worker and not an inanimate road object or vehicle. (4) It should reveal the motion of the human being as much as possible but is not totally dependent on it for its effect. Finally, (5) If the high visibility materials are properly selected and located on the individual, it is not always necessary to use large areas of retro-reflectivity to meet these requirements (ASTM, Designation F 923-00 2001).

2.2.2 The implication on project performance factors

The common problems encountered during night operation are identified in Hancher and Taylor's (2001) studies as safety, quality, and lighting as the top three.

Hinze and Carlisle's (1990) research reveals the important variables in nighttime construction and the issues involved in nighttime road rehabilitation or maintenance operations. Limited or restricted visibility is addressed as an obvious drawback of nighttime construction. The visibility problems complicate traffic control, safety and work quality. Shepard and Cotrell (1985) investigate nighttime construction and maintenance operation practices and point out the benefits and safety issues associated with nighttime operations. The report concludes that the keystone for success in nighttime operations is special care for worker and driver safety.

- **Accidents**

Based on a nationwide statistical analysis, AASHTO (1998) indicates that work zone fatalities occur in every functional highway classification. It also reports that reliable and accurate work zone crash data are not presently available due to the lack of uniform reporting procedures and addresses the necessity to facilitate uniform reporting of work zone crashes.

Awareness about worker safety in nighttime construction has been a major concern because nighttime construction is being conducted more and more in many states in recent years (Report 98–S-50, NY 1999) even though it is believed that nighttime construction creates hazardous work conditions.

Though a number of references are indirectly dealing with worker safety issues in nighttime construction, only a few studies provide valuable information directly about worker safety issues in nighttime construction.

Birch (1998) discloses that accidents at nighttime were more severe than accidents in daytime. This was attributed to the increased number of impaired drivers and speeding drivers at night.

The Experience Modification Rates (EMR) and the OSHA recorded incidence rates that are used as measures of safety, use accidents and injuries as a basis for determining safety (Levitt and Samelson 1993). These rates give an indication of safety in general, rather than of safety in nighttime construction and/or the performance of safety garments and vests.

Concerns about reduced visibility, increased traffic speeds, and the higher frequency of drunk or sleepy drivers after dark limit the use of the nighttime construction alternative. Limited data are available comparing safety and accident characteristics of nighttime and daytime highway construction activities (Birch 1998).

The biennial audit report of the state of New York DOT (Report 98–S-50, NY 1999) regarding the nighttime construction program in New York states that one of the factors to be considered in deciding to undertake nighttime construction is the safety of both the traveling public and the workers involved in nighttime construction, though there is not a significant increase in accidents in nighttime operation, presumably based on the available data.

While it is difficult to assess the relative safety of nighttime construction for workers and the traveling public in relation to daytime construction, accident rates can be a valid indicator for assessing work-zone safety only by determining the number of accidents per total cars passing through the work zone, per person-day worked (daytime vs. nighttime) or per construction day/construction night.

Also, a comparison of nighttime and daytime construction activities may not be valid because these operations take place in totally different settings. To conform to the objective of managing traffic during highway construction, which is to provide a high level of safety for workers and the public, a system to report and monitor the number and types of accidents occurring in work zones is required. The biennial audit report of the state of New York DOT (Report 98–S-50, NY 1999) addresses the necessity to develop performance indicators, such as accident rates for vehicles and workers, to help evaluate the comparative safety of daytime and nighttime work zones. In the annual work-zone safety inspection, standard rating sheets and quality scoring goals to assess the degree to which the project meets the required safety standards are implemented so as to force the contractors to put the work zone safety in place.

A study was conducted by as part of this research (reported in a later section) of fatal accidents that occurred in Illinois highway work zones and it was found that there is no indication that nighttime construction was more hazardous than daytime construction in the study period of 1996-2001. The inclusion of the weather parameter into the study did not change this conclusion. However, one should not interpret this information further in the absence information about traffic volume, and number and size of projects carried out in daytime vs. nighttime.

- **Productivity**

Several research studies report that the advantages and disadvantages of nighttime construction are controversial in terms of the fact that improved productivity is expected by reduced traffic volumes (less congestion, less interference), safer working conditions (reduced exposure to the traveling public), cooler working conditions versus high daytime temperatures during the summer months, and quicker material delivery cycles (no machinery idle time), while inadequate lighting and poor visibility reduce night productivity specifically when the traffic-control devices and lighting equipment are down. While the drawbacks are associated with a limited number of workers and a lack of machine service and truck availability, productivity tends to increase if enough workers and machines are available. Nevertheless, a productivity loss is perceived in performing nighttime construction. This can increase the costs of the work and the risk of the workforce relative to safety when adequate lighting and visibility are not ensured (Hancher and Taylor 2001, Birch 1998, Abd Elrahman and Perry 1994).

- **Cost**

Regarding the economic outcome of the nighttime construction alternative, Abd Elrahman and Perry (1985) and Hinze and Carlisle (1990) state that the economic parameter associated with roadwork can roughly be categorized into construction costs, user costs, accident costs and maintenance costs. Related with the accident cost, Abd Elrahman and Perry (1985) include poor visibility, inadequate lighting, and inadequate traffic control devices to the factors affecting nighttime accident rates. While subjectively arguing that nighttime accidents are less frequent but more severe than daytime accidents, the researchers claim that data are limited comparing the cost of night and daytime accidents in work zones. Hinze and Carlisle (1990) contend that it is not straightforward or appropriate to assign accident costs to any entity, nor is it simple to predict what these costs will be whereas Ellis and Kumar's (1993) study shows that total program cost is less for night work even though the results do not confirm a significant difference between the productivity values for nighttime and daytime projects. Possibly accidents occurring in the construction work zone will be greater in number or severity for night work because of poor visibility. On the other hand, the reduction in traffic at night might result in a safer work area for motorists and workers. The issue is controversial.

The governing factors that govern the nighttime vs. daytime operation are stated as congestion and safety, since cost is directly affected by congestion level and safety. Nighttime construction is more costly, primarily due to the added costs required for lighting. The intensity and number of lights necessary far exceeds the amount of lighting needed for daytime construction. If a construction firm has had experience in performing nighttime construction, their equipment might be modified with lighting features, eliminating the need for that expense. There is little in the available literature regarding cost efficient, safe, and effective means of equipping paving machinery with special lighting. As far as safety is concerned, it is generally agreed that reduced speeds through the construction work zone and a well-lighted site can improve the safety of workers and drivers. The point of contention among the respondents and the literature is how to get drivers to slow down (Hinze and Carlisle 1990).

- **Project duration and quality of project**

The implications of a nighttime schedule are reviewed by Hinze and Carlisle (1990) as they relate to traffic, cost, safety, lighting, quality, noise, worker morale, productivity, material delivery and public awareness under different conditions of decision-making, traffic control, quality, cost, and innovations. The report states that traffic control, safety, and community impacts are the most important performance concerns. Both State highway agencies and contractors state that adequate lighting is an important aspect of safety in nighttime construction projects in addition to assuring work quality (Hinze and Carlisle 1990).

2.2.3 Work Zone Safety Garment Studies

As more nighttime operation is being undertaken, new needs have evolved relative to safety including providing higher visibility and conspicuity of workers operating in a work zone. Furthermore, the more operations need to be carried out in less than optimum weather conditions, the more highway worker visibility issues become important. High visibility garments have been studied in nighttime construction and maintenance operations.

Anders (2000) performed a field experiment to evaluate the influence of color and size on the conspicuity of signs, not safety garments. Sign color combination, age, and visibility condition were considered as independent variables. The research evaluated the visual performance of retro-reflective objects (signs) of various color combinations. Though the research was conducted to evaluate fluorescent sign color combinations, not safety garments, it still gives an idea of the factors affecting the issues of visibility and conspicuity in general.

A number of studies directly dealing with safety garments have also been conducted. Michon et al.'s (1969) field experiment evaluated the influence of color and size on the conspicuity of safety clothing on a 12-km track in a diverse background setting, color combination, and complexity. Sixteen colored cardboard rectangles (white, yellow, fluorescent yellow, fluorescent orange) were placed at different positions along the track. Subjects were required to blow their horn when they detected the "safety garment" along the track. The rectangles were presented to the subjects at distances of either 100 or 200 m. Overall, Michon et al. (1969) found that fluorescent orange resulted in the lowest reaction times followed by yellow, fluorescent yellow, and white. They found that an area of about 1,200 cm^2 is a sufficient amount of fluorescent material, which is roughly equivalent to a 30-cm-wide band around the upper part of the body.

Janson and Smith (1973; 1976) conducted two research studies sponsored by the Michigan State Highway Commission, which dealt with safety vests. These studies evaluate different safety vests using retro-reflective patterns for nighttime.

Brackett and Stuart's (1982) and Brackett et al.'s (1985) studies conducted under the sponsorship of the Texas Transportation Institute also deal with safety vests. These studies as well as the one conducted by Turner et al. (1997) deal with the effectiveness of high-visibility garments in daytime construction.

In 1990, Lesley (1995) conducted a survey dealing with the color of safety vests in the State of Minnesota under the sponsorship of MNDOT. The results of the survey were as follows: fluorescent yellow, 5,796; fluorescent green, 2,706; fluorescent orange, 2,23 1; fluorescent pink, 2,017. Of 119 voters who described themselves as color blind, 115 selected the fluorescent yellow.

Although Isler et al.'s (1997) research is conducted in the forestry industry, it is noteworthy in that safety garment research should consider background setting.

A MNDOT's study recommends the use of lime-yellow reflective material to enhance safety. Also, the report suggests making the worker more identifiable as a person, to "outline the body as completely as possible with the brightest material available." The report states that since motion is a factor in visibility, retroreflective, and fluorescent applications should first be made on or near the hands and feet where motion is maximized. Gloves and boots should be treated with reflective material, as should cuffs and sleeves. New specifications have been built on this initial study. MNDOT has conducted research with colors and found neon yellow was the most visible to the human eye. In 1996 new specs were written approving neon yellow garments with orange for contrast, with workers required to wear only a vest daytime, but both pants and tops at night. All nighttime workers are to wear neon, but for daytime wears, workers can choose to wear the standard orange or the neon yellow. Also, a baseball style cap or summer wear, and either a baseball cap or stocking cap for winter, which has reflectivity as well as color, are other new safety garments. Initially MNDOT worked together with safety garment maker HeadLites and 3M, which makes the Scotchlite Reflective material used on the safety garments. The retro-reflective material produced by 3M enhances nighttime visibility to 1,000 ft. The retro-reflectivity of the 3M materials provides increased visibility during bad weather and in low-light conditions, according to the manufacturer. The measurement of brightness, interpretation of ANSI/ISEA Standards 107-1999, retro-reflective versus fluorescent, and performance in rain are presented in the website (http://international.3m.com/intl/CA/english/centres/safety/personal_safety/bsbse3.pdf).

With increasing work being done at night, the special hazards nighttime crews face come into play. The MNDOT has taken a policy for designing a better performance safety vest. MNDOT has adopted a policy under the name of "high visibility reflective clothing required for night work" out of their research to develop safety apparels (http://ops.fhwa.dot.gov/wz/wzguidbk/documents/hp-mn11.htm). MNDOT requires full-length-high-visibility reflective clothing (tops and bottoms) be worn by all workers during night work. While MNDOT began doing more nighttime construction and maintenance due to increased traffic congestion during the day, MNDOT requires them to wear full-length high visibility reflective clothing to increase the safety for workers at nighttime by making the workers more visible to the motorists. The benefit expected from the policy is to make motorists see the reflecting object is a human; they then generally tend to be more cautious and slow down. The location and type(s) of projects where the policy is most applicable and effective is for all nighttime construction and maintenance work (http://www.headlitescorp.com/Page10.html).

Iowa DOT adapted a practice and/or policy under the name of high visibility worker apparel to improve safety in work zones by making workers more visible in various lighting and working conditions (http://ops.fhwa.dot.gov/wz/wzguidbk/documents/hp-ia1.htm). Iowa DOT conducted a pilot study and tested a set of safety clothing that were worn by some of the department's maintenance and construction workers to improve safety in work zones (http://www.dot.state.ia.us/morgue/06239704.htm). The safety garments included a safety vest, jacket, hat for daytime activities and high visibility pants were added for nighttime operation. The reflective trim on the garments was designed to enhance daytime and nighttime visibility. It made the worker visible under daytime conditions and attract attention in poor visibility periods at dawn and dusk. The Iowa DOT has begun issuing employees a new style fluorescent yellow-green and orange safety vest including pants and caps of the same color and design. For uniformity, Iowa DOT has adapted those styles of apparels developed by MNDOT. Other DOTs are following Minnesota's lead. Iowa DOT is incorporating safety garments into their specifications.

Ca/DOT regulates high-visibility clothing for flaggers who are supposed to be nearest the edge of a work zone to control traffic. The regulation concerns not only daytime and nighttime condition but also color contrast in snow and fog conditions. It is remarkable that color contrast with background is considered in this implementation. The implementation of advanced warning is regulated in the section regarding work zone layout and flagger station (http://www.dot.ca.gov/hq/traffops/signtech/signdel/flagging/flagging.htm).

WSDOT (Washington DOT) adopted a bill titled *New Emergency Rules for Flaggers* to improve the safety of highway flaggers. It states that the permanent rules must take effect no later than March 1, 2001. The new requirements have been written as "performance-based" rules which means that the updated rules state the requirements and let the employer decide how best to accomplish the protection. Regardless of how and what is specified in the law, employers must achieve the intended performance. It is the responsibility of the employer, contractor and/or project owner to ensure that flaggers have adequate warning of objects approaching from behind the flagger (www.wsdot.wa.gov/fossc/cons/contaa/bulletin/wkzonebulaug.pdf). WSDOT sponsored a research study by launching a Safety Vest Task Force (1999) formed by members that constitute some 103 years of total field experience with safety vests. The report discusses some issues regarding fading, 360 degree reflectivity and contrasting, web-type vests, and the lack of contrast in certain situations while lime-green color as well as red-orange are both considered to have high visibility. The task force measured the performance of 100 sets of vests in terms of visibility, colors, reflectivity, wearability, durability, comfort, and resistance to fading. Visibility and reflectivity were evaluated with a rating scale format. The test of the vest was conducted at 1,000 feet under 6 conditions, namely (1) daytime and vest is dry, (2) daytime and vest is wet, (3) dusk and vest is dry, (4) dusk and vest is wet, (5) dark and vest is dry, (6) dark and vest is wet. The lighting conditions, i.e., night, dusk/dawn, and day used in the experimentation meet technically the requirements of recent standards developed by the American Society for Testing and Materials (ASTM) (http://www.headlitescorp.com/Page14.html).

MDOT (Michigan DOT) issued the new version of the *Michigan Manual of Uniform Traffic Control Devices* - Part 6, Construction and Maintenance in January 2001. This manual regulates worker safety considerations, high-visibility clothing for flaggers, and high-level warning devices in Sections 6D-2, 6E-3, 6F-4, respectively. In addition, the manual designates three different fluorescent colors or combinations of them and retro-reflective materials for safety garments; it also regulates in section 6E-1 the design of the garment so that the safety garment can be seen through the full range (360 degrees) of body motion.

2.2.4 Illumination

Lighting is a crucial element of any night project since it affects quality, productivity, and safety directly. Adequate lighting not only may make construction operations as good as by day but also affects visibility positively (Abd Elrahman and Perry 1985). Ellis and Herbsman's (1996) illumination guidelines for nighttime construction and maintenance in highways can be used for testing the performance of safety garments. The research provides preliminary illumination guidelines for nighttime construction and maintenance in highways. The guidelines identify the types of light sources and the minimum and maximum levels of illumination required depending on the type of nighttime operation. The guidelines address visibility requirements, lighting equipment, lighting configuration and arrangement, lighting system design, system operation and maintenance, and economic considerations.

The most common nighttime construction operations are identified by by Ellis and Herbsman (1996) and the common nighttime maintenance activities are categorized as sweeping and cleanup, concrete pavement repair, bridge deck rehabilitation and maintenance, resurfacing, milling and surface removal, lighting system repair, traffic signal maintenance, marking and stripe painting, surface treatment, and barrier walls.

For effective highway construction lighting design, three illumination categories are proposed as Categories I, II, and III that require average illumination levels of 54, 108, and 215 lux (5, 10, and 20 foot-candles), respectively (Ellis and Amos 1995). Category I is recommended for general illumination in the work zone and areas where crew movement takes place. Category II is recommended for illumination on and around construction equipment. Category III is recommended for tasks that require increased attention. The research presents the correlations among the category rank, the minimum luminance level, area of illumination, size of visual task, accuracy, and contrast required for caution and attention. It then concludes that highway maintenance operations need to get special attention in behalf of nighttime worker safety because of the fact that those operations that belong to category III including crack filling, pothole filling, signalization or similar work require extreme caution and attention. The more worker segregations are performed in the work zone, the higher level of illumination and awareness is required.

3. ANALYSIS OF FATAL ACCIDENTS IN WORK ZONES IN ILLINOIS

3.1 Introduction

The first study addressing differences between daytime and nighttime construction was conducted in Colorado back in 1986 (Price 1986). Comparing the quality and cost of daytime and nighttime projects, Price (1986) concludes that the material delivery was more efficient due to less traffic but temperature extremes could have an adverse effect on crew and equipment performance. Hinze and Carlisle (1990) examined the factors related to nighttime construction. Ellis and Kumar (1993) investigated differences in cost and productivity between daytime and nighttime construction in Florida. They found that there is no significant difference in productivity, but that nighttime projects cost less. Researchers have also noticed the potential adverse effect of nighttime construction on quality (Price 1986, Hinze and Carlisle 1990). Dunston et al (2000) presented the weekend closure strategy and its implementation in an actual project in Washington State. Their findings include improved quality and productivity over nighttime construction. Ellis and Amos (1996) developed work zone lighting standards for nighttime highway work. Many articles were found on work zone safety issues. Wang et al (1996) investigated highway work zone crashes by using the electronic data obtained from the multistate Highway Safety Information System (HSIS). Pal and Sinha (1996) studied various lane closure strategies. Shibuya et al (1996) presented traffic control measures at flagger-operated work zones on two-lane roads. However, there has been no specific research comparing the effect of daytime and nighttime construction on work zone safety.

3.2 Methodology

3.2.1 Data Source

The raw data of fatal accidents has been downloaded as a fat file from the FTP site in Web-Based Encyclopedia of Fatality Analysis Reporting System (FARS) that is serviced by the National Highway Traffic Safety Administration (NHTSA: http://www-fars.nhtsa.dot.gov). FARS is a collection of files documenting all qualifying fatal crashes since 1975 that occurred within the 50 states, the District of Columbia, and Puerto Rico. The reference provided by FARS has been used in conducting accident research on highway construction sites at nighttime.

3.2.2 Conversion of the Raw Data into a Database

Since the web application serviced by NHTSA does not allow complex queries for the retrieval and analysis fatal crash information under specific conditions such as fatal accidents that are construction work zone related and that occur at nighttime, the fat file had to be downloaded in its original format with file_Name.dbf (Accbac__.dbf, Accident__.dbf, Perbac__.dbf, Person__.dbf, and Vehicle__.dbf) and converted into a database file (Accident.mdb) as presented in Figure 3.1. The instructions of the USERGUIDE.asc file in the FARS-DOC directory of the FTP site (ftp://www.nhtsa.dot.gov/FARS) were carefully followed in transferring the raw data to a new database file.

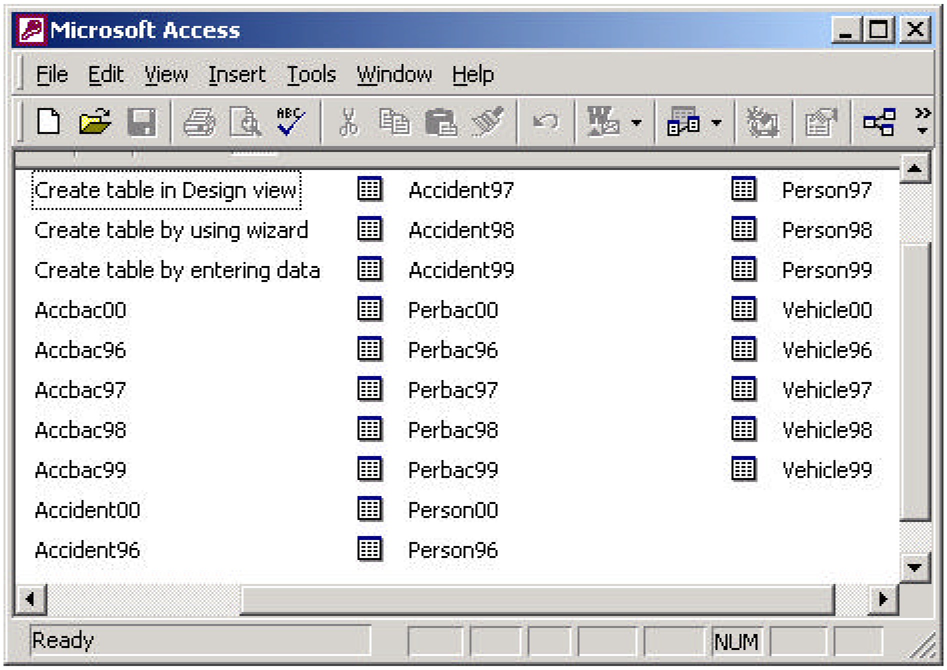


Figure 3.1 The tables in the Accident Database (Accident.mdb)

The accident database Accident.mdb was designed in such a way as to include the proper relationships among tables, as displayed in Figure 3.2. All the entities and relationships were identified and designed based on the description of the variables in the USERGUIDE.asc file. The primary key was identified as the State Case (ST_CASE: which can be found in A-36, V-58, P-59 in the USERGUIDE), which is a variable in each Accident, Vehicle, and Person record. It is a combination of the GSA state code and an assigned consecutive number. It is a unique identifier for a crash within the year. It is used as the key, when any two of these files, from the same year, are merged. This variable is stored as a numeric variable of six characters, where the first two characters represent the state code, and the next four characters are the case number, with leading zeros if necessary. The referential integrity of the database was verified by eliminating anomalies.

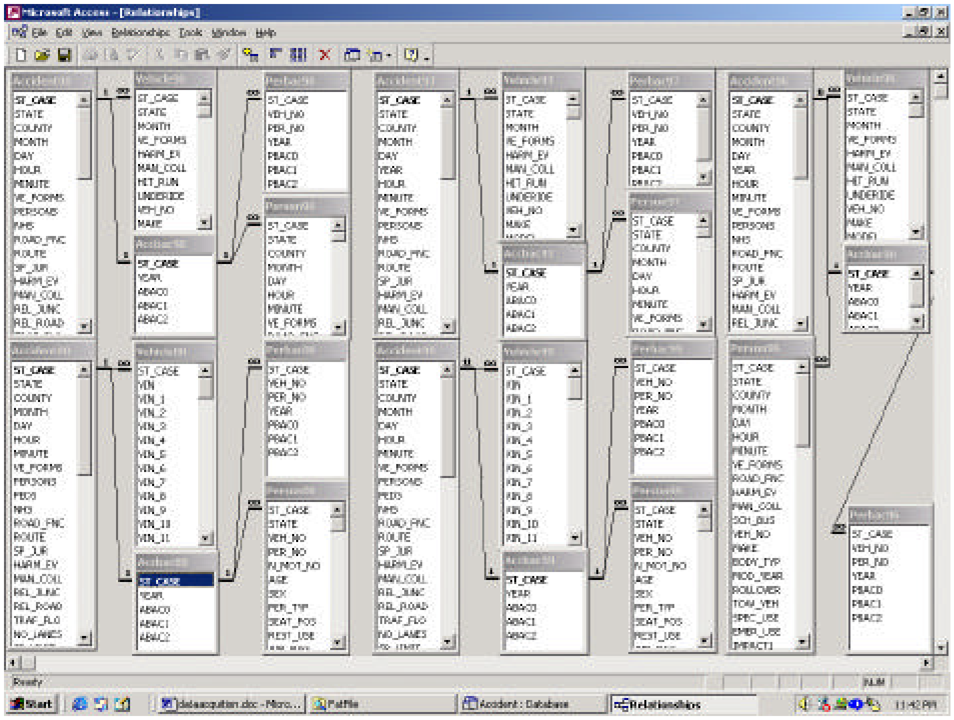


Figure 3.2 The relationships among tables in the Accident.mdb database

After acquiring the nationwide fatal accident records and storing them in the Accident.mdb database file as in Figures 3.1 and 3.2, the contents of the database were verified by crosschecking with the web application. To retrieve the accidents related to construction work zones in Illinois only, Structured Query Language (SQL) was used (Figure 3.3) and a query table was generated corresponding to each year (Figure 3.4).

Because the primary key, State Case (ST_CASE) is a unique identifier for an accident within a year, not all the years, query tables containing construction work zone related accidents were created for each year as in Figure 3.4. Due to the data processing limitation of MS Access, only the records concerning the accidents that occurred in construction work zones in Illinois were queried from the fatal accidents database of NHTSA.

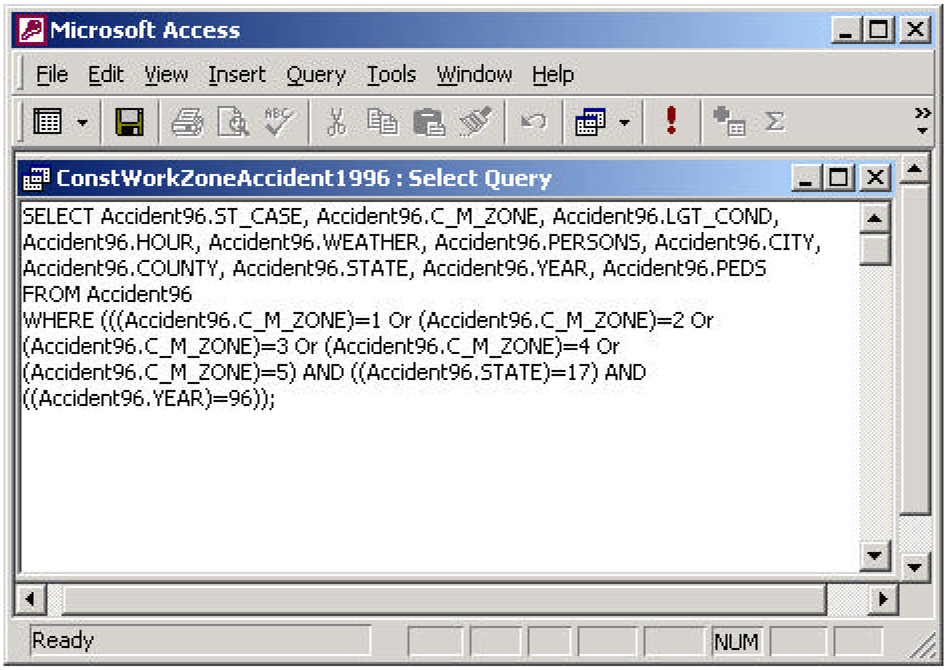


Figure 3.3 A SQL program for querying construction work zone accidents in a year

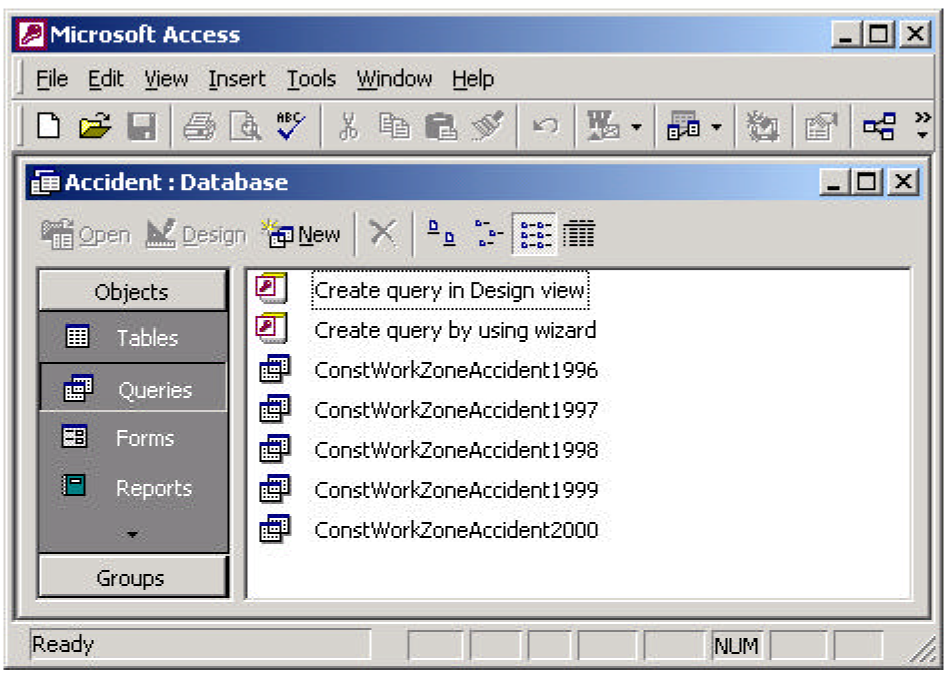
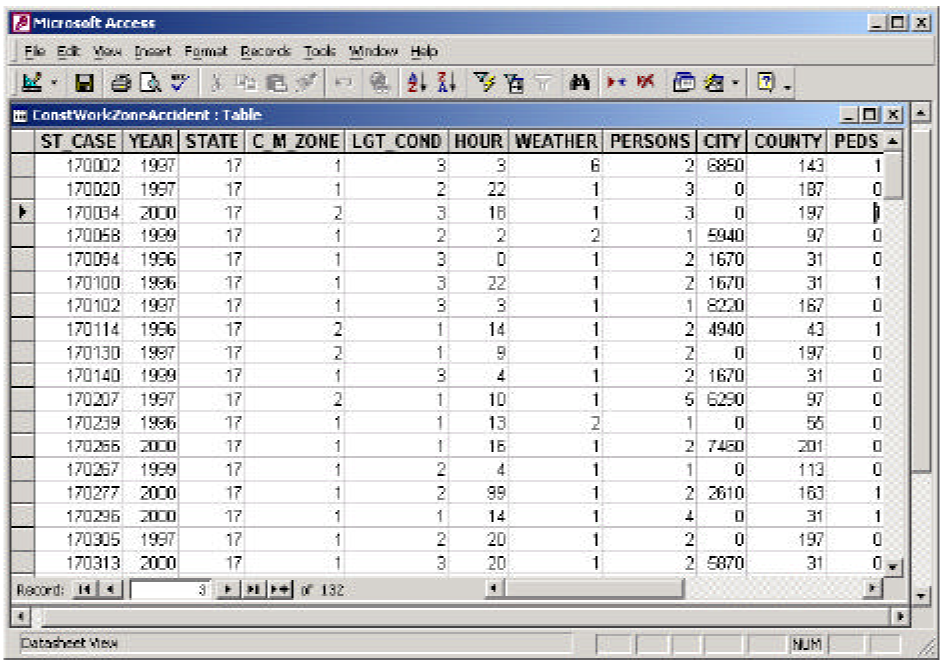


Figure 3.4 Query tables retaining construction work zone related accidents

3.2.3 Creating Accidents Database containing construction work zone related accidents in Illinois.

To augment the efficiency of data analysis, all the query tables in Figure 3.4 were joined together using the primary key State Case (ST_CASE) and Year. As a result, a new table was created, which contains the raw data regarding only accidents that occurred in construction work zones in Illinois (Figure 3.5). The total number of accidents in the 5-year period 1996-2000 is 132. Exactly the same result could be obtained from the web application of NHTSA. All the subsequent data analysis was based on this table.



ST_CASE	YEAR	STATE	C_M_ZONE	LGT_COND	HOUR	WEATHER	PERSONS	CITY	COUNTY	PEDS
170002	1997	17	1	3	3	6	2	6850	143	1
170020	1997	17	1	2	22	1	3	0	187	0
170034	2000	17	2	3	18	1	3	0	197	0
170058	1999	17	1	2	2	2	1	5940	97	0
170094	1996	17	1	3	0	1	2	1670	31	0
170100	1996	17	1	3	22	1	2	1670	31	1
170102	1997	17	1	3	3	1	1	8220	167	0
170114	1996	17	2	1	14	1	2	4940	43	1
170130	1997	17	2	1	9	1	2	0	197	0
170140	1999	17	1	3	4	1	2	1670	31	0
170207	1997	17	2	1	10	1	5	6290	97	0
170239	1996	17	1	1	13	2	1	0	55	0
170266	2000	17	1	1	16	1	2	7460	201	0
170267	1999	17	1	2	4	1	1	0	113	0
170277	2000	17	1	2	99	1	2	2610	163	1
170296	2000	17	1	1	14	1	4	0	31	1
170305	1997	17	1	2	20	1	2	0	197	0
170313	2000	17	1	3	20	1	2	5870	31	0

Figure 3.5 Accidents table containing construction work zone related accidents in Illinois

To identify the type, frequency, severity, and share of accidents involving construction workers in a construction work zone in Illinois, an SQL program was designed and a query table was generated corresponding to each condition such as in Figure 3.6. All the variables presented in Table 3.1 were identified and the variables affecting the conditions were used in the queries presented in Figures 3.7, 3.8, and 3.9.

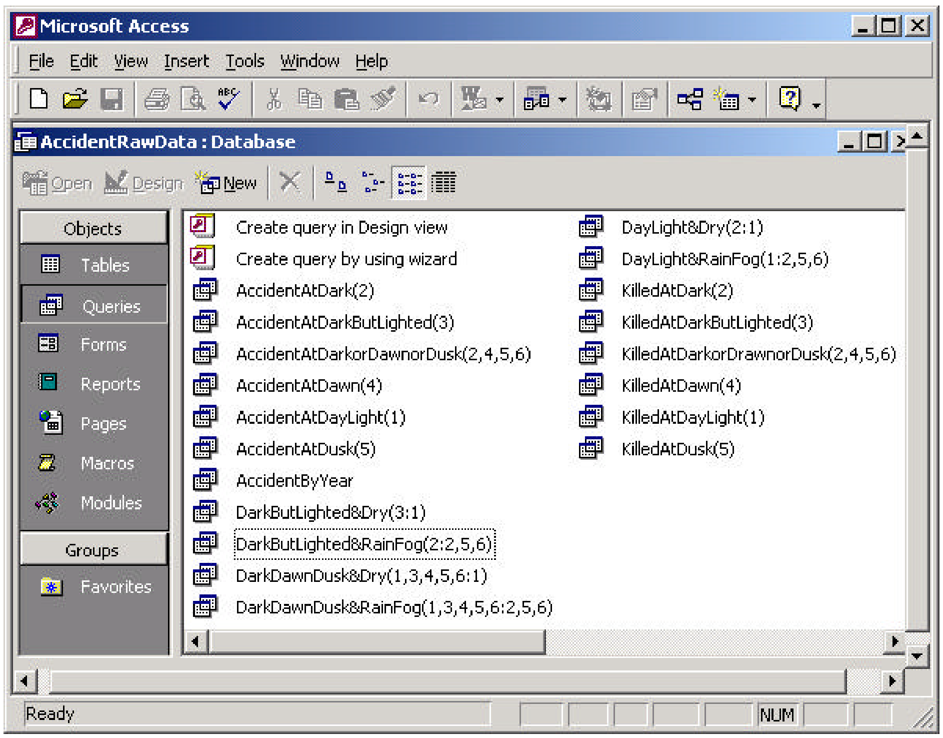


Figure 3.6 Query tables

Table 3.1 Description of variables used in the ConstWorkZoneAccident table

Variable	Description of variables
ST_CASE (1980 and later)	• This variable is in each Accident, Vehicle and Person record. It is a combination of the GSA state code and an assigned consecutive number. It is a unique identifier for the Crash within the year. It is used as the key, when any two of these files from the same year, are merged. This variable is stored as a numeric variable of six characters; the first two characters are the state code, and the next four characters are case number, with leading zeros if necessary.
YEAR (1975 and later)	• The year in which the crash took place.
STATE	• GSA state codes except for 43, Puerto Rico - This is the state in which the crash occurred. The state in which the vehicle(s) is (are) registered, REG_STAT, is found in the vehicle file, the coding is the same. 17 Illinois
C_M_ZONE (1982 and later)	• The variable identifies crashes that occurred in a construction or maintenance zone. Use of the codes does not imply that the crash was caused by the construction or maintenance activity or zone. 0. None 1. Construction 2. Maintenance 3. Utility 4. Work Zone, Type Unknown
LGT_COND	1 Daylight 2 Dark 3 Dark but lighted 4 Dawn 5 Dusk 9 Unknown
WEATHER (1982 and later)	1 No Adverse Atmospheric Conditions 2 Rain 3 Sleet 4 Snow 5 Fog 6 Rain and Fog 7 Sleet and Fog 8 Other: Smog, Smoke, Blowing Sand or Dust 9 Unknown
PERSONS	• The number of persons involved in the crash except for uninjured bus and train passengers. A form describing all other persons involved in a crash, will be filed, i.e., this variable is a count of the persons in the crash.
PEDS (1991 and later)	• Number of non-motorists, i.e., any person(s) who is (are) not an occupant of a motor vehicle in transport.

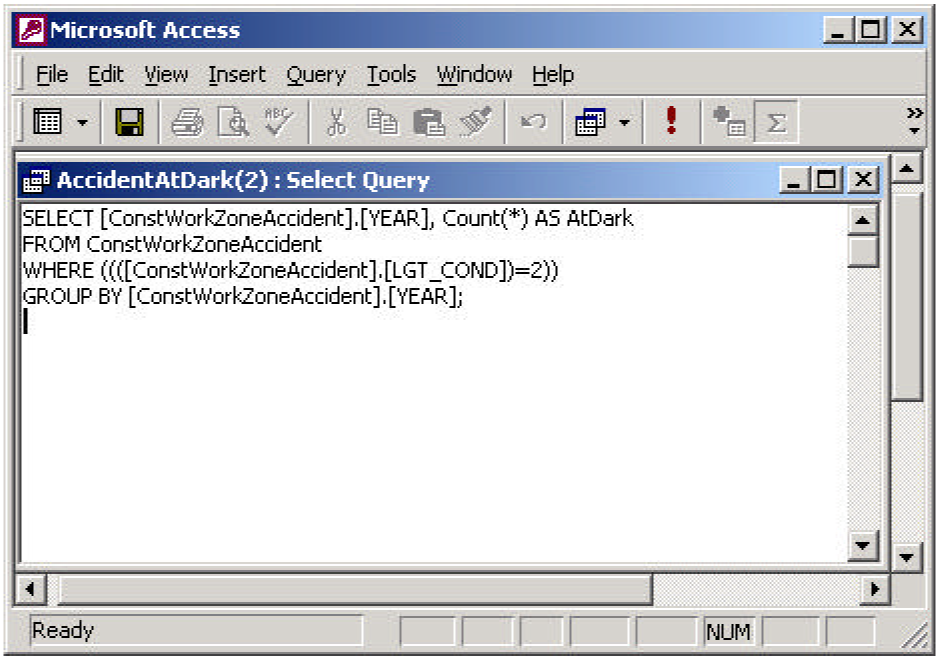


Figure 3.7 SQL program for querying accident information by light conditions

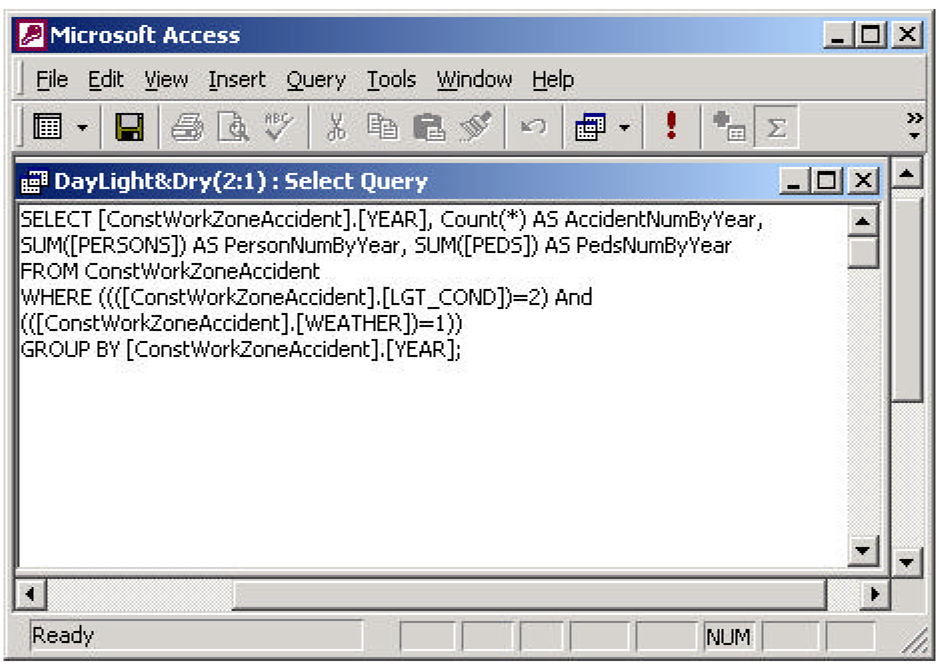


Figure 3.8 SQL program for querying accident information by light and weather conditions

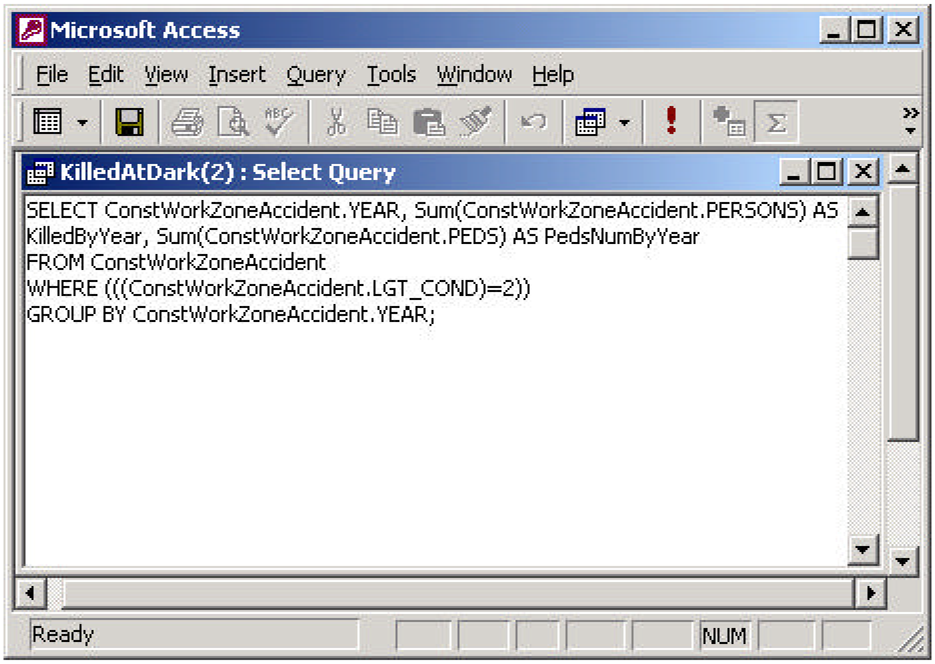


Figure 3.9 SQL program for querying accident information by light conditions

3.3 Data Mining and Analysis

By executing the queries, the number of fatal accidents, the number of persons killed, and the number of workers killed were calculated and are presented in Table 3.2 and plotted in Figure 3.10. The data show that there has been a drastic increase in the number of fatal accidents and in the number of fatalities in construction zones in the state of Illinois in the year 2000 while there had been a decreasing trend in the years 1996 through 1999. The main reasons contributing to the sudden change in the decreasing trend is not known. The reasons could include more construction work and/or maintenance, improved accident reporting system, increased traffic volumes, or deterioration of safety procedures in highway construction sites in the year 2000.

Table 3.2 Number of fatal accidents, persons killed, and workers killed in construction work zones in Illinois

Years	Numbers by Year		
	Fatal Accidents	Persons Killed	Workers Killed
1996	26	74	11
1997	31	99	7
1998	18	74	3
1999	15	39	2
2000	42	120	11
Five-Year Totals	132	406	34

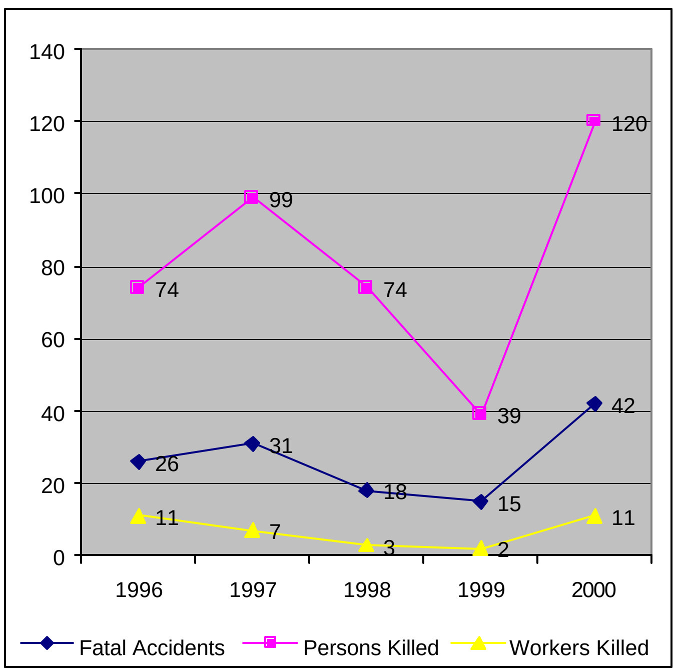


Figure 3.10 Number of fatal accidents, persons killed, and workers killed in construction work zones in Illinois

3.3.1 Light Conditions

FARS classifies light conditions at the time of the accident in six groups, namely (1) Day, (2) Dark, (3) Dark but lighted, (4) Dawn, (5) Dusk, and (9) Unknown (see Table 3.1). Classification (9) Unknown was not reported in any accident that occurred in the five-year study period of 1996-2000; that is why (9) Unknown has not been considered in the analyses. The numbers of fatal accidents in highway work zones in Illinois are presented by light conditions in Table 3.3 and Figure 3.11. The drastic increase in daytime accidents in the year 2000 is also visible in Table 3.3 and Figure 3.11, irrespective of light conditions.

Two analyses were conducted using these classifications. One analysis involved a comparison of accidents that occurred during the day (including only Classification 1) with accidents that occurred at any other time (including Classifications 2, 3, 4, and 5). These two groups were called Day and NotDay, respectively. The other analysis involved a comparison of accidents that occurred at night (including only Classification 2) with accidents that occurred at any other time (including Classifications 1, 3, 4, and 5). These two groups were called Night and NotNight, respectively. The outcomes of these two analyses are reported in Figures 3.12 and 3.13. In both analyses, it is possible to observe that work zones are becoming safer at nighttime compared to daytime.

When the numbers of fatalities are analyzed in terms of persons killed (including workers, other pedestrians, drivers, operators, etc.) and workers killed (excluding any other persons), the same observation that work zones are becoming safer at nighttime compared to daytime, can be made. Indeed, Table 3.4 and Figure 3.14 show the number of persons killed in highway work zone accidents in Illinois arranged by light conditions.

Table 3.3 Fatal accidents by light conditions

Year	Numbers by Year								Percentages			
	Fatal Accidents	Day(1)	Dark(2)	DarkButLighted(3)	Dawn(4)	Dusk(5)	NotDay(2,3,4,5)	NotNight(1,3,4,5)	Day (1)	NotDay (2,3,4,5)	Night (2)	NotNight (1,3,4,5)
1996	26	12	7	7	0	0	14	19	46.15	53.85	26.92	73.08
1997	31	11	9	11	0	0	20	22	35.48	64.52	29.03	70.97
1998	18	9	4	4	0	1	9	14	50.00	50.00	22.22	77.78
1999	15	7	6	2	0	0	8	9	46.67	53.33	40.00	60.00
2000	42	24	8	8	0	2	18	34	57.14	42.86	19.05	80.95

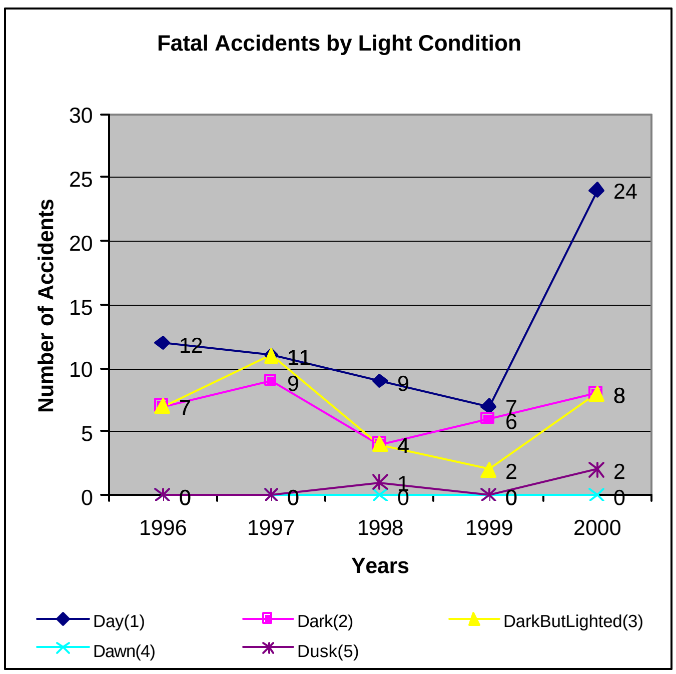


Figure 3.11 Number of accidents by years according to light conditions

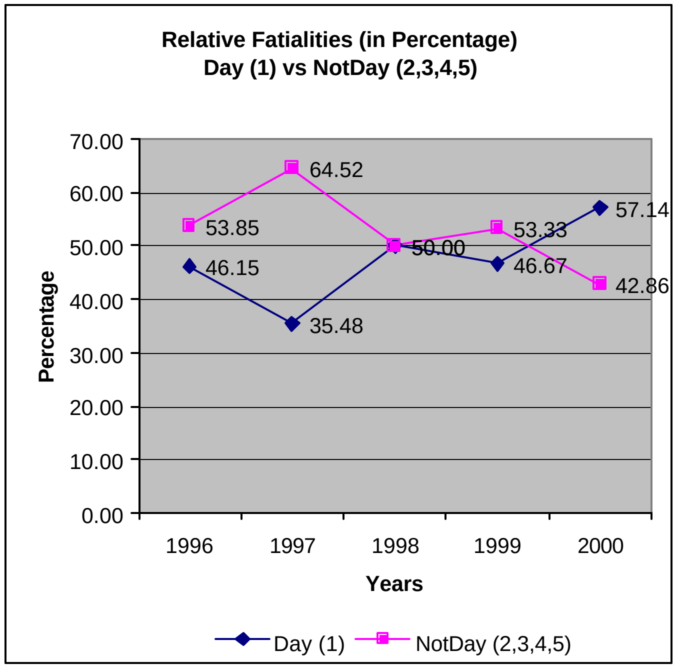


Figure 3.12 Relative fatalities in percentage of accidents (Day (1) vs. NotDay (2,3,4,5))

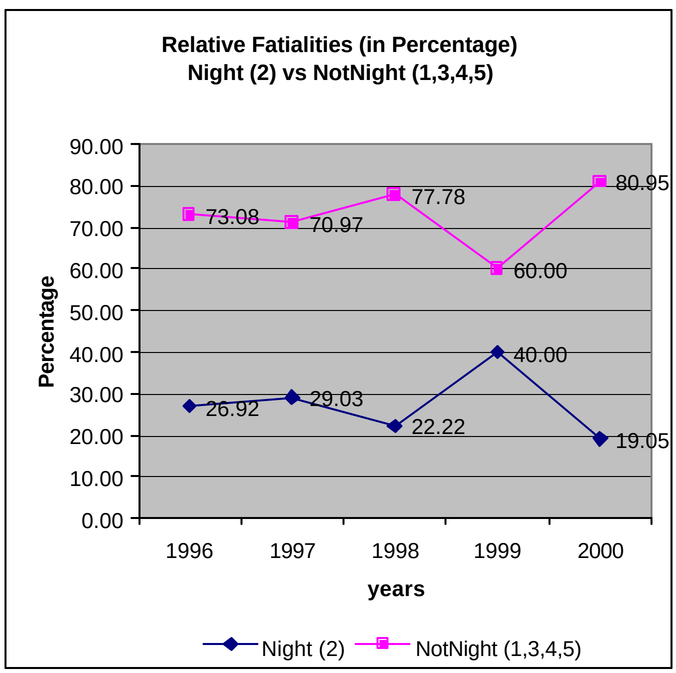


Figure 3.13 Relative fatalities in percentage of accidents (Night (2) vs. NotNight (1,3,4,5))

Table 3.4 Fatalities (in number of persons killed) by light conditions

Year	Numbers by Year								Percentages			
	Persons Killed	Day(1)	Dark(2)	DarkButLighted(3)	Dawn(4)	Dusk(5)	NotDay(2,3,4,5)	NotNight(1,3,4,5)	Day (1)	NotDay (2,3,4,5)	Night (2)	NotNight (1,3,4,5)
1996	74	37	11	26	0	0	37	63	50.00	50.00	14.86	85.14
1997	99	33	40	26	0	0	66	59	33.33	66.67	40.40	59.60
1998	74	36	23	13	0	2	38	51	48.65	51.35	31.08	68.92
1999	39	23	12	4	0	0	16	27	58.97	41.03	30.77	69.23
2000	120	70	25	17	0	8	50	95	58.33	41.67	20.83	79.17

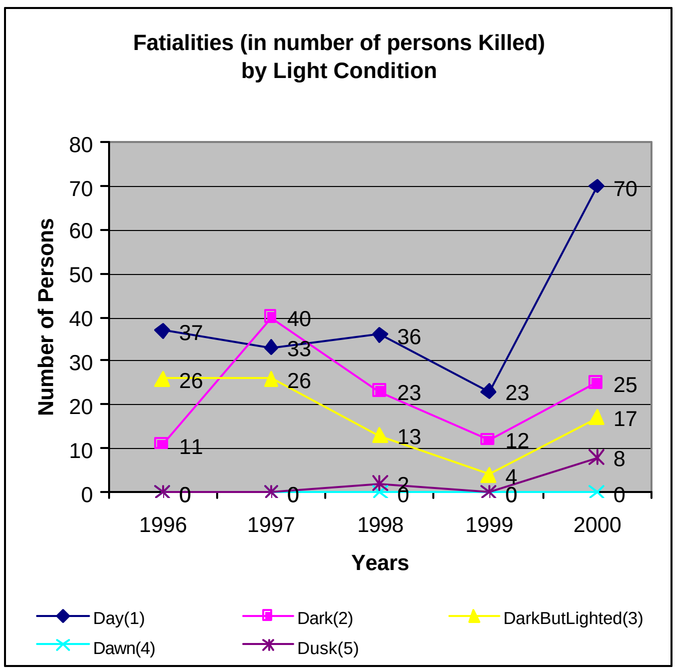


Figure 3.14 Number of persons killed by years according to light conditions

Figures 3.15 and 3.16 look at the differences between Day and NotDay, and between Night and NotNight, respectively. On the other hand, Table 3.5 and Figure 3.17 show the number of workers killed in highway work zone accidents in Illinois presented by light conditions. Figures 3.18 and 3.19 look at the differences between Day and NotDay, and between Night and NotNight, respectively. The trend in all cases is clear.

3.3.2 Light and Weather Conditions

FARS classifies weather conditions at the time of the accident in nine groups, namely (1) No adverse atmospheric conditions, (2) Rain, (3) Sleet, (4) Snow, (5) Fog, (6) Rain and fog, (7) Sleet and fog, (8) Other: smog, smoke, blowing sand or dust, and (9) Unknown. Classification (9) Unknown was not reported in any accident that occurred in the five-year study period of 1996-2000; that is why (9) Unknown has not been considered in the analyses.

The FARS weather classifications were used to create two groups: Dry (including only Classification 1) and Wet (including all other classifications). The effects of dry or wet conditions on work zone accidents were then analyzed by taking into consideration the two sets of light conditions generated in the previous section (i.e., Day vs. NotDay, and Night vs. NotNight). Accident data are reported by dry and wet conditions for Day vs. NotDay conditions in Table 3.6 and Figures 3.20, 3.21, and 3.22; accident data are also reported by dry and wet conditions for Night vs. NotNight conditions in Table 3.7 and Figures 3.23, 3.24, and 3.25. In all tables and figures, it is observed that the number of fatal accidents, the number of persons killed in these accidents, and the number of workers killed in these accidents are getting larger over the years under dry daytime conditions.

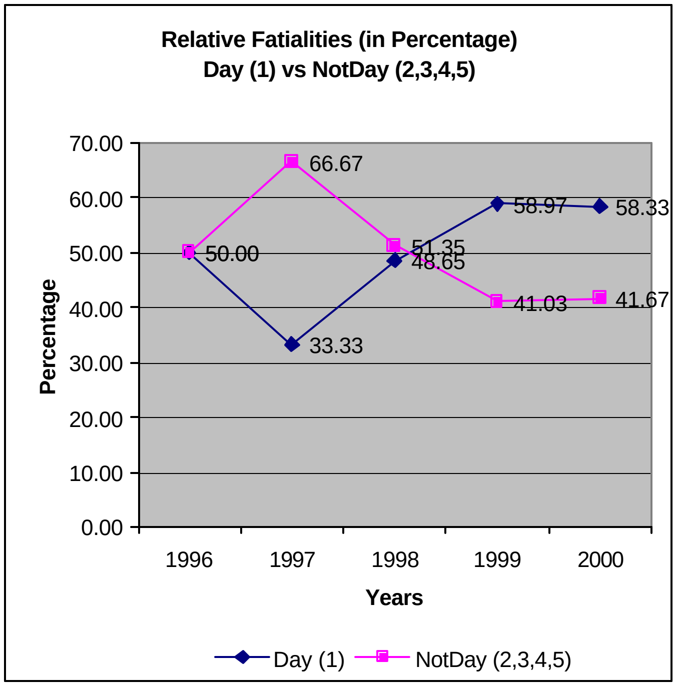


Figure 3.15 Relative fatalities (in percentage of persons killed)
(Day (1) vs. NotDay (2,3,4,5))

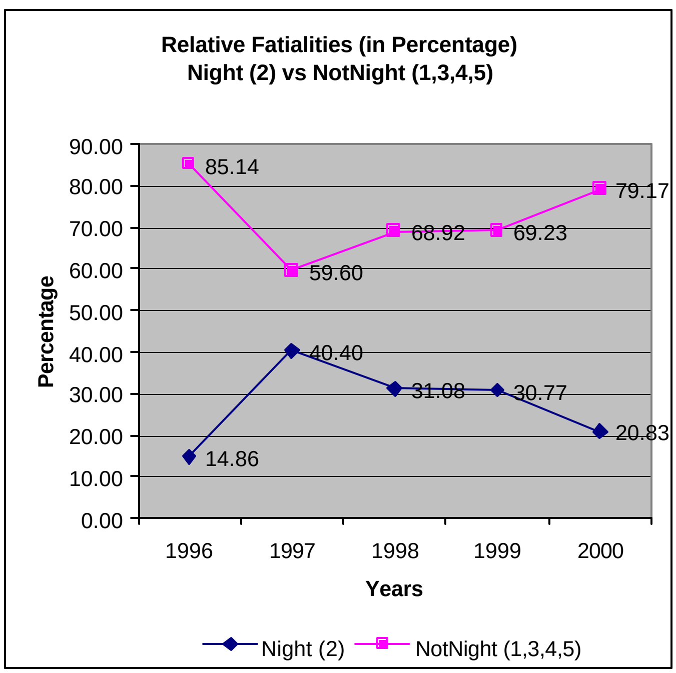


Figure 3.16 Relative fatalities (in percentage of persons killed)
(Night (2) vs. NotNight (1,3,4,5))

Table 3.5 Fatalities (in number of workers killed) by light conditions

Year	Numbers by Year								Percentages			
	Workers Killed	Day(1)	Dark(2)	DarkButLighted(3)	Dawn(4)	Dusk(5)	NotDay(2,3,4,5)	NotNight(1,3,4,5)	Day (1)	NotDay (2,3,4,5)	Night (2)	NotNight (1,3,4,5)
1996	11	3	0	8	0	0	8	11	27.27	72.73	0.00	100.00
1997	7	1	1	5	0	0	6	6	14.29	85.71	14.29	85.71
1998	3	2	0	1	0	0	1	3	66.67	33.33	0.00	100.00
1999	2	2	0	0	0	0	0	2	100.00	0.00	0.00	100.00
2000	11	9	1	1	0	0	2	10	81.82	18.18	9.09	90.91

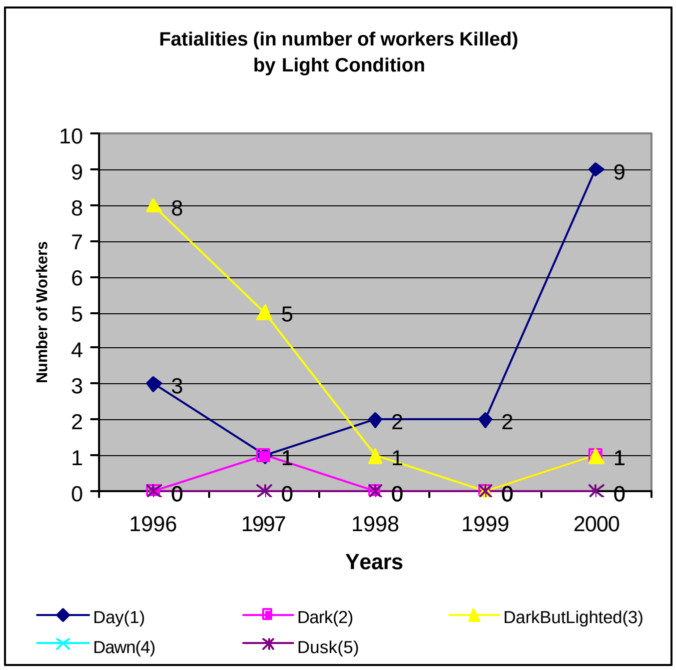


Figure 3.17 Number of workers killed by years according to light conditions

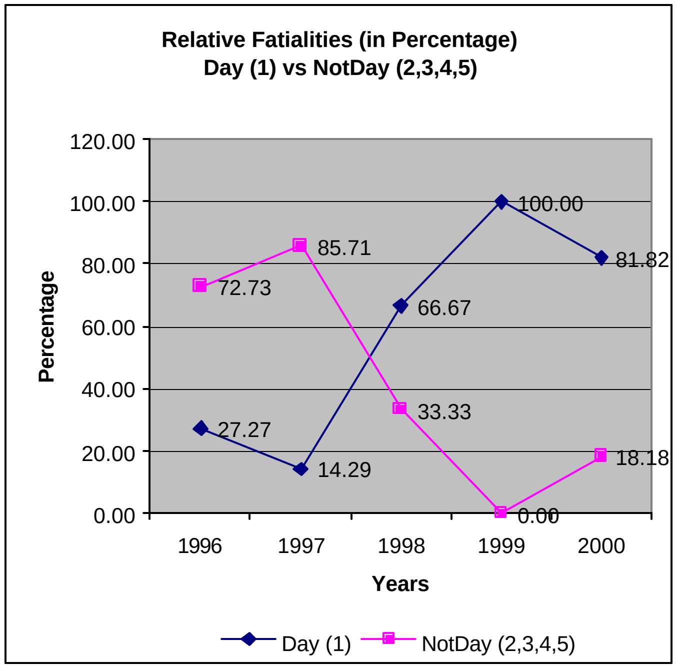


Figure 3.18 Relative fatalities (in percentage of workers killed) (Day (1) vs. NotDay (2,3,4,5))

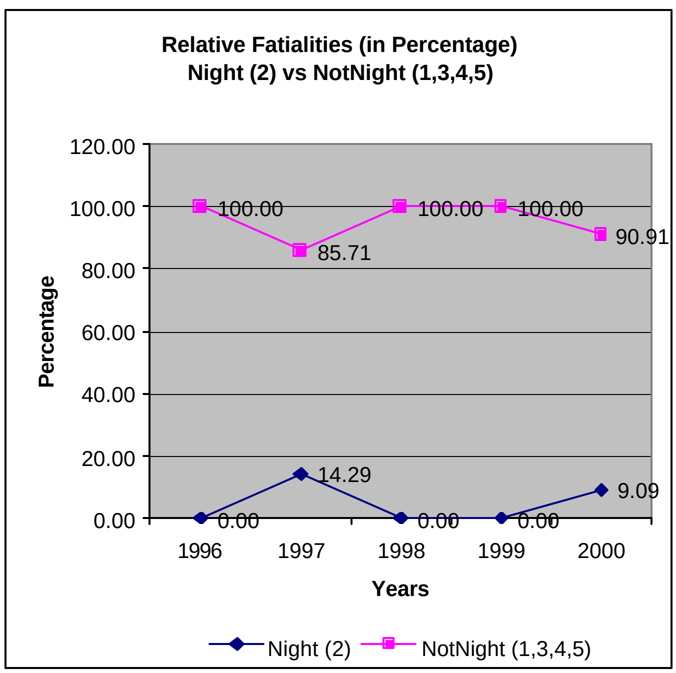


Figure 3.19 Relative fatalities (in percentage of workers killed) (Night (2) vs. NotNight (1,3,4,5))

Table 3.6 Analysis by light and weather conditions

Year	Day (1)						NotDay (2,3,4,5)						Total		
	Dry			Wet			Dry			Wet					
	Number of Accidents (Day:Dry)	Number of Persons Killed (Day:Dry)	Number of Workers Killed (Day:Dry)	Number of Accidents (Day:Wet)	Number of Persons Killed (Day:Wet)	Number of Workers Killed (Day:Wet)	Number of Accidents (NotDay:Dry)	Number of Persons Killed (NotDay:Dry)	Number of Workers Killed (NotDay:Dry)	Number of Accidents (NotDay:Wet)	Number of Persons Killed (NotDay:Wet)	Number of Workers Killed (NotDay:Wet)	Accident	Persons	Worker
1996	10	31	3	2	6	0	13	35	7	1	2	1	26	74	11
1997	9	24	1	2	9	0	18	60	5	2	6	1	31	99	7
1998	9	36	2	0	0	0	8	35	1	1	3	0	18	74	3
1999	7	23	2	0	0	0	7	15	0	1	1	0	15	39	2
2000	22	60	9	2	10	0	17	44	2	1	6	0	42	120	11

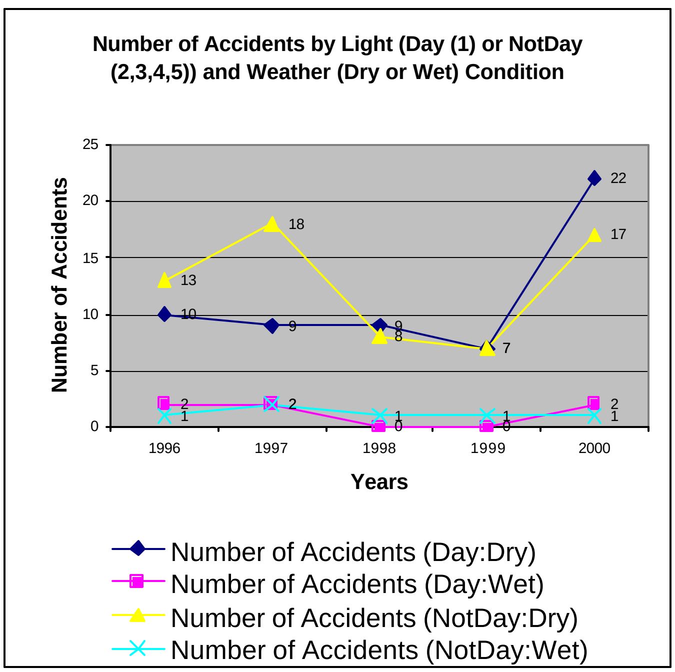


Figure 3.20 Number of accidents by light (Day (1) or NotDay (2,3,4,5)) and weather (Dry or Wet) conditions

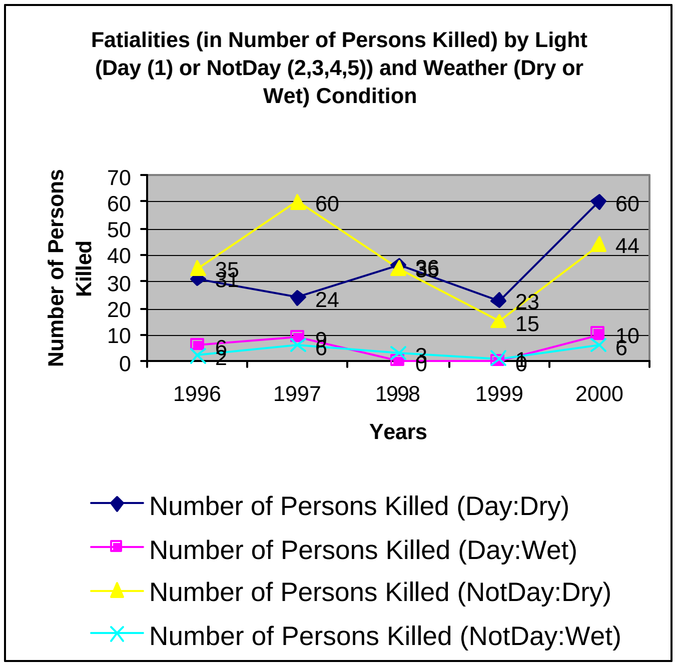


Figure 3.21 Fatalities (in number of persons killed) by light (Day (1) or NotDay (2,3,4,5)) and weather (Dry or Wet) conditions

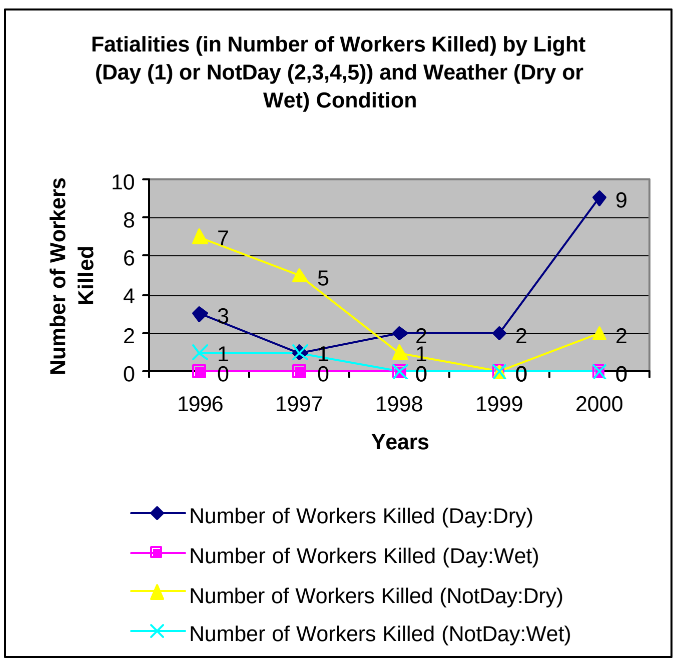


Figure 3.22 Fatalities (in number of workers killed) by light (Day (1) or NotDay (2,3,4,5)) and weather (Dry or Wet) conditions

Table 3.7 Number of accidents by light (Night (2) or NotNight (1,3,4,5)) and weather (Dry or Wet) conditions

Year	NotNight (1,3,4,5)						Night (2)						Total		
	Dry			Wet			Dry			Wet					
	Number of Accidents (NotNight:Dry)	Number of Persons Killed (NotNight:Dry)	Number of Workers Killed (NotNight:Dry)	Number of Accidents (NotNight:Wet)	Number of Persons Killed (NotNight:Wet)	Number of Workers Killed (NotNight:Wet)	Number of Accidents (Night:Dry)	Number of Persons Killed (Night:Dry)	Number of Workers Killed (Night:Dry)	Number of Accidents (Night:Wet)	Number of Persons Killed (Night:Wet)	Number of Workers Killed (Night:Wet)	Accidents	Persons	Workers
1996	16	55	10	3	8	1	7	11	0	0	0	0	26	74	11
1997	19	48	5	3	11	1	8	36	1	1	4	0	31	99	7
1998	13	48	3	1	3	0	4	23	0	0	0	0	18	74	3
1999	9	27	2	0	0	0	5	11	0	1	1	0	15	39	2
2000	32	85	10	2	10	0	7	19	1	1	6	0	42	120	11

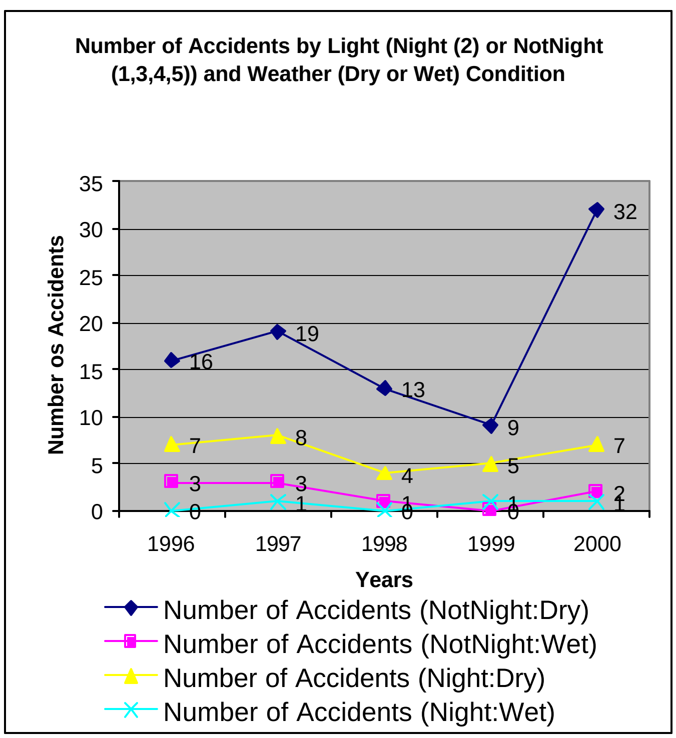


Figure 3.23 Number of accidents by light (Night (2) or NotNight (1,3,4,5)) and weather (Dry or Wet) conditions

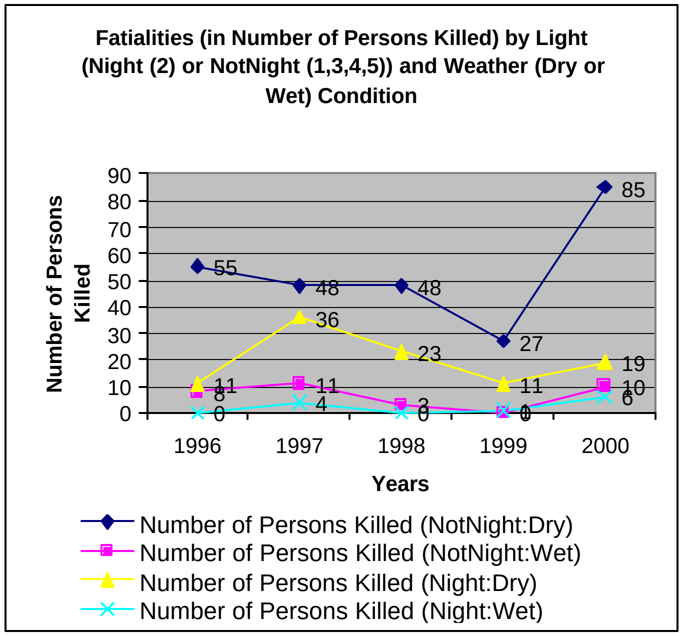


Figure 3.24 Fatalities (in number of persons killed) by light (Night (2) or NotNight (1,3,4,5)) and weather (Dry or Wet) conditions

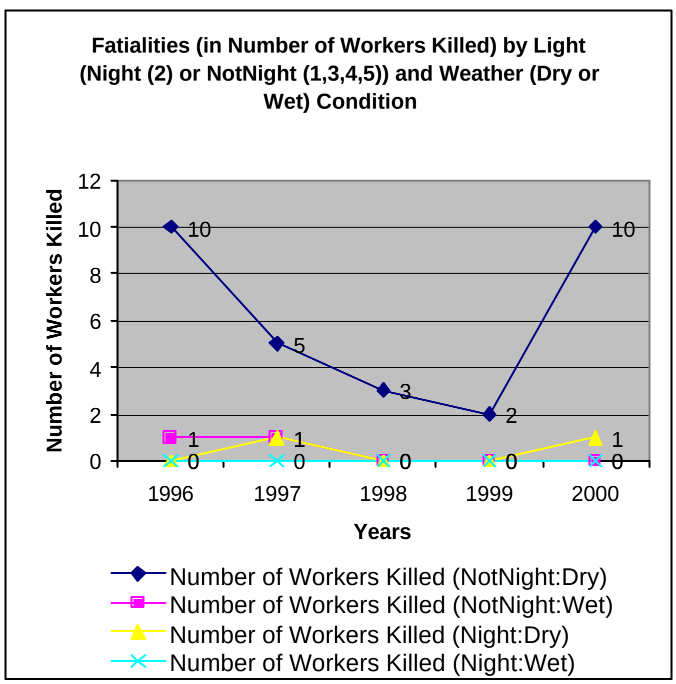


Figure 3.25 Fatalities (in number of workers killed) by light (Night (2) or NotNight (1,3,4,5)) and weather (Dry or Wet) conditions

3.4 Conclusion

According to data on fatal accidents in highway work zones in the State of Illinois in the five-year study period of 1996-2001, there is no indication that nighttime construction is more hazardous than daytime construction. The inclusion of a weather parameter into the analysis does not change this finding. However, one should not interpret this information further in the absence of information about traffic volume, and number and size of projects carried out in daytime vs. nighttime.

4. METHODOLOGY OF THE STUDY

4.1 General Approach to the Problem

This section describes the research team's plan of action and methodology. The following activities were conducted with the approval of the TRP:

- A comprehensive review of the literature on work zone safety garments and worker visibility issues in daytime and nighttime construction operations including new and innovative technologies was conducted. The literature survey involved the review of archived publications, internal reports and websites. The review included new and innovative technologies associated with worker visibility issues, and high visibility work zone safety garments used in the U.S. and other countries (Britain, Australia, and New Zealand) and by other professions such as the military. This deliverable was submitted to the TRP in January 2002.
- The records of construction work zone accidents (daytime and nighttime) in Illinois over the 5-year period 1996-2001 involving construction workers were extracted from the FRS and examined to determine the potential influence of worker visibility as a cause of work zone accidents. This deliverable was submitted to the TRP in January 2002.
- A survey was conducted of IDOT operation personnel, resident engineers, and contractors involved in nighttime construction operations in Illinois within the past five years to determine safety concerns. The survey investigated (a) the type, severity, and frequency of nighttime accidents involving workers in work areas, (b)

the performance of existing safety garments, and (c) safety garment design factors and features. The survey tool was approved by the project TRP. This deliverable was submitted to the TRP in July 2002.

- A survey of other DOTs was conducted regarding the type of safety garments used in nighttime construction operations including information on the materials used to construct the garments and the source of such garments. Like in the preceding bullet point, the survey also investigated (a) the type, severity, and frequency of nighttime accidents involving workers in work areas, (b) the performance of existing safety garments, and (c) safety garment design factors and features. The survey tool was approved by the project TRP. This deliverable was submitted to the TRP in July 2002.
- A comprehensive list of the manufacturers and distributors of high-visibility garments was compiled to account for the many safety garments currently on the marketplace. Information collected in the surveys mentioned in the preceding two bullet points was used as well as a thorough internet survey to identify and locate these companies. A list of the companies is given in Appendix A.
- Based on the findings of the surveys mentioned in the preceding three bullet points, nine safety vests were identified as being used by different states. Three of these vests were eliminated because they were exact replicas of some of the other vests even though they were marketed under different names. The remaining six safety vests were picked for testing, after consultation with the project TRP. It should be noted that three of these six vests are currently being used by IDOT. The six safety vests tested include:

IODT Standard Vest
IDOT LED Vest
Head Lite Roadstar 200 Vest
Iron Horse Texas Style Vest
Chami Design Washington Style Vest
Safetyline Minnesota Style Vest

The pictures of these vests are presented in Appendix B.

- A field evaluation was conducted to measure the performance of the safety garments selected. A test setup was devised and a procedure called LUMINA was developed to electronically analyze the data collected and to produce an example movie of the tests. The field evaluation included different lighting, weather and location conditions. A total of four tests were consulted with the approval of the project TRP. Videotapes of these tests were made.
- A survey of potential users of high visibility safety garments was conducted to investigate (a) 360° visibility, (b) conspicuity against the background, (c) the brightness of the retro-reflective material, (d) the configuration of the vests (pockets, zipper, etc.), and (e) the overall perceived effectiveness. The survey tool was approved by the project TRP.

4.2 DOT Survey Instrument

A questionnaire survey was administered to IDOT operations personnel, resident engineers, and contractors involved in nighttime construction. A copy of the survey instrument is presented in Appendix C. The questionnaire involved three parts:

PART I Type, severity, and frequency of nighttime accidents involving workers in work areas
PART II Evaluation of existing safety garments
PART III Safety garment design factors and features

The first part involved questions about the observations and experiences of the respondents concerning nighttime accidents. The second part investigated the performance of existing safety vests that are currently being used in IDOT nighttime projects. The third sought information concerning the features and the design factors of safety vests. The terms encountered in the questions were defined in two tables placed in the questionnaire. Specific questions were formulated for the questionnaire based on the information obtained from the literature review described in Chapter 2.

A similar questionnaire survey was administered to the departments of transportation other than Illinois'. The contents of this questionnaire are basically the same as the IDOT questionnaire except that some of the wording (IDOT was replaced by DOT) was different. A copy of the survey instrument is presented in Appendix D.

Both questionnaires were extensively reviewed and revised by the project TRP. The names and email addresses of IDOT operations personnel, resident engineers and contractors involved in nighttime construction/maintenance in each district were provided by the TRP. Contacts with these contact persons in each district led to a pool of prospective respondents.

The survey administered to other states' DOTs was conducted with the help of IDOT's David Lippert who has access to a network of individuals in each state who can forward the request to the right person in their organization.

The help received from IDOT in identifying potential respondents to our surveys was invaluable.

4.3 Site Tests

LUMINA is a system composed of hardware and software that was developed to conduct this study. LUMINA was used (a) to perform field experiments that involved recording on video the performance of various safety vests under different site conditions; and (b) to conduct office operations that involved converting the video movie into snapshots, calculating the average luminance of the vests tested, and indexing them. The features of LUMINA are described in the following sections.

4.3.1 Site Operations

A video camera recorder, Sony CCD-TR700, which was provided by the Transportation Engineering Laboratory at Illinois Institute of Technology, was used to record the movies at construction sites. The camcorder is capable of using Hi8 video technology, recording the movies in NTSC (National Television System Committee) format. Hi8 videos are recorded in a slightly different fashion than its lower resolution counterpart, 8mm. The luminance portion of the video signal is allocated a substantially wider bandwidth on the frequency spectrum. An Hi8 video signal has a resolution of approximately 400 lines, while an 8mm video signal has approximately 220 lines of resolution. With the current technology, a common 8mm camcorder tape has a video recording time of 120 min in Hi8 format. The existing camera and the Hi8 format were selected for use in the recording phase.

A total of six, half round, injection molded men's display forms (mannequins) were procured for use in experiments conducted in the field (Figure 4.1). Black colored mannequins were chosen to avoid reflections from mannequins. The black color does not reflect any light.

Three stands were fabricated to hang the mannequins with vests on them. These stands were constructed in the workshop of the department. Two mannequins were hung back to back on each stand to get a torso that appears to be as similar to a man's torso as possible. Using the three stands and six mannequins, three man's torsos were formed. A photometer was placed right above the mannequins on the center stand. The photometer recorded the light condition on the site and automatically calculated the average light during a shift.

Figure 4.1 Mannequin used in field tests

The setup of the field tests was developed after conducting an experiment in the university's parking lot. The field tests were conducted as described below:

1. The setup of the camera and the mannequins at a construction site can be seen in Figure 4.2. The stands on which the mannequins are hung were placed such as the fronts of the vests were perpendicular to incoming traffic. The stands were placed next to each other at the edge of the closed work zone (on the traffic side) to be as

close to traffic as possible and to capture maximum light from traffic. The safety of the project team was a great concern during field tests. To enhance safety, the project team's SUV was parked between the camcorder and the traffic but still within the closed work zone. The setup in Figure 4.2 was designed to enhance the accuracy, functionality and safety of the measurements. Pictures of the site setup are presented in Appendix E.

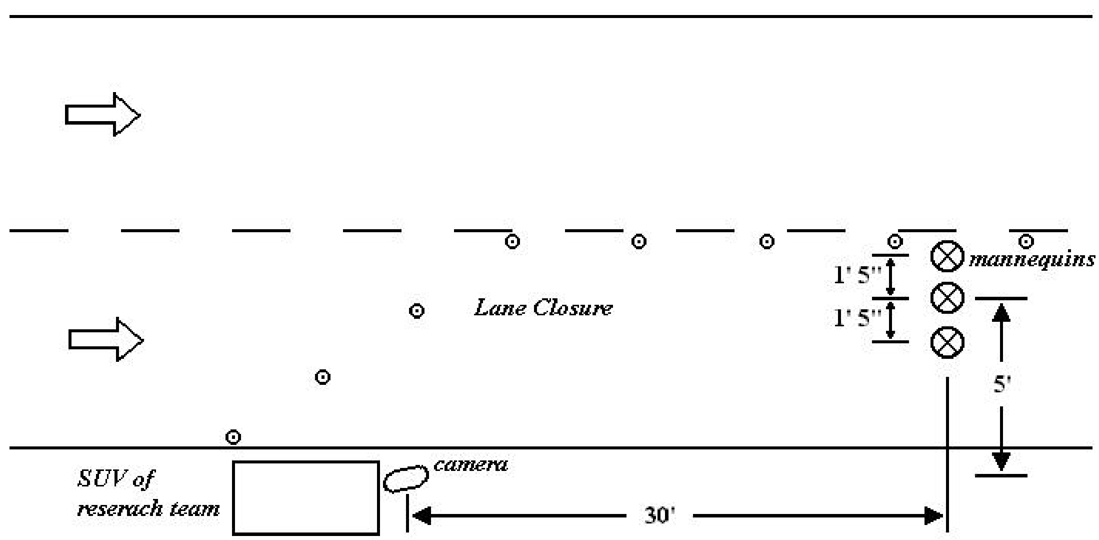


Figure 4.2 Setup of field tests

2. Field measurements were started after sunset. Also rush hours were avoided as there are rarely construction/rehabilitation or maintenance works done on highways at rush hours. During the measurements, the traffic volume and the amount of light in the test area change continuously. A photometer provided by the Lewis Construction Laboratory at IIT was used to record the intensity of the light at the test site. The photometer was attached to the center stand and average luminance values (lux) were

recorded for each shift. The average luminance values were used to normalize the light reflected by the safety vests.

3. After a set of three vest (2 sets of 3 vests each were tested) was put on the mannequins, the camera and the photometer were turned on simultaneously. The camera and the photometer were tuned off after 10 minutes of recording.
4. The location of the vests vis-à-vis the border of the work zone (and therefore their proximity to traffic) is expected to influence the results. To evaluate the impact of placing the vests in different locations, it was decided to switch the location of the vests periodically. After a recording time of 10 minutes, the average luminance value was recorded and the places of the vests were switched while the photometer was reset. This way, every vest was recorded for 10 minutes in each one of the three locations (stand closest to cones, center stand, and stand farthest from the open lane).
5. After performing Step 4 for all three combinations, the second set of three vests was tested. Step 4 was also repeated three times for the second set of three vests.
6. After completion of Step 5, the recording of the front of the vests was completed. According to the findings of the survey administered to IDOT operations personnel, resident engineers, contractors and to departments of transportation of other states than Illinois (See Chapter 5), 360° visibility was considered as the most important safety garment design factor. Therefore all four faces (front, back, left and right) of the vests should be tested. The left and right faces are exactly the same; whereas the front and back faces are very similar. So recording the front and one side of the vests was considered to be adequate for the purpose of the research.
7. Steps 4 and 5 were repeated for the sides of vests.

4.3.2 Office operations

Hardware

The movies on the videocassettes were digitalized using a frame grabber program called AIGOTCHA, a hardware device coupled with its own software developed by AI Tech.

The National Standard Television Committee has established 30 frames per second (fps) as the standard frame rate in the USA. If a movie made with a frame rate of 30 fps, all the details of the filmed operation can easily be observed during playback. There are two major problems associated with this frame rate; it takes equal time to play back the movie as recording it, and it occupies a huge amount of space on an electronic storage device such as a hard disk. The time-lapse technique reduces the frame rate when recording, but uses 30 fps when playing back; this way, it is possible to see the movie in much less time than the time spent filming the real event. Thus, if a six hour long event is recorded at a rate of 5 fps, it is possible to play back the movie in one hour at the standard frame rate of 30 fps; the shortening in the view time is obtained at the expense of missing some of the detail in the filmed operation. But the storage space for the time-lapse film is much less than a film shot at a rate of 30 fps. AIGOTCHA is capable of capturing frames from a movie at a rate of 1 frame per 2 seconds. It means, a six hour long event that is recorded at a rate of 1 frame per 2 seconds can be played back in 6 minutes at the standard frame rate of 30 fps. The frame grabber AIGOTCHA can capture frame sizes of 180×120, 360×240, 512×384, 720×480,…, 1600×1200. The 512×384 pixel was selected for the size of the frames because a 512×384 frame includes enough detail and occupies less space in hard drive than larger sizes do.

The frames output by AIGOTCHA are in BMP, Windows bitmap format. The size of each file varies from 500 to 600 Kb, which occupies considerable space on the hard disc and slows down the computer. So the frames are compressed to another Windows compatible image file. Several different compressing engines are available on the market. The JPEG system has been used in this research. This system has been chosen because the Windows system has a class to compress pictures using it. The JPEG class allows the user to determine the rate of quality compression desirable. Experiments have been conducted during this research varying the quality-compression rate between 80% and 100%. The results achieved from the frames which were compressed with a quality of 80% and 100% were exactly same. So all the frames in BMP format were compressed into JPEG files with a quality-compression rate of 80%. The size of each file was this way reduced to 22 to 26 Kb.

Software

After getting the frames, the smallest rectangle into which a vest can fit was determined. The rectangle should be selected in a manner that maximum vest area is included with minimum background. The coordinates of the two diagonal corners of the rectangles and the size of the rectangles are recorded as seen in Figure 4.3. The picture and values illustrated in Figure 4.3 were obtained from the field test performed as a trial at the university's parking lot. The coordinates and the size of the rectangles were kept constant for each shift of three vests. Neither the position of the mannequins nor of the vests were changed during this part of the test. Once the vests were switched, the coordinates and sizes of the rectangles were reset.

In the trial shift presented in Figure 4.3, a rectangle having dimensions of 106×168 was placed on both of the vests. The coordinates were determined so that each vest appeared in the center of the rectangle.

Figure 4.3 Capturing vest data

These rectangles are cropped out of the pictures using IrfanView 3.75. IrfanView is an image viewer and editor software that can be downloaded from http://download.com.com/3000-2192-10132330.html?tag=lst-0-1. After entering the coordinates of the rectangles and the destination folders for the cropped pictures, IrfanView saves the cropped images in files with the same name as the original files.

A program was then written in Microsoft Visual Basic 6.0 to calculate the average RGB (red, green, blue) and luminance values of the vests in the frames. The flowchart of the program is presented in Figure 4.4. The program was run for each vest. The data were collected in an Access file for evaluation.

RGB (Red, Green, and Blue) refers to a system for representing the colors to be used on a computer display or television. Red, green, and blue can be combined in various proportions to obtain any color in the visible spectrum. In the most common model used in imaging programs and also in the model covered in this research, the values of the R, G and B range from 0 to 255 as integers (256 unique levels for each color component).

In the luminance calculations, the NTSC (National Television System Committee) model is used. This system makes use of certain limitations in the ability of the human eye and brain to register what they are actually seeing, and so the performance of the eye under various conditions is described. In the NTSC system, the first step is to convert RGB to a color space that is based on human perception. This system also has three qualities: Y, luminance, is the brightness axis; I, intermodulation, is the orange-blue axis; and Q, quadrature, is the purple-green axis. In the NTSC system the main signal, termed Y, carries the monochrome or luminance information and is formed by adding fractions of the R (red), G (green) and B (blue) values together so that these values contribute to the brightness of a pixel. For the NTSC primaries, the Y-luminance component is formulated as follows:

$$Y = (0.299 \times R) + (0.587 \times G) + (0.114 \times B)$$

In this research, this formula was used to calculate the luminance values.

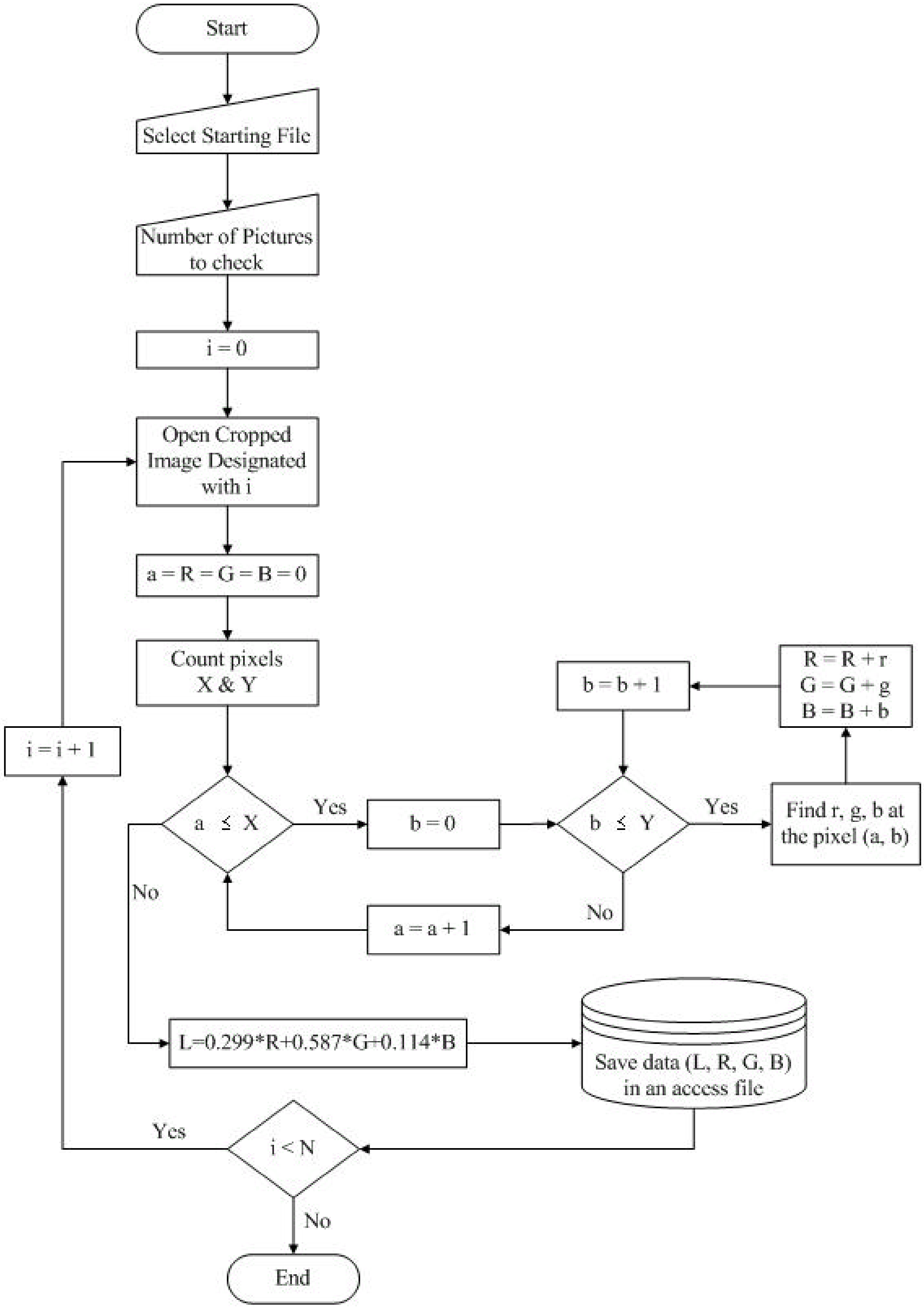


Figure 4.4 Flowchart of program

4.4 Site Survey Instrument

According to the original proposal, a questionnaire had to be administered to workers who would be asked to wear the test vests for a period of time. These workers would be asked to rate the vests' design factors and features. However, because of the nature of highway construction, there is always a risk of accident. If an accident occurs during the testing of the vests, it can be attributed to the lower visibility of the vest being tested. In the absence of insurance coverage against such a liability, the TRP agreed with the research team to cancel this part of the project. Instead, it was decided to exhibit the vests at the university's parking lot at night and ask graduate students currently enrolled in the Construction Engineering and Management Program to rate the vests. These graduate students were civil engineers and architects mostly with some site experience.

A questionnaire survey (Appendix F) was administered to two different batches of graduate students, each batch on a different night. On both nights, the six vests were placed in the parking lot and the students were asked to evaluate the vests using five criteria:

- 360° visibility
- Conspicuity against background
- Brightness of the retro-reflective material
- Configuration of the vests (pockets, zipper, etc.)
- Overall perceived effectiveness

. A scale of 1-5 was used to evaluate the data collected:

1	-	Not acceptable
2	-	Needs improvement
3	-	OK
4	-	Very good
5	-	Excellent

4.5 Evaluation of the Findings

The evaluation of the data collected in the filed tests and the site survey is described in detail in the flowchart presented in Figure 4.5.

Once the data were collected, luminance values were calculated using the relationship in the preceding section. Tables were prepared which include the descriptive statistics of the original luminance values for both front faces and sides of vests (one for each) at each construction site. These tables include mean, sample size, standard deviation, minimum and maximum original luminance values of the each vest at three positions (left, middle and right) plus the consolidated (total) values.

The original luminance values were measured under the light conditions prevailing in the construction site where tests were conducted. The photometer which was attached to the center stand, recorded the average intensity of light at the test site. The lighting in the test site comes first from the light sources in the construction site and second from passing cars. So the mean luminance values of the vests were normalized using the photometer readings only for large photometer readings because at small light intensities such as 1, 2, and 3 lux, rounding off (the photometer calculated the average luminance intensity with no digits after the decimal point) resulted in inaccurate and unreliable values. The mean luminance values of the vests were normalized using average traffic volume whenever photometer readings were not discriminating enough.

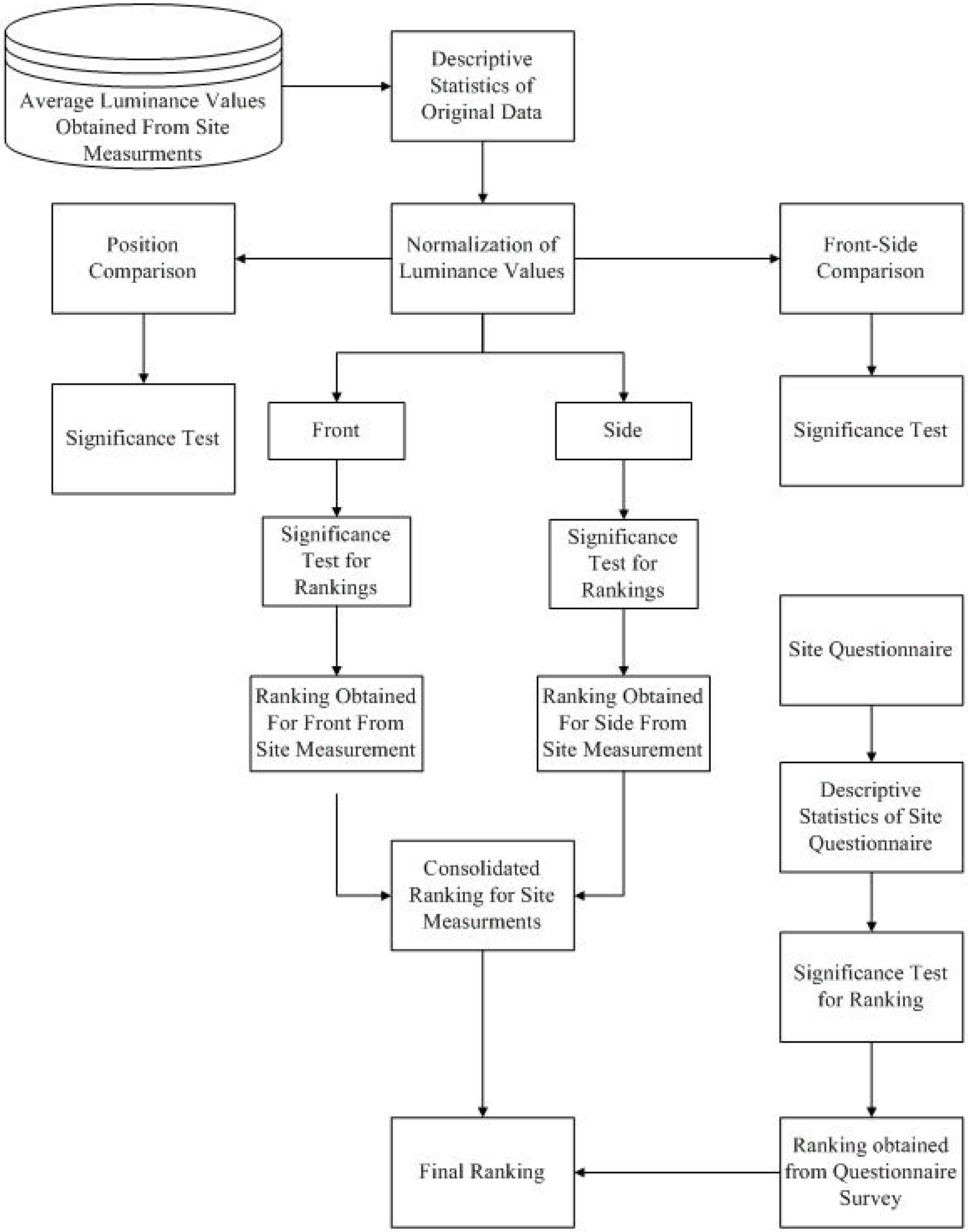


Figure 4.5 Flowchart of the data evaluation process

After forming the descriptive statistics tables of original luminance values for the vests, normalized mean luminance values were calculated make the data comparable and reliable. Tables were generated that listed the original and normalized mean luminance values, along with sample size (number of frames), standard deviation, minimum and maximum values. Normalization tables also included average traffic volumes or average photometer readings, depending on which one was used for normalization.

The vests were recorded for 10 minutes at each of the three positions (stand closest to cones, center stand, and stand farthest from cones) assuming that the vests closest to the open lane get more light from passing traffic and therefore reflect more light that vests located away from the open lane. The next step involved examining the significance of the difference between the three positions. Tamhane's T2 test, a pair wise multiple mean comparison test based on the t-test, was run for the front faces of each vest at each site. The test indicated whether the differences between luminance values are significant at 5%. The purpose of this test was to see if recording the vests in each of the three positions was justified or not.

The vests were tested for the light they reflected from their front face and from their side as the design of the front face is quite different from the side. Considering the fact that a construction worker may face the incoming traffic or may stand sideways, it was decided to conduct two sets of tests, one with the vests facing the incoming traffic and one with the vests standing sideways. An independent sample t-test was run for each vest at each construction site to test the whether the luminance values of the front and side of the vests are significant at 5%.

Tamhane's T2 test and the independent sample t-test were run using SPSS, a statistical software package.

Once the mean luminance values were normalized for front faces and sides of vests at each test location, the vests were ranked in order of preference. At this point, Tamhane's T2 test was run to compare normalized mean luminance of the six vests at each site. The test was run to compare front faces and sides of the vests. Based on the significance of the differences, a new ranking was obtained. Then the ranking were consolidated to get a final ranking for the field tests.

A table of descriptive statistics was also prepared to present the findings of the questionnaire survey administered to graduate students. "Overall perceived effectiveness" was taken into consideration as the governing criterion. Tamhane's T2 test was run to compare the mean scores assigned by the respondents to the vests and a corresponding ranking was obtained.

The rankings obtained from field tests and the site survey were consolidated into a final ranking of the vests.

5. EVALUATION OF SAFETY GARMENT SURVEYS ADMINISTERED TO DOTs

5.1 Evaluation of Safety Garment Surveys Administered to IDOT Operations Personnel, Resident Engineers, and Contractors Involved in Nighttime Construction Operations in Illinois within the Past 5 Years

A questionnaire survey was administered to IDOT operation personnel, resident engineers, and contractors involved in nighttime construction. The idea was to identify the safety concerns of these different groups of respondents. The questionnaire was approved by the project TRP and sent to 20 IDOT resident engineers, 10 IDOT operational personnel and 14 IDOT contractors whose names and email addresses were provided by the project TRP for all districts in IDOT. 45% (9) of resident engineers, 20% (2) of operational personnel and 29% (4) of contractors responded. The total respond rate was 34% (15). The number of respondents from each group was not enough to make a comparison of the findings. So the findings are merged and evaluated for Illinois nighttime construction operations. The questionnaire involves three parts:

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

II. Evaluation of existing safety garments

III. Safety garment design factors and features

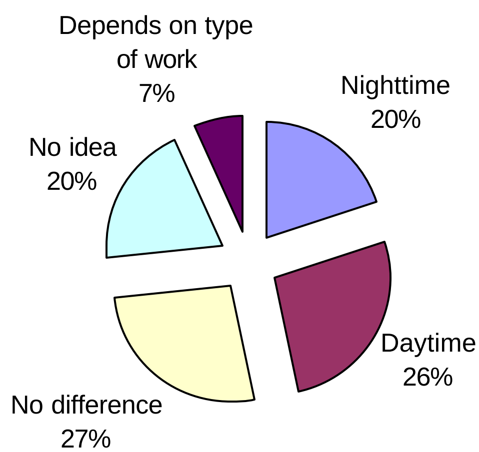
The first part investigates the observations and experiences of the respondents concerning nighttime accidents. In the second part, respondents evaluate the performance of existing safety vests that are currently being used in IDOT nighttime projects. Finally, in the third and last part, the features and the design factors of safety vests are investigated. The terms encountered in the questions are defined in Tables 1 and 2 in questionnaire.

The questionnaire is designed to include specific questions that are formulated based on the information obtained from the literature review described in Deliverable 1. After a brainstorming session with the project TRP, the questionnaire was modified and the final version was used in the survey.

The findings of the survey administered to Illinois respondents can be reported as follows:

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

- Do you think safety is more of a problem during nighttime or during daytime on Illinois highway construction/rehabilitation/maintenance work areas?



Notes:

1) 47% (7) of the Illinois participants did not encounter any nighttime accidents in work areas in the last 5 years.
2) 7% (1) of the Illinois participants know that some accidents occurred in their sites but do not know enough information about these accidents.

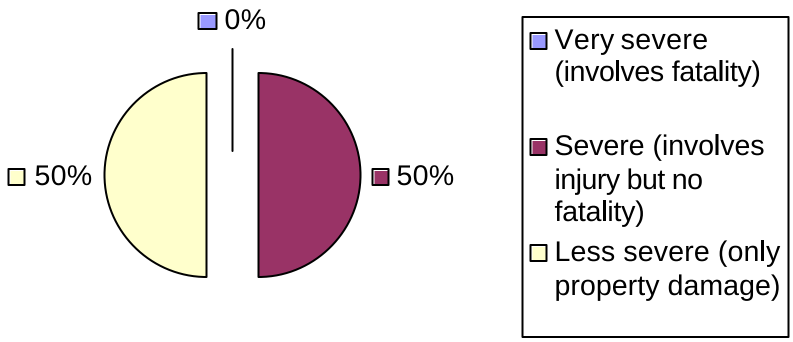
- How would you characterize the typical nighttime accident involving through traffic or construction equipment in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)
  - Construction/Rehabilitation: 53% (8) of the respondents have nighttime experience in construction/rehabilitation projects.

	Percentage (number) of responses
Worker struck by through traffic inside the work area	50% (4)
Worker struck by through traffic outside the work area	38% (3)
Worker struck by construction equipment inside the work area	75% (6)
Worker struck by construction equipment outside the work area	13% (1)
Others (traffic crashing into each)	25% (2)

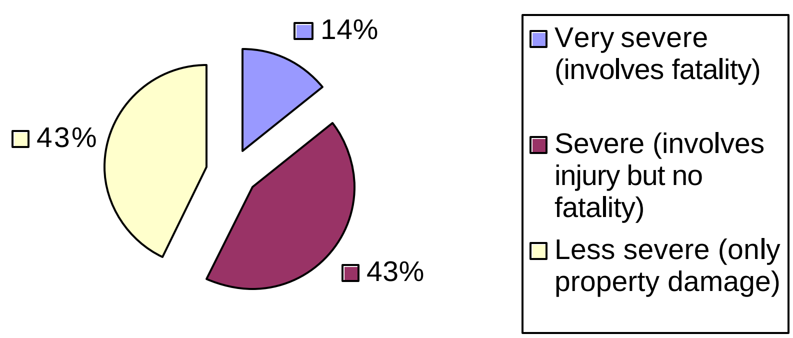
  - Maintenance: 13% (2) of the respondents reported accidents in nighttime maintenance projects. All these accidents involved "worker struck by through traffic inside the work area".
  - Consolidated Findings (including construction/ rehabilitation and maintenance projects)

	Percentage (number) of responses
Worker struck by through traffic inside the work area	60% (6)
Worker struck by through traffic outside the work area	30% (3)
Worker struck by construction equipment inside the work area	60% (6)
Worker struck by construction equipment outside the work area	10% (1)
Others (traffic crashing into each)	20% (2)

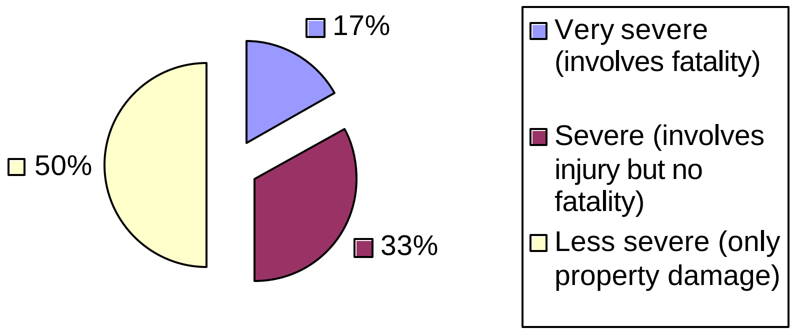
- How severe was the worst worker-related nighttime accident caused by **vehicles driving through** any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work areas you are familiar with)
    - Construction/Rehabilitation: A total of 6 respondents were involved in construction/rehabilitation work. Their responses were split between severe (involved only injury) and less severe (involved only property damage).



    - Maintenance: There was only one respondent who had worked in a maintenance project where an accident occurred involving vehicles driving through work area, and it was very severe (involves fatality).
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 7.

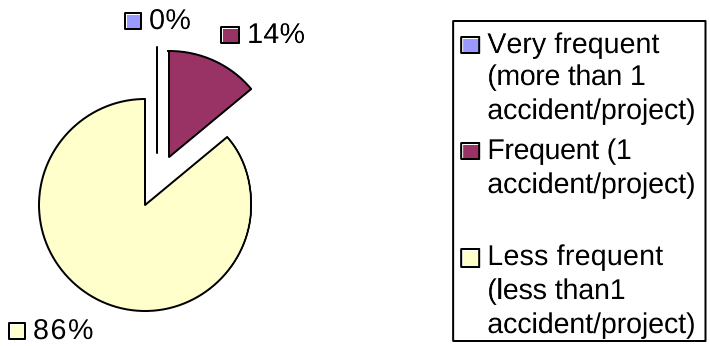


- How severe was the worst worker-related nighttime accident caused by **construction equipment** operating on any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: Only 6 respondents answered this question.

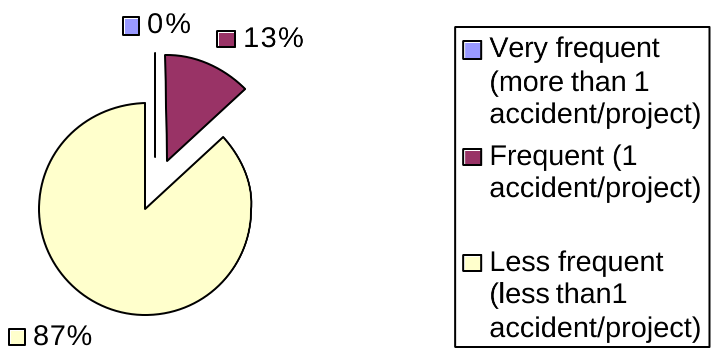


    - Maintenance: There was no respondent involved in a maintenance project where an accident caused by construction equipment operating in the work area.
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): Since no respondent reported this type of accident in a maintenance project, the values for construction/rehabilitation projects represent the entire population.

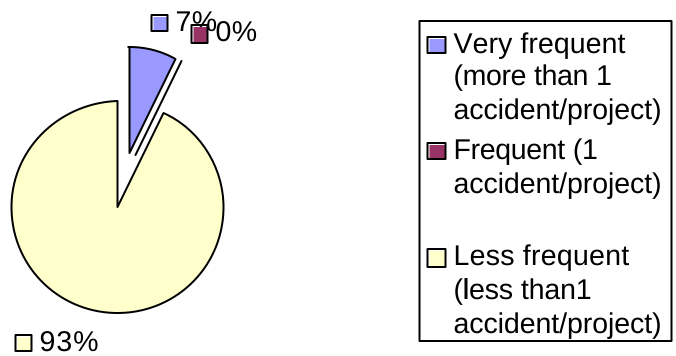
- How frequent (on the average) were the worker-related nighttime accidents caused by **vehicles driving through** any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 14 respondents answered this question.



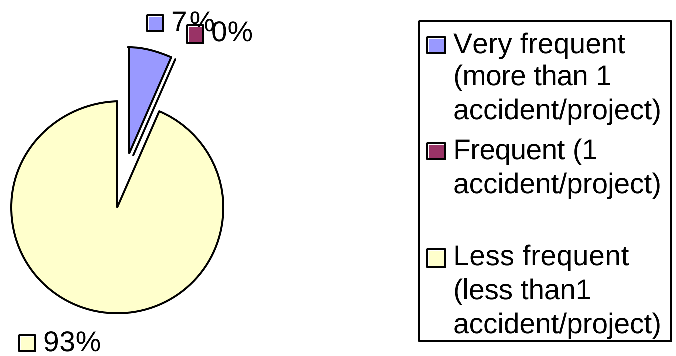
    - Maintenance: There was only one respondent who encountered worker-related accidents caused by vehicles driving through work areas and this respondent reported a rate of less than 1 accident/project.
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 15.



- How frequent (on the average) were the worker-related nighttime accidents caused by **construction equipment** operating on your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 14 respondents answered this question.



    - Maintenance: There was only one respondent who encountered worker-related accidents caused by construction equipment operating on work areas in the last five years and this respondent reported a rate of less than 1 accident/project.
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was15.



- What are the major factors contributing to worker-related nighttime accidents in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 9 respondents filled out this part of the questionnaire.

	Percentage (number) of responses
Poor lighting conditions	67% (6)
Unfavorable weather conditions	33% (3)
Poor performance of safety garment	22% (2)
Workers not wearing safety garments	22% (2)
Condition of vehicle operator (sleepy, DUI, age, etc.)	55% (5)
Others:	22% (2)

    - Maintenance: 2 respondents filled out this part of the questionnaire.

	Percentage (number) of responses
Poor lighting conditions	0% (0)
Unfavorable weather conditions	50% (1)
Poor performance of safety garment	0% (0)
Workers not wearing safety garments	0% (0)
Condition of vehicle operator (sleepy, DUI, age, etc.)	100% (2)
Others:	50% (1)

    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 11.

	Percentage (number) of responses
Poor lighting conditions	55% (6)
Unfavorable weather conditions	36% (4)
Poor performance of safety garment	18% (2)
Workers not wearing safety garments	18% (2)
Condition of vehicle operator (sleepy, DUI, age, etc.)	64% (7)
Others:	27% (3)

II. Evaluation of existing safety garments

- Describe the safety garments that are currently being used at nighttime on your highway work areas:

Manufacturer: ………………. ……… Model: ………………………….
Color of vest: .………………..……… Description: ……………………
Color of retro-reflective material: …………………………………………….

From which source are you providing safety garments for your site?

Please specify (____)

This part of the survey was prepared to find out the type and origin of the safety vests used in Illinois. The answers to this question are presented in the following table.

Respondent	***Organization***	***Position***	***Manufacturer***
Respondent 1	IDOT/ Dist. 8	Resident Engineer	Warning Lights (supplier)
Respondent 2	IDOT/ Dist. 2	Resident Engineer	IDOT (supplier)
Respondent 3	IDOT/ Dist. 6	CE IV	Dist. 6 Admin Office (supplier)
Respondent 4	IDOT/ Dist. 5	Resident Engineer	IDOT (supplier)
Respondent 5	Gallagher Asphalt	General Constructor Coordinator	Main Store Room
Respondent 6	IDOT/ Dist. 8	Resident Engineer	Construction Office
Respondent 7	Rockford Const.	Operations Manager	Ahop/Pants Department
Respondent 8	IDOT/ Dist. 8	Resident Engineer	District Safety Bureau (supplier)
Respondent 9	IDOT/ Dist. 8	CE III	IDOT (supplier)

Notes:

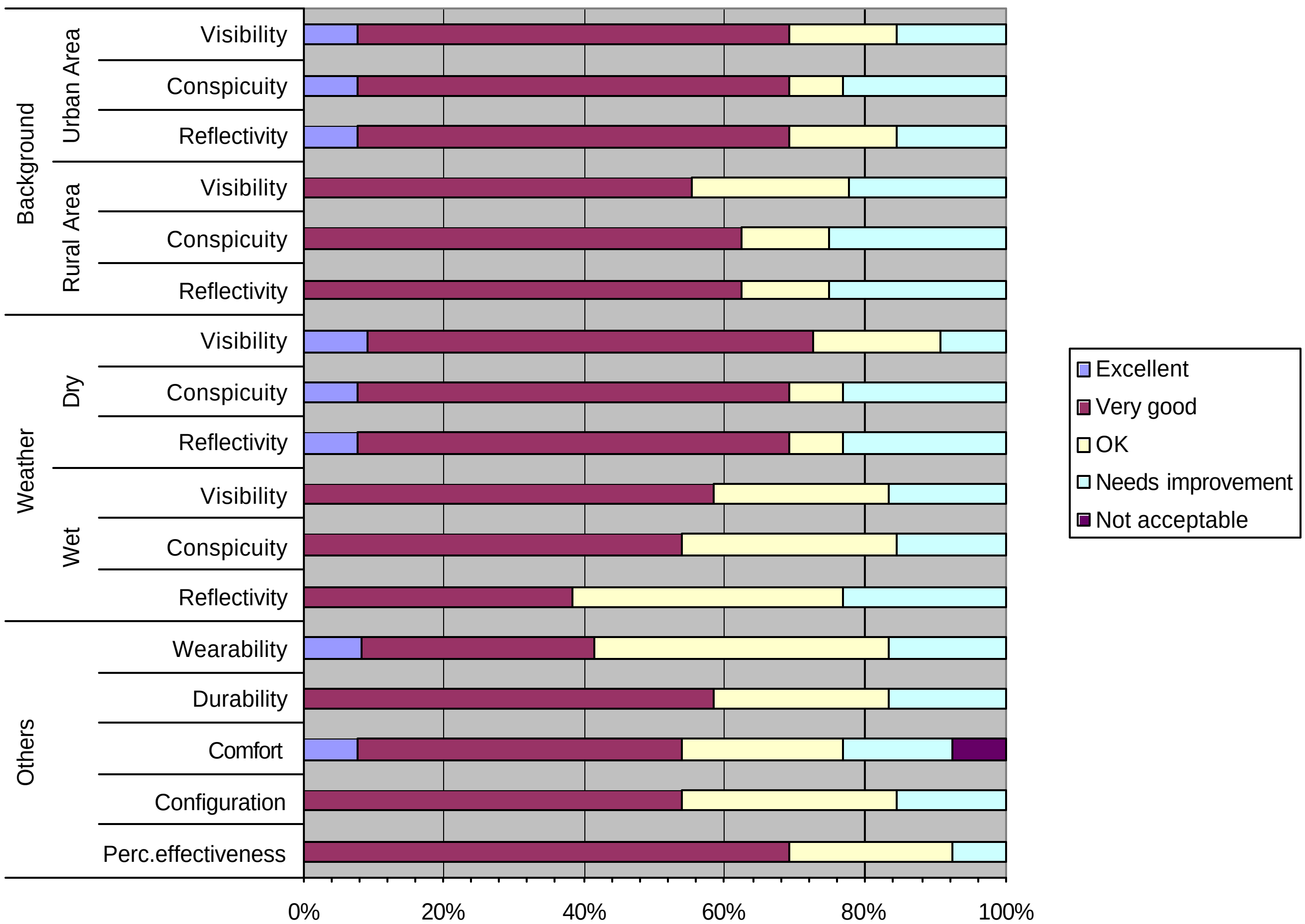
1) 40% of the respondents did not mention the name of the supplier of their existing vests.
2) 60% of the respondents mentioned the color of the vests and reflective materials. According to those who responded, 89% are using orange vests, 11% green vests, 89% vests with green reflective material, 11% vests with red reflective material.
3) One respondent (7%) stated that they are using different vests for different kind of jobs.
4) Respondents' names are on file.

- How would you characterize the **nighttime performance** of the safety garments currently in use on your work areas? (Refer to Table 1 for definitions)

Table 1. Performance factors of safety garments (Modified from ASTM; Designation: F923-00, 3M)

Factors	**Definitions**
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
Conspicuity	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
Reflectivity	The measure of brightness of retro-reflective material used in workers' garments making the garments more visible at nighttime.
Wearability	The qualities of the garments that provide good fit, up-to-date look, likable colors and shapes, and weather protection.
Durability	The ability of garments to retain their original characteristics after many wears and washes.
Comfort	Garments' features that prevent the worker from perspiring, being cold or hot, getting wet, or limiting their movements.
Configuration	The exterior and interior design of safety garments such as size, number and function of pockets, use of buttons/zippers/Velcro.
Perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

The following bar-chart represents the distribution of the answers.



A scale (0-4) is used to evaluate the data obtained in the Part 2 (evaluation of existing safety garments) and Part 3 (safety garment design factors and features).

0- Not very important, negatively impacted or not acceptable
1- Somewhat important or needs improvement
2- Important, not changed or OK
3- Very important or very good
4- Extremely important, positively impacted or excellent

The average ratings of the performance characteristics are calculated in the following table:

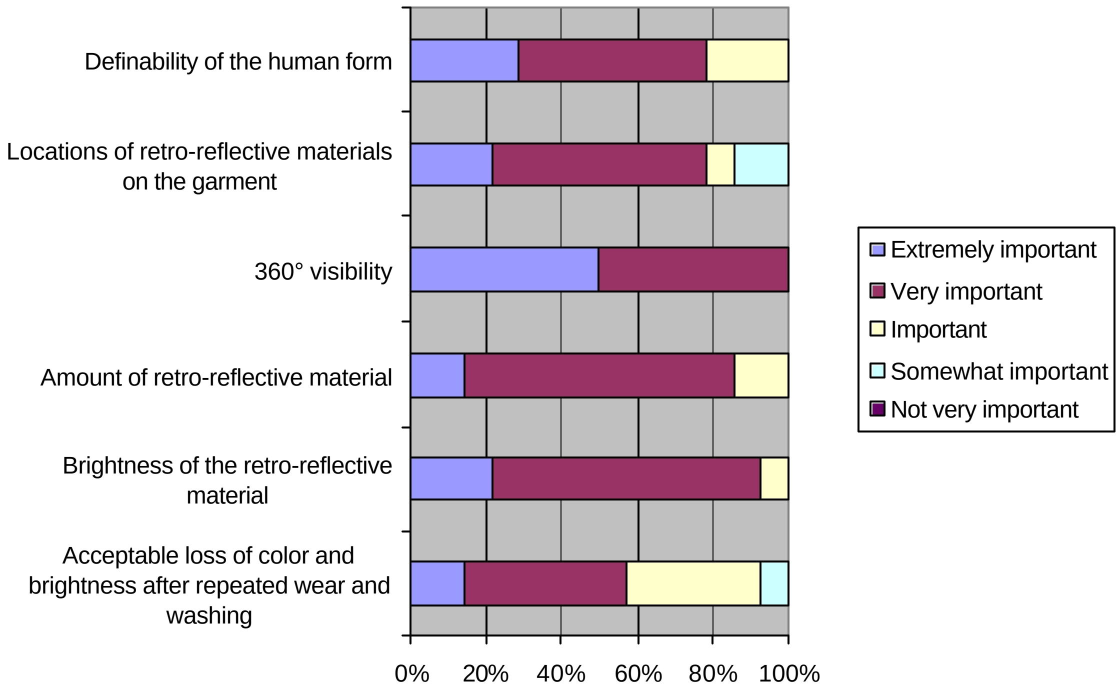
			Excellent (4)	Very good (3)	OK (2)	Needs improvement (1)	Not acceptable (0)	Total Ranking	Number of Respondents	Average Rating
Background	Urban Area	Visibility	1	8	2	2	0	34	13	2.62
		Conspicuity	1	8	1	3	0	33	13	2.54
		Reflectivity	1	8	2	2	0	34	13	2.62
	Rural Area	Visibility	0	5	2	2	0	21	9	2.33
		Conspicuity	0	5	1	2	0	19	8	2.38
		Reflectivity	0	5	1	2	0	19	8	2.38
Weather	Dry	Visibility	1	7	2	1	0	30	11	2.73
		Conspicuity	1	8	1	3	0	33	13	2.54
		Reflectivity	1	8	1	3	0	33	13	2.54
	Wet	Visibility	0	7	3	2	0	29	12	2.42
		Conspicuity	0	7	4	2	0	31	13	2.39
		Reflectivity	0	5	5	3	0	28	13	2.15
Others		Wearability	1	4	5	2	0	28	12	2.33
		Durability	0	7	3	2	0	29	12	2.42
		Comfort	1	6	3	2	1	30	13	2.31
		Configuration	0	7	4	2	0	31	13	2.39
		Perc.effectiveness	0	9	3	1	0	34	13	2.62

III. Safety garment design factors and features

- What is the importance of the following design factors in the use of retro-reflective materials to enhance the nighttime visibility of your safety garments? (Refer to the Table 2 for definitions)

Table 2. Design Factors that Enhance Nighttime Visibility (Modified from 3M)

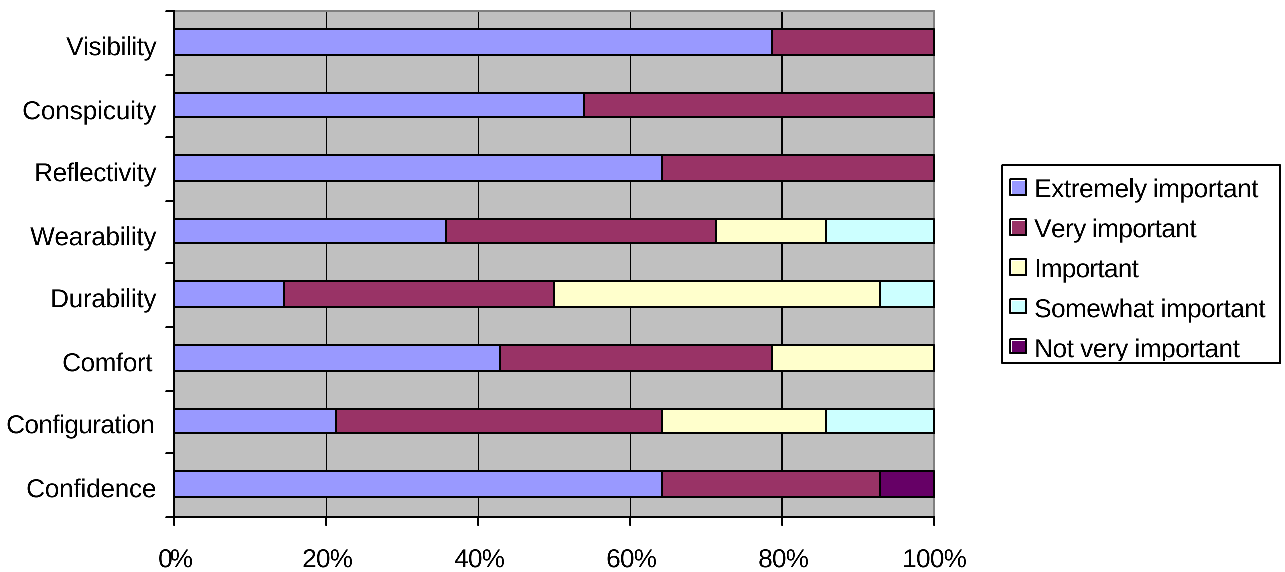
Factors	Definitions
Definability of the human form	The retro-reflective material on a garment being the only component visible to a driver at nighttime, it should make the driver recognize the object as a worker.
Location of retro-reflective materials on the garment	The appropriate location of the retro-reflective material on a safety garment should enhance its visibility by drawing the human eye to the moving object as the worker moves.
360° visibility	The human form should be detected from all directions regardless of the human form, movement, location, and situation.
Amount of retro-reflective material	The amount of retro-reflective material applied should increase a worker's visibility.
Brightness of the retro-reflective material	The brightness of retro-reflective material should increase a worker's visibility.
Acceptable loss of color and brightness after repeated wear and washing	The garment should be resistant to wear and washing such that the garment maintains its color and brightness longer.



The average ratings and the ranks of the design factors are calculated in the following table:

	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Definability of the human form	4	7	3	0	0	43	14	3.07	3
Locations of retro-reflective materials on the garment	3	8	1	2	0	40	14	2.86	5
360° visibility	7	7	0	0	0	49	14	3.50	1
Amount of retro-reflective material	2	10	2	0	0	42	14	3.00	4
Brightness of the retro-reflective material	3	10	1	0	0	44	14	3.14	2
Acceptable loss of color and brightness after repeated wear and washing	2	6	5	1	0	37	14	2.64	6

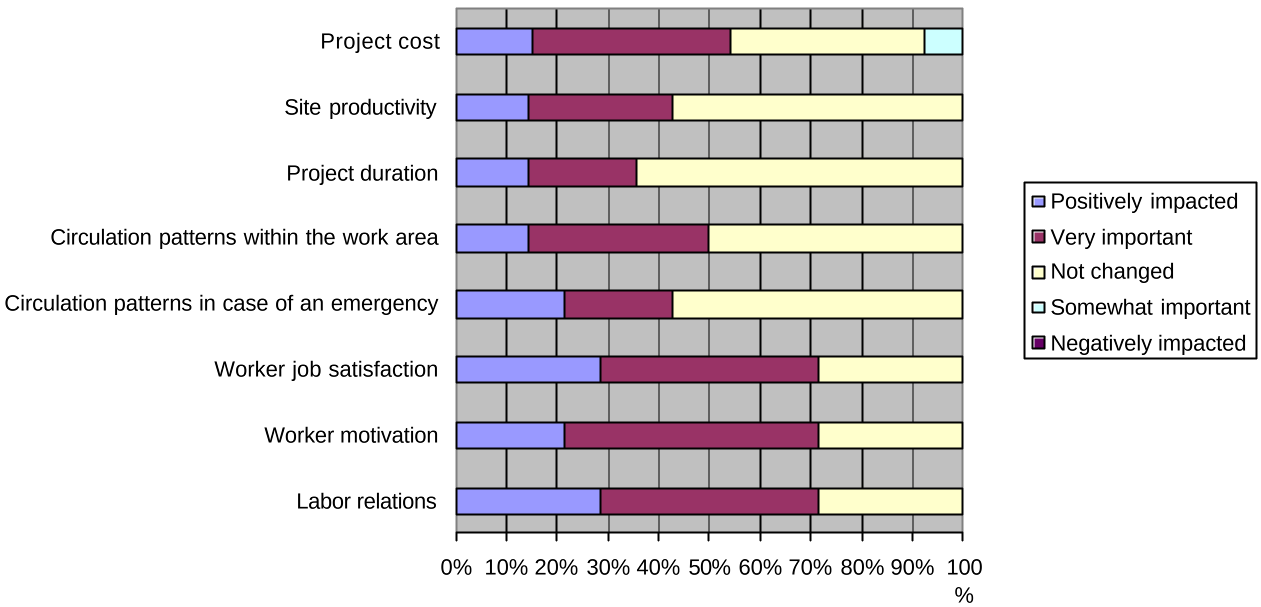
- How important do you consider the following features of safety garments used in nighttime construction? (See Table 1 for definitions)



The average ratings and the ranks of the safety garment features are calculated in the following table:

Safety garment features	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Visibility	11	3	0	0	0	53	14	3.79	1
Conspicuity	7	6	0	0	0	46	13	3.54	3
Reflectivity	9	5	0	0	0	51	14	3.64	2
Wearability	5	5	2	2	0	41	14	2.93	6
Durability	2	5	6	1	0	36	14	2.57	8
Comfort	6	5	3	0	0	45	14	3.21	5
Configuration	3	6	3	2	0	38	14	2.71	7
Worker's confidence	9	4	0	0	1	48	14	3.43	4

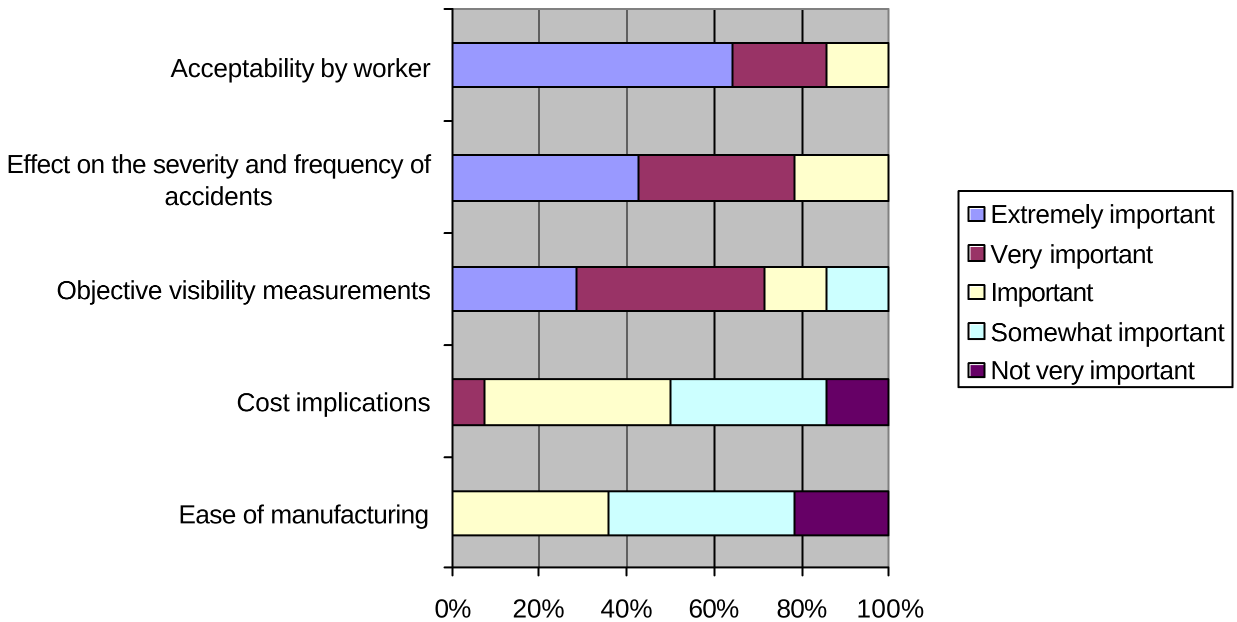
- What is the impact of **extremely good nighttime visibility** of workers on the following project factors?



The average ratings and the ranks of the project factors are calculated in the following table:

Project Factors	Positively Impacted (4)	(3)	Not Changed (2)	(1)	Negatively Impact (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Project cost	2	5	5	1	0	34	13	2.62	6
Site productivity	2	4	8	0	0	36	14	2.57	7
Project duration	2	3	9	0	0	35	14	2.50	8
Circulation patterns within the work area	2	5	7	0	0	37	14	2.64	4
Circulation patterns in case of an emergency	3	3	8	0	0	37	14	2.64	4
Worker job satisfaction	4	6	4	0	0	42	14	3.00	1
Worker motivation	3	7	4	0	0	41	14	2.93	3
Labor relations	4	6	4	0	0	42	14	3.00	1

- Please rate the importance of the following criteria that should help select a particular type of safety garment. We are seeking **your opinion** rather than the current practice in your organization.



The average ratings and the ranks of the selection criteria are calculated in the following table:

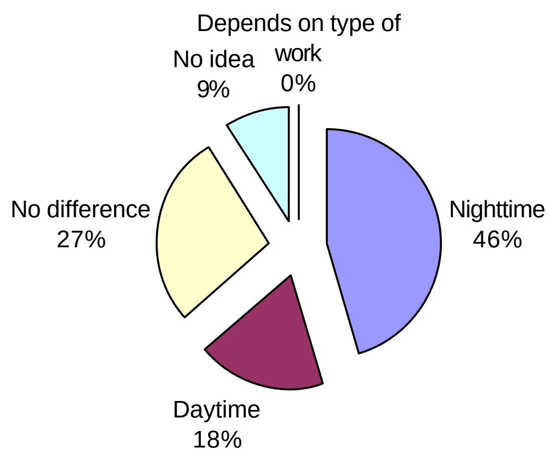
Selection criteria	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Acceptability by worker	9	3	2	0	0	49	14	3.50	1
Effect on the severity and frequency of accidents	6	5	3	0	0	45	14	3.21	2
Objective visibility measurements	4	6	2	2	0	40	14	2.86	3
Cost implications	0	1	6	5	2	20	14	1.43	4
Ease of manufacturing	0	0	5	6	3	16	14	1.14	5

5.2 Evaluation of Safety Garment Surveys Administered to Departments of Transportation of Other States Than Illinois Involved in Nighttime Construction Operations Within the Past 5 Years

The same questionnaire approved by the project TRP and used in the survey of Illinois personnel was also administered to the departments of transportation of the 49 states other than Illinois. A response rate of 22% (11 DOTs) was achieved. The low rate of response is attributed to some states not having nighttime highway construction. The findings of the survey are presented in the following sections:

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

- Do you think safety is more of a problem during nighttime or during daytime on highway construction/rehabilitation/maintenance work areas?



Notes:

1) 82% (9) of the respondents encountered at least one nighttime accident in their projects.

2) More respondents from other states (46%) are concerned about nighttime accidents than Illinois respondents (20%).

3) 9% (1) of the participants did not have enough information about the accidents that occurred in their sites.

- How would you characterize the typical nighttime accident involving through traffic or construction equipment in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation:

	Percentage (number) of responses
Worker struck by through traffic inside the work area	30% (3)
Worker struck by through traffic outside the work area	40% (4)
Worker struck by construction equipment inside the work area	50% (5)
Worker struck by construction equipment outside the work area	0% (0)
Others (traffic crashing into each)	20% (2)

    - Maintenance: Only 55% (6) of the respondents had been involved in maintenance projects, and of these 33% (2) encountered nighttime accidents.

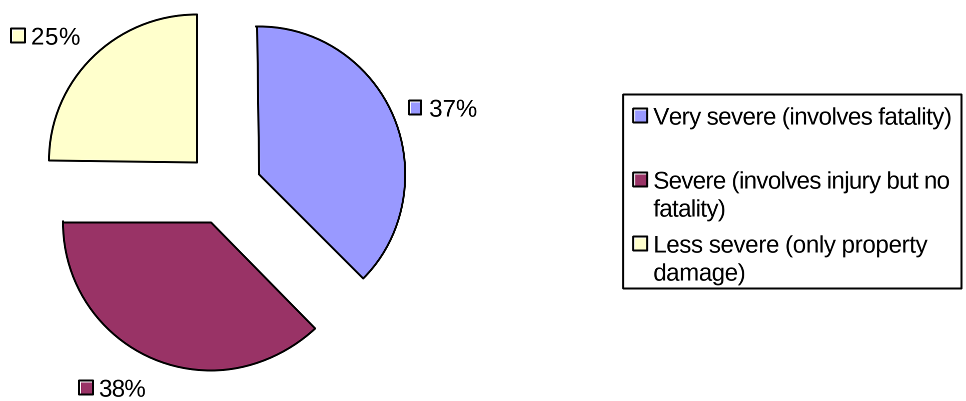
	Percentage (number) of responses
Worker struck by through traffic inside the work area	40% (2)
Worker struck by through traffic outside the work area	20% (1)
Worker struck by construction equipment inside the work area	0% (0)
Worker struck by construction equipment outside the work area	0% (0)
Others (traffic crashing into each)	40% (2)

- <u>Consolidated Findings</u> (including construction/ rehabilitation and maintenance projects):

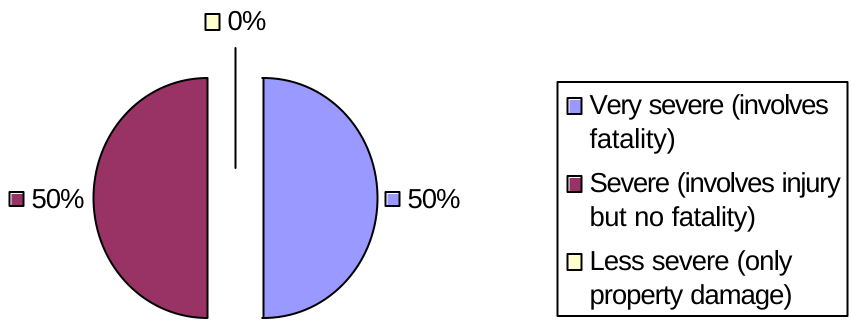
	Percentage (number) of responses
Worker struck by through traffic inside the work area	33% (5)
Worker struck by through traffic outside the work area	33% (5)
Worker struck by construction equipment inside the work area	33% (5)
Worker struck by construction equipment outside the work area	0% (0)
Others (traffic crashing into each)	27% (4)

Note: The dominant nighttime accident types are similar in Illinois and other states.

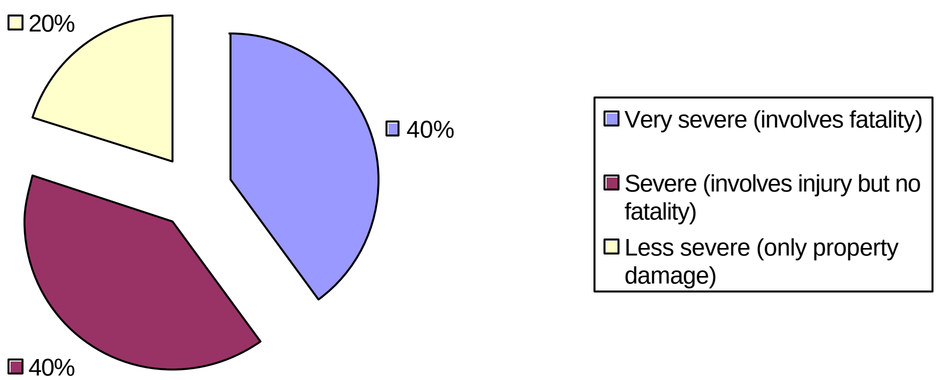
- How severe was the worst worker-related nighttime accident caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work areas you are familiar with)
  - <u>Construction/Rehabilitation:</u> 8 respondents answered this question.



- Maintenance: 2 respondents answered this question.

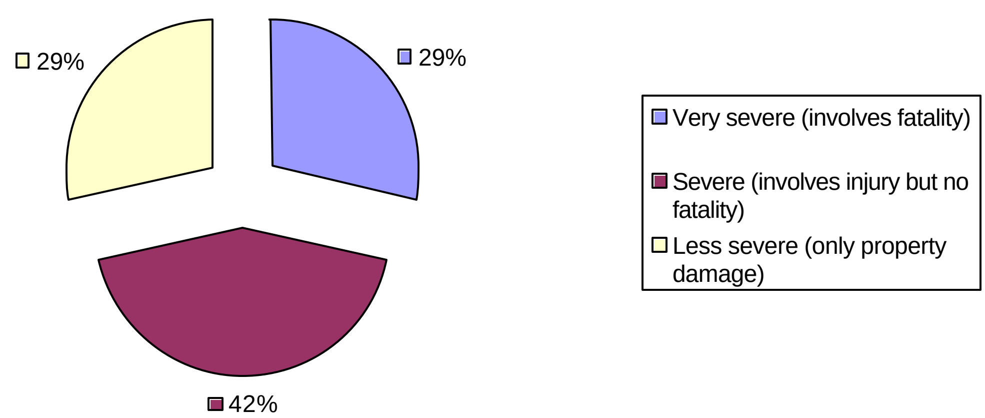


- Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 10.

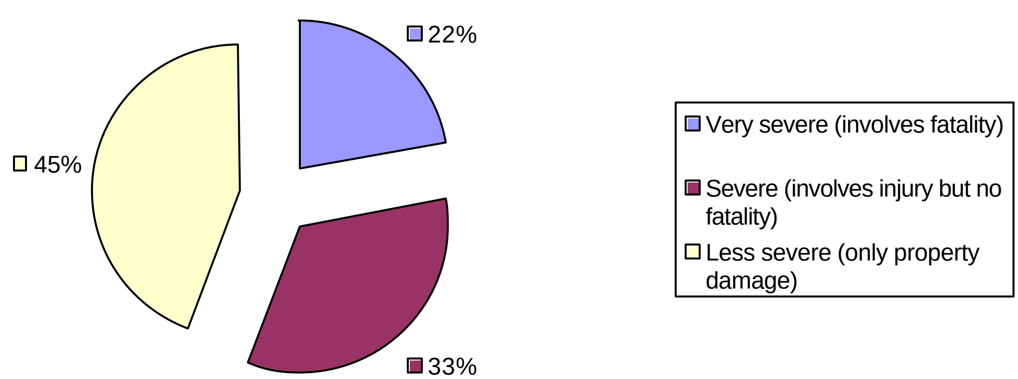


Note: Nighttime accidents caused by vehicles driving through work zones in other states are more severe than similar accidents in Illinois.

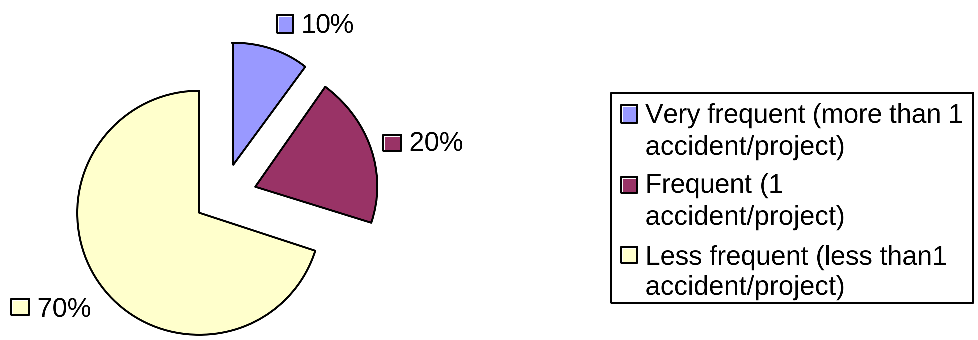
- How severe was the worst worker-related nighttime accident caused by **construction equipment** operating on any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 7 respondents answered this question.



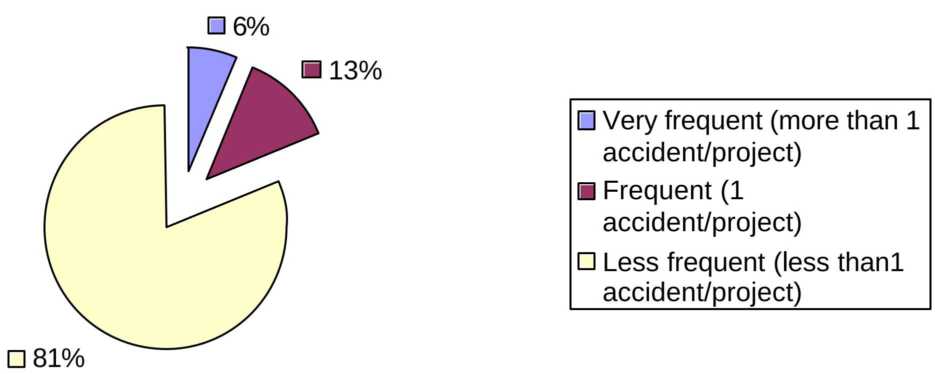
    - Maintenance: The two respondents involved in nighttime maintenance work reported accidents that created only property damage caused by construction equipment operating on their maintenance work areas.
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 9.



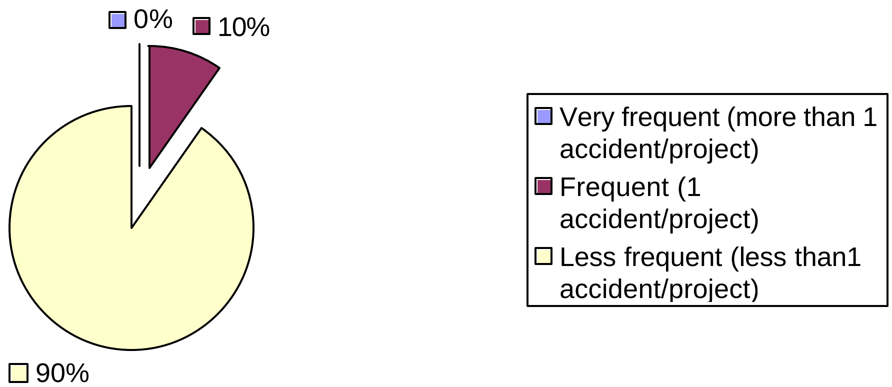
- How frequent (on the average) were the worker-related nighttime accidents caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 10 respondents answered this question.



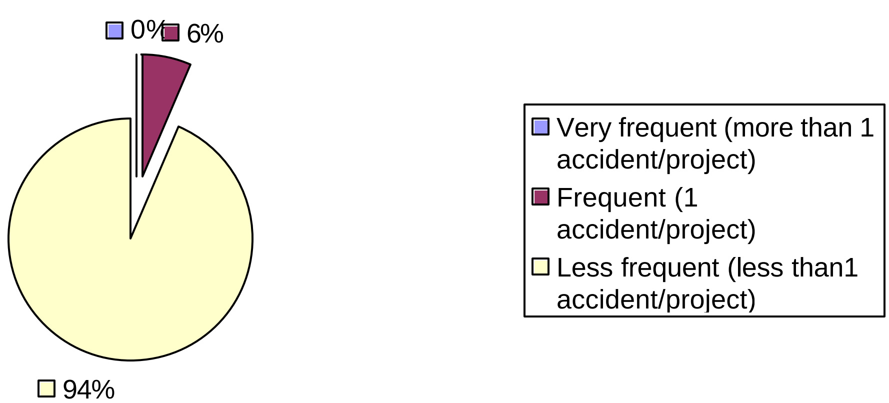
- Maintenance: All six respondents encountered worker-related nighttime accidents that were caused by vehicles driving through maintenance work areas in the last 5 years, at a rate of less than 1 accident/project.
- Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 16.



- How frequent (on the average) were the worker-related nighttime accidents caused by **construction equipment** operating on your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - <u>Construction/Rehabilitation:</u> 10 respondents answered this question.



    - <u>Maintenance:</u> All 6 respondents reported worker-related nighttime accidents caused by construction equipment operating on their DOT work areas at a rate of less than 1 accident/project.
    - <u>Consolidated Findings</u> (including construction/ rehabilitation and maintenance projects): The total number of respondents was 16.



Note: The frequencies of nighttime accidents in Illinois and other states are very close.

- What are the major factors contributing to worker-related nighttime accidents in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

    - Construction/Rehabilitation: 11 respondents answered this question.

	Percentage (number) of responses
Poor lighting conditions	36% (4)
Unfavorable weather conditions	9% (1)
Poor performance of safety garment	0% (0)
Workers not wearing safety garments	18% (2)
Condition of vehicle operator (sleepy, DUI, age, etc.)	73% (8)
Others:	36% (4)

    - Maintenance: 6 respondents answered this question.

	Percentage (number) of responses
Poor lighting conditions	33% (2)
Unfavorable weather conditions	0% (0)
Poor performance of safety garment	0% (0)
Workers not wearing safety garments	0% (0)
Condition of vehicle operator (sleepy, DUI, age, etc.)	50% (3)
Others:	33% (2)

    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 17.

	Percentage (number) of responses
Poor lighting conditions	35% (6)
Unfavorable weather conditions	6% (1)
Poor performance of safety garment	0% (0)
Workers not wearing safety garments	12% (2)
Condition of vehicle operator (sleepy, DUI, age, etc.)	65% (11)
Others:	35% (6)

II. Evaluation of existing safety garments

- Describe the safety garments that are currently being used at nighttime on your highway work areas:

Manufacturer: ………………. ……… Model: ………………………….
Color of vest: .………………..……… Description: ……………………
Color of retro-reflective material: ……………………………………….

From which source are you providing safety garments for your site?

Please specify (____)

This part of the survey was prepared to find out the type and origin of the safety vests used nationwide. The answers to this question are presented in the following table:

Respondent	***Organization***	***Position***	***Manufacturer***
Respondent A	Iowa DOT	Traffic Safety/Automation Eng.	Head Lites Corporation
Respondent B	Michigan DOT	Construction Staff Eng.	Head Lites Corporation
Respondent C	SC DOT	Employee Safety Coordinator	MTS Safety Products
Respondent D	Idaho DOT	Assistant State Traffic Eng.	NorthWest Safety
Respondent E	Maryland DOT		Kishigo
Respondent F	Wisconsin DOT	Traffic Operations Eng.	Head Lites Corporation
Respondent G	Washington DOT	Safety and Health Administrator	Chami Design
Respondent H	Arkansas DOT	Staff Construction Engineer	Iron Horse
Respondent I	Oregon DOT	Safety Program Coordinator	Columbia George Center

Notes:

1) 82% of respondents mentioned the manufacturer of their existing vests.
2) All respondents mentioned the color of the vests and reflective material. 70% and 30% are using orange and green vests, respectively. 70% are using vests with white/silver reflective material, 30% vests with yellow reflective material.
3) Respondents' names are on file.

- How would you characterize the **nighttime performance** of the safety garments currently in use on your work areas? (The terms are referred to Table 1)

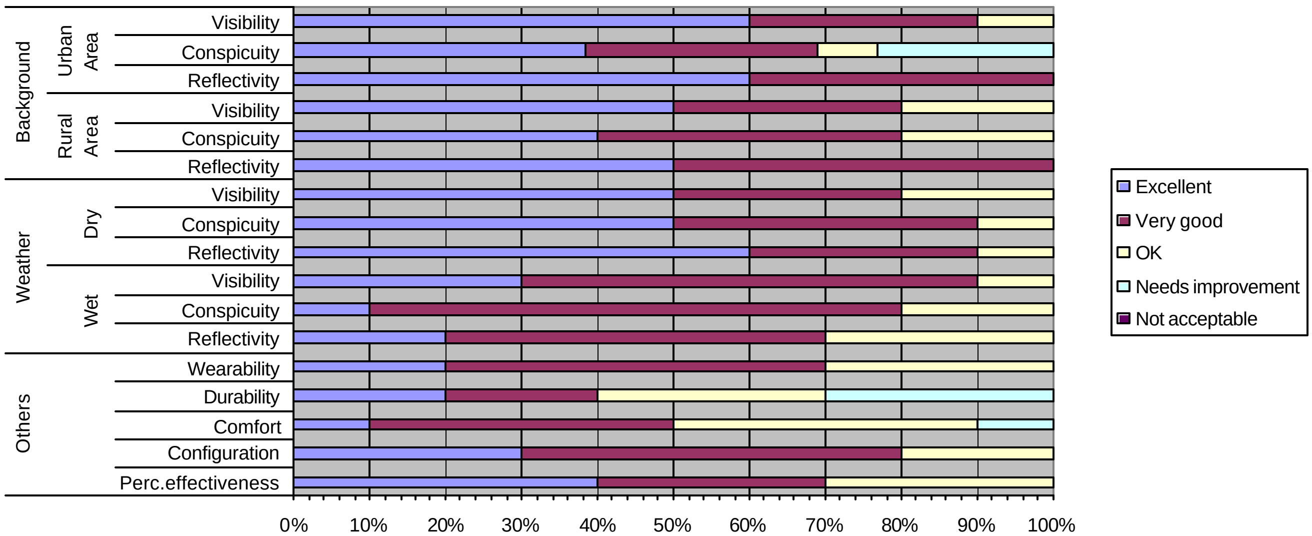
Table 1. Performance factors of safety garments (Modified from ASTM; Designation: F923-00, 3M)

Factors	Definitions
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
Conspicuity	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
Reflectivity	The measure of brightness of retro-reflective material used in workers' garments making the garments more visible at nighttime.
Wearability	The qualities of the garments that provide good fit, up-to-date look, likable colors and shapes, and weather protection.
Durability	The ability of garments to retain their original characteristics after many wears and washes.
Comfort	Garments' features that prevent the worker from perspiring, being cold or hot, getting wet, or limiting their movements.
Configuration	The exterior and interior design of safety garments such as size, number and function of pockets, use of buttons/zippers/Velcro.
Perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

A scale (0-4) is used to evaluate the data obtained in the Part 2 (evaluation of existing safety garments) and Part 3 (safety garment design factors and features).

0- Not very important, negatively impacted or not acceptable
1- Somewhat important or needs improvement
2- Important, not changed or OK
3- Very important or very good
4- Extremely important, positively impacted or excellent

The following bar-chart represents the distribution of the answers to this question:



The average ratings of the performance characteristics are calculated in the following table:

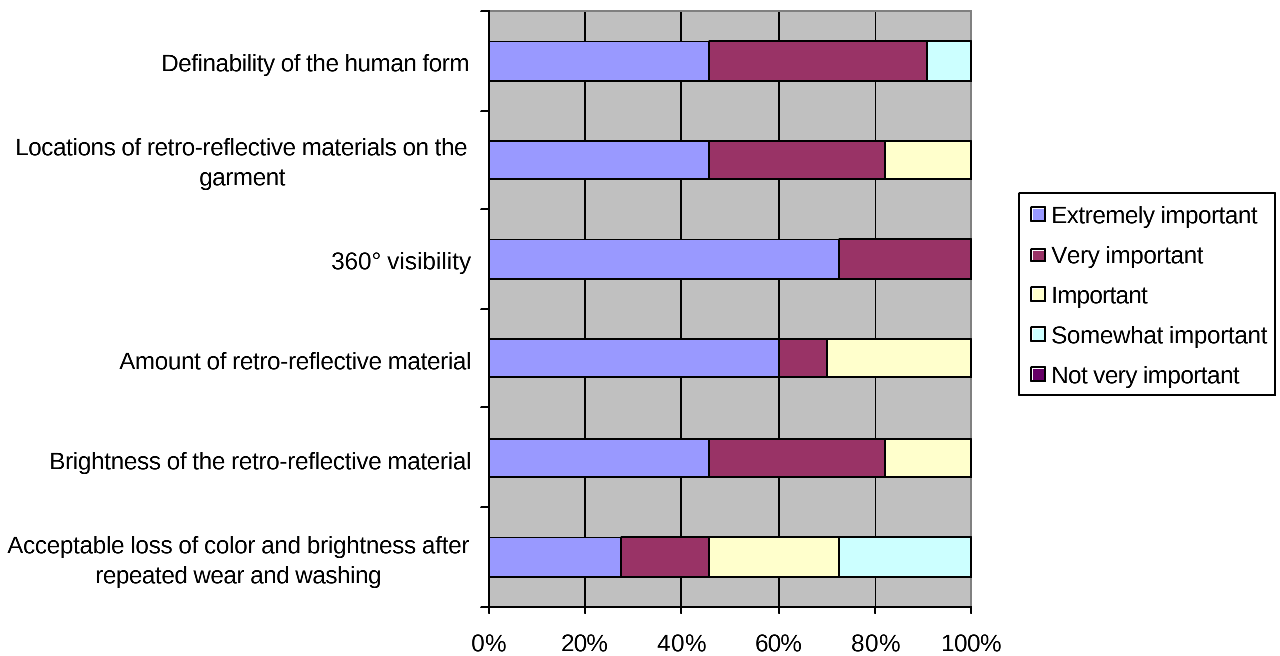
			Excellent (4)	Very good (3)	OK (2)	Needs improvement (1)	Not acceptable (0)	Total Ranking	Number of Respondents	Average Rating
Background	Urban Area	Visibility	6	3	1	0	0	35	10	3.50
		Conspicuity	5	4	1	3	0	37	13	2.85
		Reflectivity	6	4	0	0	0	36	10	3.60
	Rural Area	Visibility	5	3	2	0	0	33	10	3.30
		Conspicuity	4	4	2	0	0	32	10	3.20
		Reflectivity	5	5	0	0	0	35	10	3.50
Weather	Dry	Visibility	5	3	2	0	0	33	10	3.30
		Conspicuity	5	4	1	0	0	34	10	3.40
		Reflectivity	6	3	1	0	0	35	10	3.50
	Wet	Visibility	3	6	1	0	0	32	10	3.20
		Conspicuity	1	7	2	0	0	29	10	2.90
		Reflectivity	2	5	3	0	0	29	10	2.90
Others		Wearability	2	5	3	0	0	29	10	2.90
		Durability	2	2	3	3	0	23	10	2.30
		Comfort	1	4	4	1	0	25	10	2.50
		Configuration	3	5	2	0	0	31	10	3.10
		Perc.effectiveness	4	3	3	0	0	31	10	3.10

III. Safety garment design factors and features

- What is the importance of the following design factors in the use of retro-reflective materials to enhance the nighttime visibility of your safety garments? (Refer to Table 2 for definitions)

Table 2. Design Factors that Enhance Nighttime Visibility (Modified from 3M)

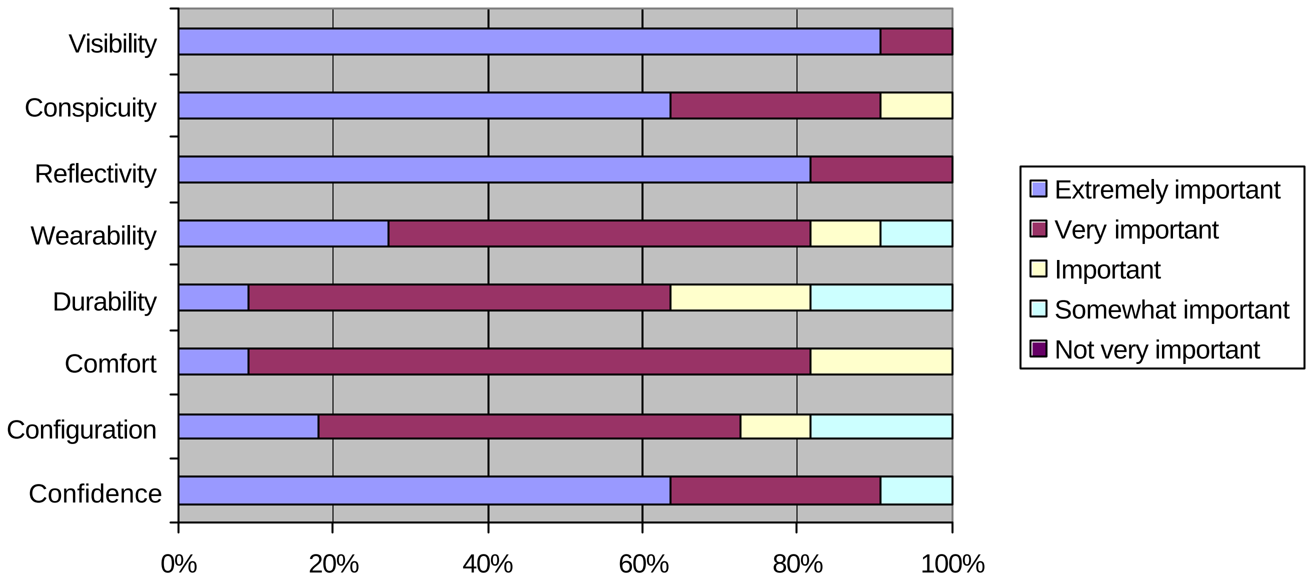
Factors	Definitions
Definability of the human form	The retro-reflective material on a garment being the only component visible to a driver at nighttime, it should make the driver recognize the object as a worker.
Location of retro-reflective materials on the garment	The appropriate location of the retro-reflective material on a safety garment should enhance its visibility by drawing the human eye to the moving object as the worker moves.
360° visibility	The human form should be detected from all directions regardless of the human form, movement, location, and situation.
Amount of retro-reflective material	The amount of retro-reflective material applied should increase a worker's visibility.
Brightness of the retro-reflective material	The brightness of retro-reflective material should increase a worker's visibility.
Acceptable loss of color and brightness after repeated wear and washing	The garment should be resistant to wear and washing such that the garment maintains its color and brightness longer.



The average ratings and the ranks of the design factors are calculated in the following table:

	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Definability of the human form	5	5	0	1	0	36	11	3.27	3
Locations of retro-reflective materials on the garment	5	4	2	0	0	36	11	3.27	3
360° visibility	8	3	0	0	0	41	11	3.73	1
Amount of retro-reflective material	6	1	3	0	0	33	10	3.30	2
Brightness of the retro-reflective material	5	4	2	0	0	36	11	3.27	3
Acceptable loss of color and brightness after repeated wear and washing	3	2	3	3	0	27	11	2.45	6

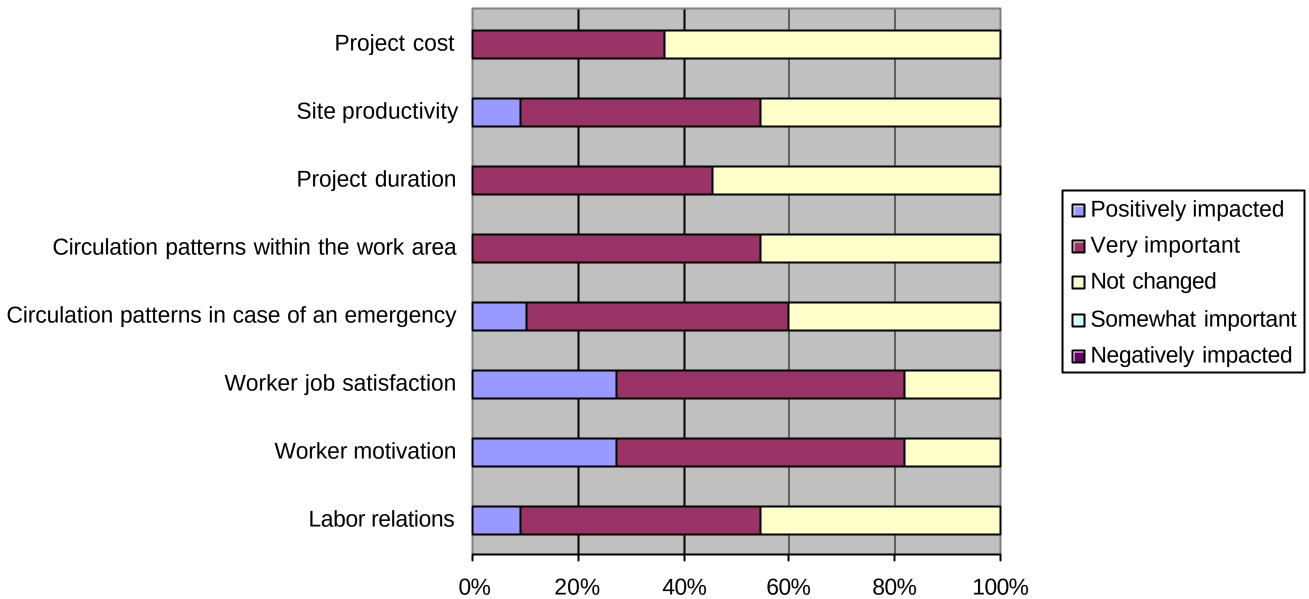
- How important do you consider the following features of safety garments used in nighttime construction? (See Table 1 for definitions)



The average ratings and the ranks of the safety garment features are calculated in the following table:

Safety garment features	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Visibility	10	1	0	0	0	43	11	3.91	1
Conspicuity	7	3	1	0	0	39	11	3.55	3
Reflectivity	9	2	0	0	0	42	11	3.82	2
Wearability	3	6	1	1	0	33	11	3.00	5
Durability	1	6	2	2	0	28	11	2.55	8
Comfort	1	8	2	0	0	32	11	2.91	6
Configuration	2	6	1	2	0	30	11	2.73	7
Worker's confidence	7	3	0	1	0	38	11	3.45	4

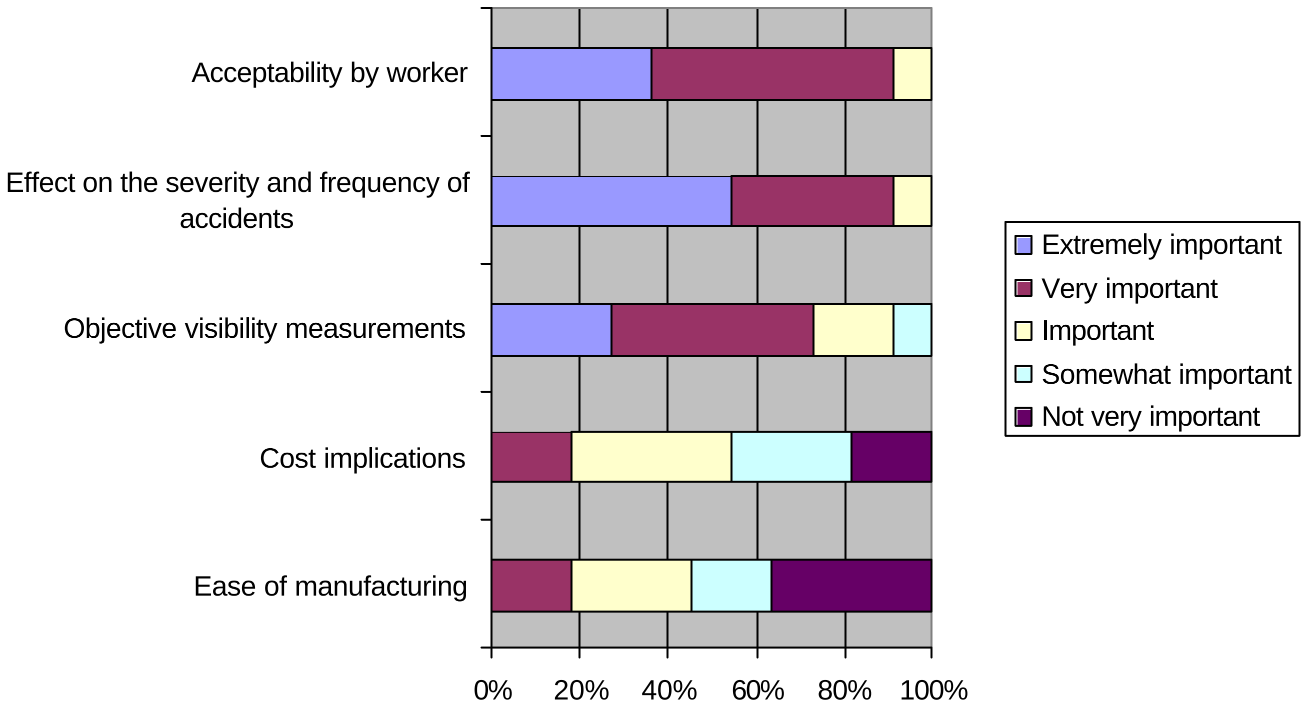
- What is the impact of **extremely good nighttime visibility** of workers on the following project factors?



The average ratings and the ranks of the project factors are calculated in the following table:

Project Factors	Positively Impacted (4)	(3)	Not Changed (2)	(1)	Negatively Impact (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Project cost	0	4	7	0	0	26	11	2.36	8
Site productivity	1	5	5	0	0	29	11	2.64	4
Project duration	0	5	6	0	0	27	11	2.45	7
Circulation patterns within the work area	0	6	5	0	0	28	11	2.55	6
Circulation patterns in case of an emergency	1	5	4	0	0	27	10	2.70	3
Worker job satisfaction	3	6	2	0	0	34	11	3.09	1
Worker motivation	3	6	2	0	0	34	11	3.09	1
Labor relations	1	5	5	0	0	29	11	2.64	4

- Please rate the importance of the following criteria that should help select a particular type of safety garment. We are seeking **your opinion** rather than the current practice in your organization.



The average ratings and the ranks of the selection criteria are calculated in the following table:

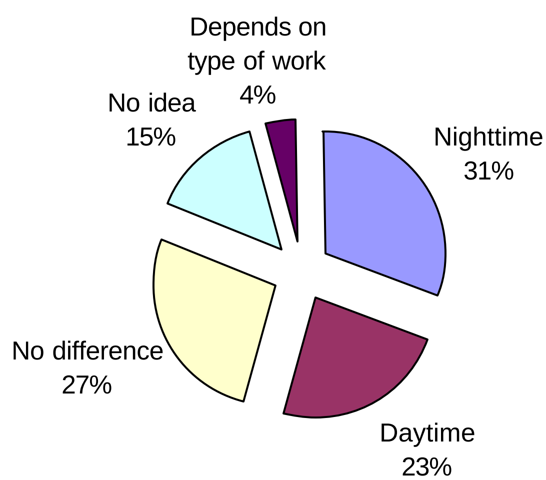
Selection criteria	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Acceptability by worker	4	6	1	0	0	36	11	3.27	2
Effect on the severity and frequency of accidents	6	4	1	0	0	38	11	3.45	1
Objective visibility measurements	3	5	2	1	0	32	11	2.91	3
Cost implications	0	2	4	3	2	17	11	1.55	4
Ease of manufacturing	0	2	3	2	4	14	11	1.27	5

5.3 Evaluation of Safety Garment Surveys Administered to IDOT Operation Personnel, Resident Engineers and Contractors and to Departments of Transportation of Other States than Illinois Involved in Nighttime Construction Operations within the Past 5 Years

The data obtained from the first survey administered to IDOT operation personnel, resident engineers and contractors and from the second survey administered to departments of transportation of the remaining 49 states were combined to get what can be considered national findings. The outcome of this is presented in the following sections:

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

- Do you think safety is more of a problem during nighttime or during daytime on highway construction/rehabilitation/maintenance work areas?



Safety seems to be only slightly more of a problem in nighttime than in day time works. The same attention should be given to safety both in nighttime and daytime.

Notes:

1) 65% (17) of respondents encountered at least one nighttime accident in work areas in the last 5 years.
2) 8% (2) of participants did not have enough information about the nighttime accidents in their sites.

- How would you characterize the typical nighttime accident involving through traffic or construction equipment in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation:

	Percentage (number) of responses
Worker struck by through traffic inside the work area	39% (7)
Worker struck by through traffic outside the work area	38% (7)
Worker struck by construction equipment inside the work area	31% (11)
Worker struck by construction equipment outside the work area	6% (1)
Others (TCDs struck)	22% (4)

    - Maintenance:

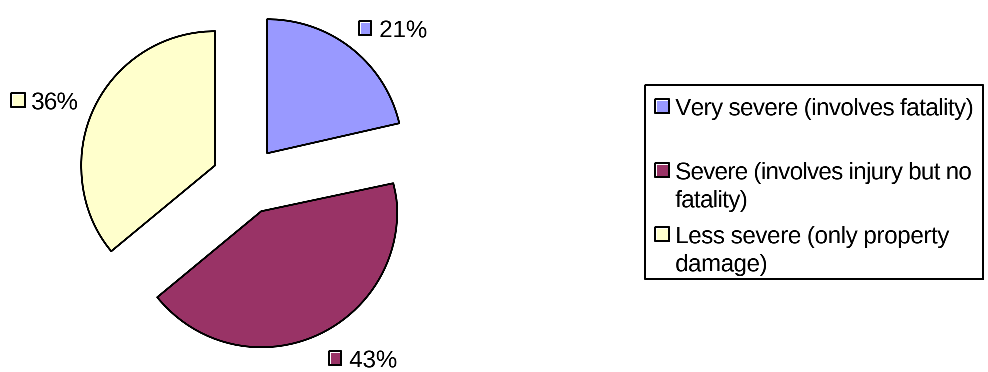
	Percentage (number) of responses
Worker struck by through traffic inside the work area	57% (4)
Worker struck by through traffic outside the work area	14% (1)
Worker struck by construction equipment inside the work area	0% (0)
Worker struck by construction equipment outside the work area	0% (0)
Others (TCDs struck)	29% (2)

- Consolidated Findings (including construction/ rehabilitation and maintenance projects)

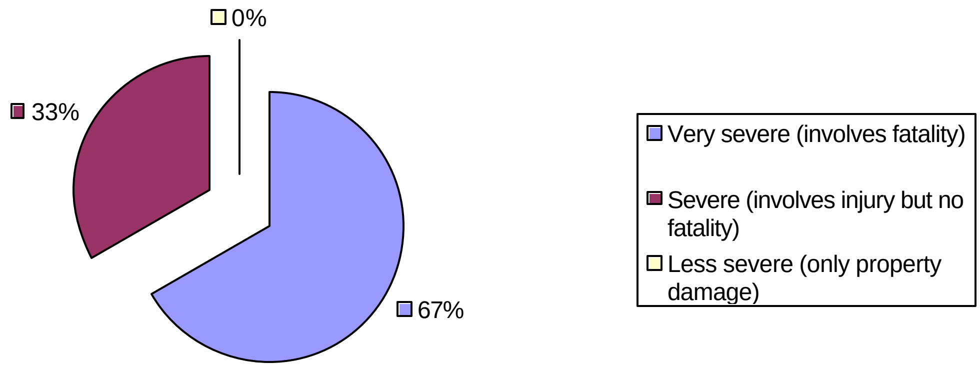
	Percentage (number) of responses
Worker struck by through traffic inside the work area	44% (11)
Worker struck by through traffic outside the work area	32% (8)
Worker struck by construction equipment inside the work area	44% (11)
Worker struck by construction equipment outside the work area	4% (1)
Others (TCDs struck)	24% (6)

The results show that there are 3 dominant accident types. "Worker struck by through traffic inside the work area" and "worker struck by construction equipment inside the work area" are the two most common accident types.

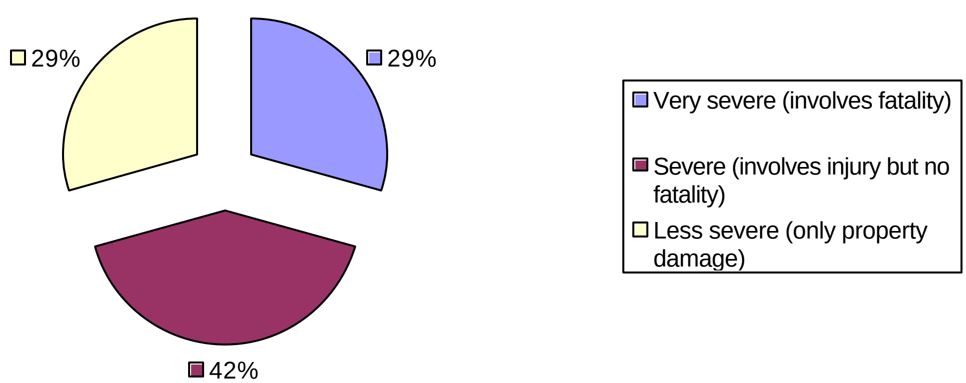
- How severe was the worst worker-related nighttime accident caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work areas you are familiar with)
    - Construction/Rehabilitation: 14 respondents answered this question.



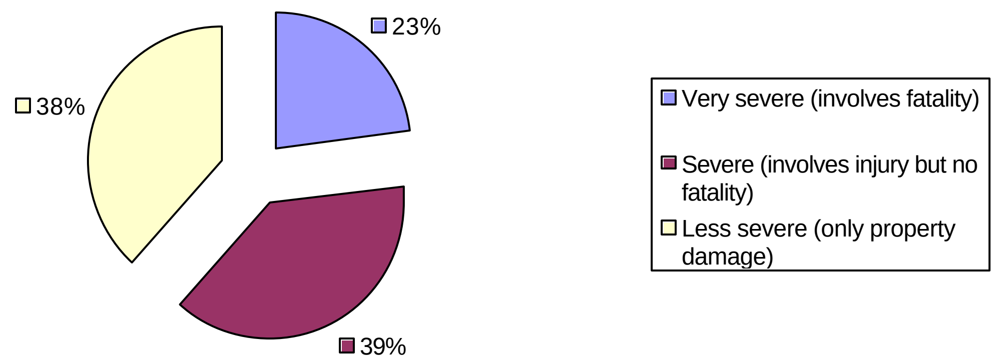
o <u>Maintenance</u>: Only 3 of the respondents have reported this kind of accident. In maintenance projects, accidents are more severe.



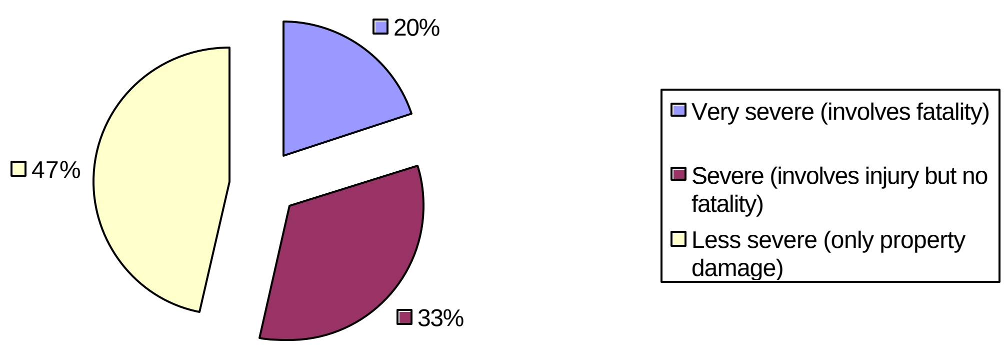
o <u>Consolidated Findings</u> (including construction/ rehabilitation and maintenance projects): The total number of respondents was 17.



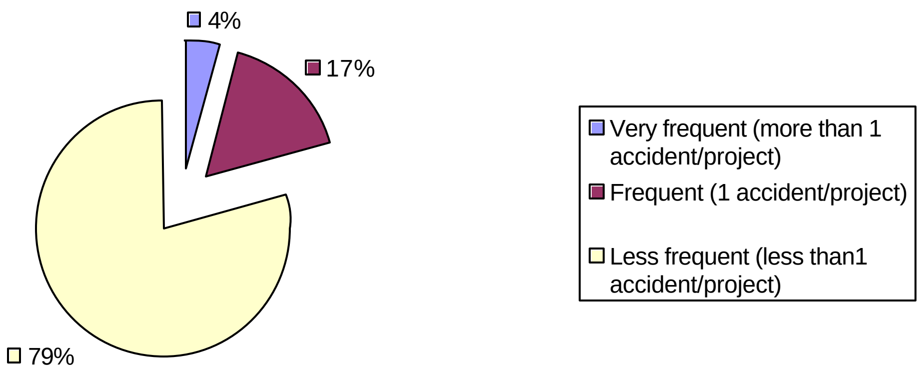
- How severe was the worst worker-related nighttime accident caused by **construction equipment** operating on any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 13 respondents answered this question.



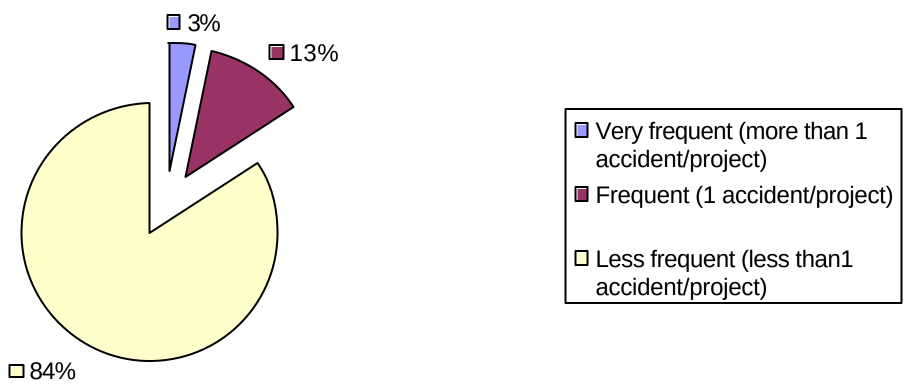
    - Maintenance: 2 respondents reported nighttime accidents caused by construction equipment operating on a maintenance work area and both stated that these accidents were not severe (only property damage).
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 15.



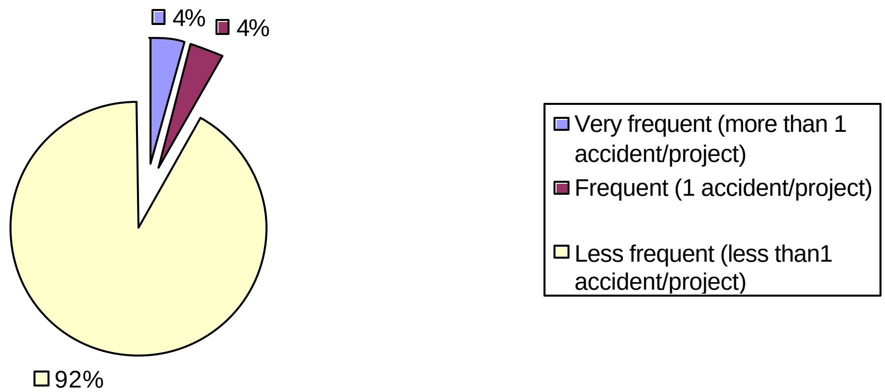
- How frequent (on the average) were the worker-related nighttime accidents caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - Construction/Rehabilitation: 24 respondents answered this question.



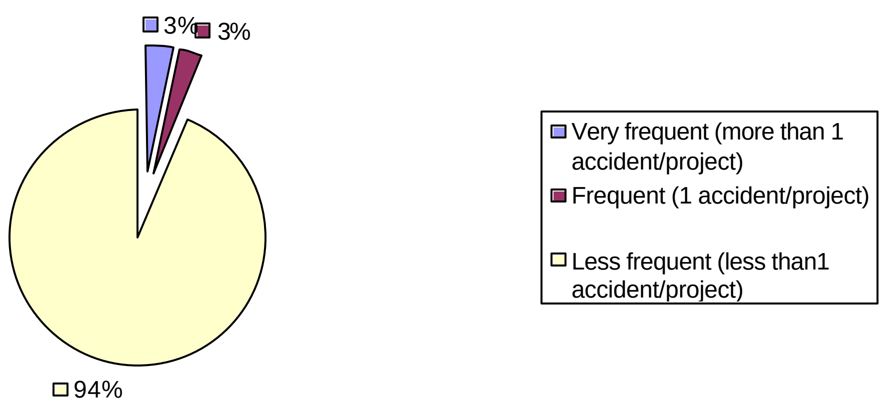
    - Maintenance: All 7 respondents who answered this question reported that worker-related nighttime accidents caused by vehicles driving through work areas occurred at a rate of 1 accident/project.
    - Consolidated Findings (including construction/ rehabilitation and maintenance projects): The total number of respondents was 26.



- How frequent (on the average) were the worker-related nighttime accidents caused by **construction equipment** operating on your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)
    - <u>Construction/Rehabilitation:</u> 24 respondents answered this question.



    - <u>Maintenance</u>: The worker-related nighttime accidents caused by construction equipment operating on maintenance type work area are reported by 6 respondents to be occurring at a rate of less than 1 accident/project.
    - <u>Consolidated Findings</u> (including construction/ rehabilitation and maintenance projects): The total number of respondents was 31.



- What are the major factors contributing to worker-related nighttime accidents in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

    - Construction/Rehabilitation:

	Percentage (number) of responses
Poor lighting conditions	50% (10)
Unfavorable weather conditions	20% (4)
Poor performance of safety garment	10% (2)
Workers not wearing safety garments	20% (4)
Condition of vehicle operator (sleepy, DUI, age, etc.)	65% (13)
Others:	30% (6)

    - Maintenance:

	Percentage (number) of responses
Poor lighting conditions	25% (2)
Unfavorable weather conditions	13% (1)
Poor performance of safety garment	0% (0)
Workers not wearing safety garments	0% (0)
Condition of vehicle operator (sleepy, DUI, age, etc.)	63% (5)
Others:	38% (3)

    - Consolidated Findings (including construction/ rehabilitation and maintenance projects)

	Percentage (number) of responses
Poor lighting conditions	43% (12)
Unfavorable weather conditions	18% (5)
Poor performance of safety garment	7% (2)
Workers not wearing safety garments	14% (4)
Condition of vehicle operator (sleepy, DUI, age, etc.)	64% (18)
Others:	32% (9)

The accidents caused by vehicles driving through the work area are more severe and frequent than the accidents caused by the construction equipment operating in the work area. The main reason is condition of vehicle operators. Poor lighting condition is the second most common reason for those accidents.

II. Evaluation of existing safety garments

- Describe the safety garments that are currently being used at nighttime on your highway work areas:

  Manufacturer: ………………. ……… Model: ………………………….
  Color of vest: .……………...……… Description: ……………………
  Color of retro-reflective material: …………………………………………….

This part of the survey was prepared to find out the type and origin of the safety vests used. The answers to this question are presented in the following table.

Respondent	***Organization***	***Position***	***Manufacturer***
Respondent 1	Illinois DOT/Dist. 8	Resident Engineer	Warning Lights (supplier)
Respondent 2	Illinois DOT/Dist. 2	Resident Engineer	IDOT (supplier)
Respondent 3	Illinois DOT/ Dist. 6	CE IV	Dist. 6 Admin Office (supplier)
Respondent 4	Illinois DOT/ Dist. 5	Resident Engineer	IDOT (supplier)
Respondent 5	Gallagher Asphalt	General Constructor Coordinator	Main Store Room
Respondent 6	Illinois DOT/ Dist. 8	Resident Engineer	Construction Office
Respondent 7	Rockford Const.	Operations Manager	Ahop/Pants Department
Respondent 8	Illinois DOT/ Dist. 8	Resident Engineer	District Safety Bureau (supplier)
Respondent 9	Illinois DOT/ Dist. 8	CE III	IDOT (supplier)
Respondent A	Iowa DOT	Traffic Safety/Automation Eng.	Head Lites Corporation
Respondent B	Michigan DOT	Construction Staff Eng.	Head Lites Corporation
Respondent C	SC DOT	Employee Safety Coordinator	MTS Safety Products
Respondent D	Idaho DOT	Assistant State Traffic Eng.	NorthWest Safety
Respondent E	Maryland DOT		Kishigo
Respondent F	Wisconsin DOT	Traffic Operations Eng.	Head Lites Corporation
Respondent G	Washington DOT	Safety and Health Administrator	Chami Design
Respondent H	Arkansas DOT	Staff Construction Engineer	Iron Horse
Respondent I	Oregon DOT	Safety Program Coordinator	Columbia George Center

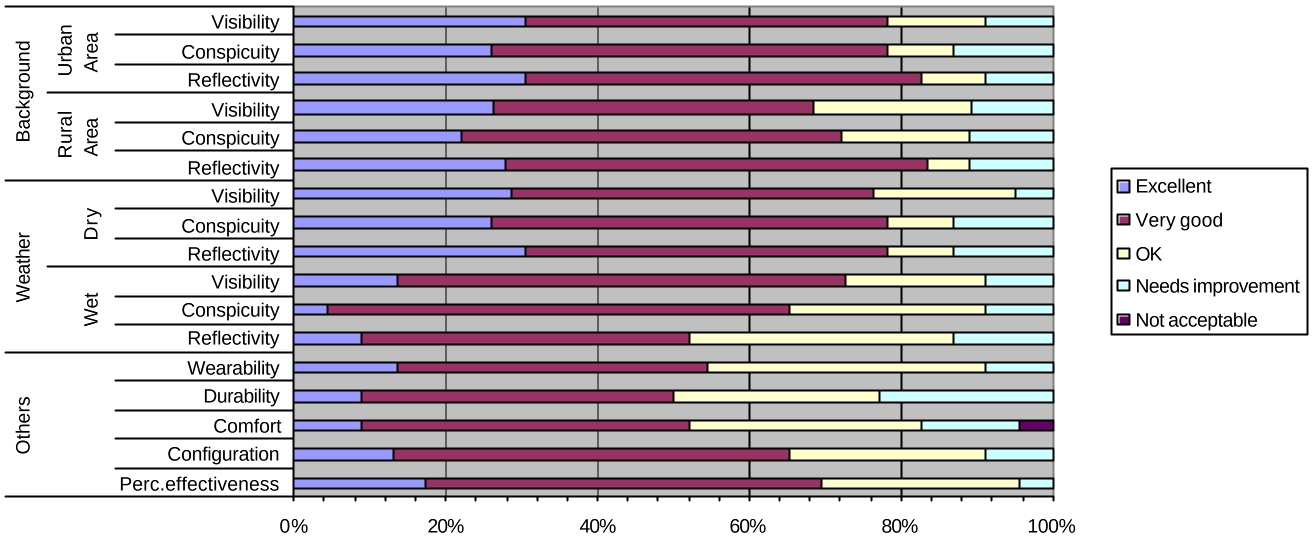
Note: 73% of the respondents mentioned the color of the vests and reflective materials. Of these respondents, 79% were using orange vests, 21% green vests, 58% vest with green retro-reflective material, 37% vests with silver retro-reflective material and 5% vests with red retro-reflective material. DOT's other than IDOT prefer mostly silver retro-reflective material but Illinois respondents prefer green. Respondents' names are on file.

- How would you characterize the **nighttime performance** of the safety garments currently in use on your work areas? (Refer to Table 1 for definitions)

Table 1. Performance factors of safety garments (Modified from ASTM; Designation: F923-00, 3M)

Factors	**Definitions**
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
Conspicuity	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
Reflectivity	The measure of brightness of retro-reflective material used in workers' garments making the garments more visible at nighttime.
Wearability	The qualities of the garments that provide good fit, up-to-date look, likable colors and shapes, and weather protection.
Durability	The ability of garments to retain their original characteristics after many wears and washes.
Comfort	Garments' features that prevent the worker from perspiring, being cold or hot, getting wet, or limiting their movements.
Configuration	The exterior and interior design of safety garments such as size, number and function of pockets, use of buttons/zippers/Velcro.
Perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

The following bar-chart represents the distribution of the answers to this question:



A scale (0-4) is used to evaluate the data obtained in the Part 2 (evaluation of existing safety garments) and Part 3 (safety garment design factors and features).

1- Not very important, negatively impacted or not acceptable
2- Somewhat important or needs improvement
3- Important, not changed or OK
4- Very important or very good
5- Extremely important, positively impacted or excellent

The average ratings of the performance characteristics are calculated in the following table:

			Excellent (4)	Very good (3)	OK (2)	Needs improvement (1)	Not acceptable (0)	Total Ranking	Number of Respondents	Average Rating
Background	Urban Area	Visibility	7	11	3	2	0	69	23	3.00
		Conspicuity	6	12	2	3	0	67	23	2.91
		Reflectivity	7	12	2	2	0	70	23	3.04
	Rural Area	Visibility	5	8	4	2	0	54	19	2.84
		Conspicuity	4	9	3	2	0	51	18	2.83
		Reflectivity	5	10	1	2	0	54	18	3.00
Weather	Dry	Visibility	6	10	4	1	0	63	21	3.00
		Conspicuity	6	12	2	3	0	67	23	2.91
		Reflectivity	7	11	2	3	0	68	23	2.96
	Wet	Visibility	3	13	4	2	0	61	22	2.77
		Conspicuity	1	14	6	2	0	60	23	2.61
		Reflectivity	2	10	8	3	0	57	23	2.48
Others		Wearability	3	9	8	2	0	57	22	2.59
		Durability	2	9	6	5	0	52	22	2.36
		Comfort	2	10	7	3	1	55	23	2.39
		Configuration	3	12	6	2	0	62	23	2.70
		Perc.effectiveness	4	12	6	1	0	65	23	2.83

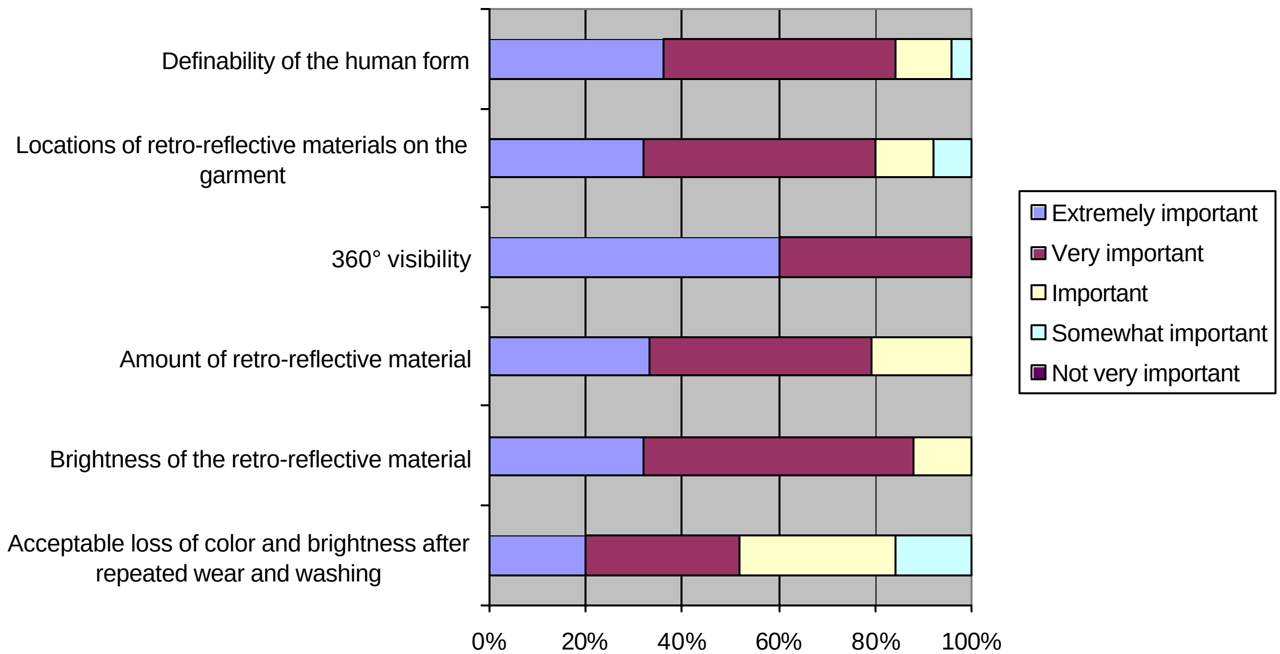
Note: Respondents from other DOT's are more satisfied with the nighttime performance of the safety garments currently in use on their work areas than IL respondents.

III. Safety garment design factors and features

- What is the importance of the following design factors in the use of retro-reflective materials to enhance the nighttime visibility of your safety garments? (Refer to the Table 2 for definitions)

Table 2. Design Factors that Enhance Nighttime Visibility (Modified from 3M)

Factors	Definitions
Definability of the human form	The retro-reflective material on a garment being the only component visible to a driver at nighttime, it should make the driver recognize the object as a worker.
Location of retro-reflective materials on the garment	The appropriate location of the retro-reflective material on a safety garment should enhance its visibility by drawing the human eye to the moving object as the worker moves.
360° visibility	The human form should be detected from all directions regardless of the human form, movement, location, and situation.
Amount of retro-reflective material	The amount of retro-reflective material applied should increase a worker's visibility.
Brightness of the retro-reflective material	The brightness of retro-reflective material should increase a worker's visibility.
Acceptable loss of color and brightness after repeated wear and washing	The garment should be resistant to wear and washing such that the garment maintains its color and brightness longer.



The average ratings and the ranks of the design factors are calculated in the following table:

	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Definability of the human form	9	12	3	1	0	79	25	3.16	3
Locations of retro-reflective materials on the garment	8	12	3	2	0	76	25	3.04	5
360° visibility	15	10	0	0	0	90	25	3.60	1
Amount of retro-reflective material	8	11	5	0	0	75	24	3.13	4
Brightness of the retro-reflective material	8	14	3	0	0	80	25	3.20	2
Acceptable loss of color and brightness after repeated wear and washing	5	8	8	4	0	64	25	2.56	6

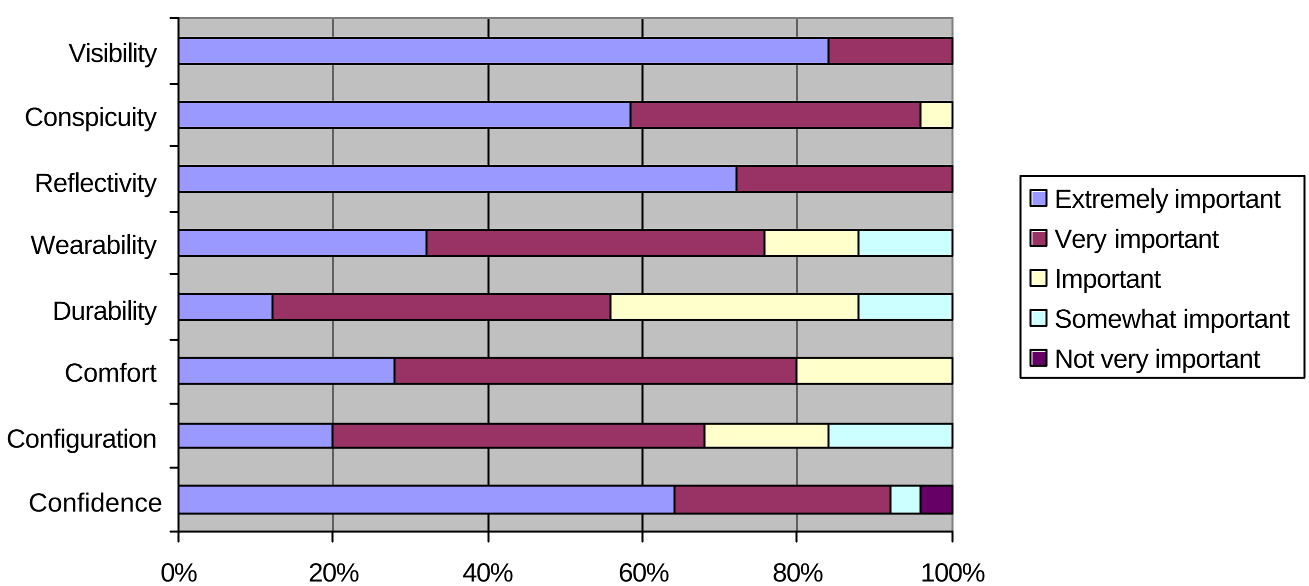
Notes:

(1) The respondents are mostly concerned with 360° visibility of the safety vests. In ANSI/ISED 107-1999 standard (American National Standard for High-Visibility Safety Apparel), it is stated that:

(2) "Class 1, 2 or 3 garments such as vests, waistcoats, jackets, ponchos, coveralls, and bib overalls shall meet the requirements for the respective Class of high-visibility safety clothing, and shall have contiguous areas of retroreflective material encircling the torso, placed in such a manner to provide 360° visibility of the wearer."

(3) So ANSI makes 360° visibility a must for safety apparel. ANSI-107 also includes a table, which shows the minimum area of the retroreflective material and its performance. In the Appendix B of ANSI-107 there are some suggested garment designs.

- How important do you consider the following features of safety garments used in nighttime construction? (See Table 1 for definitions)

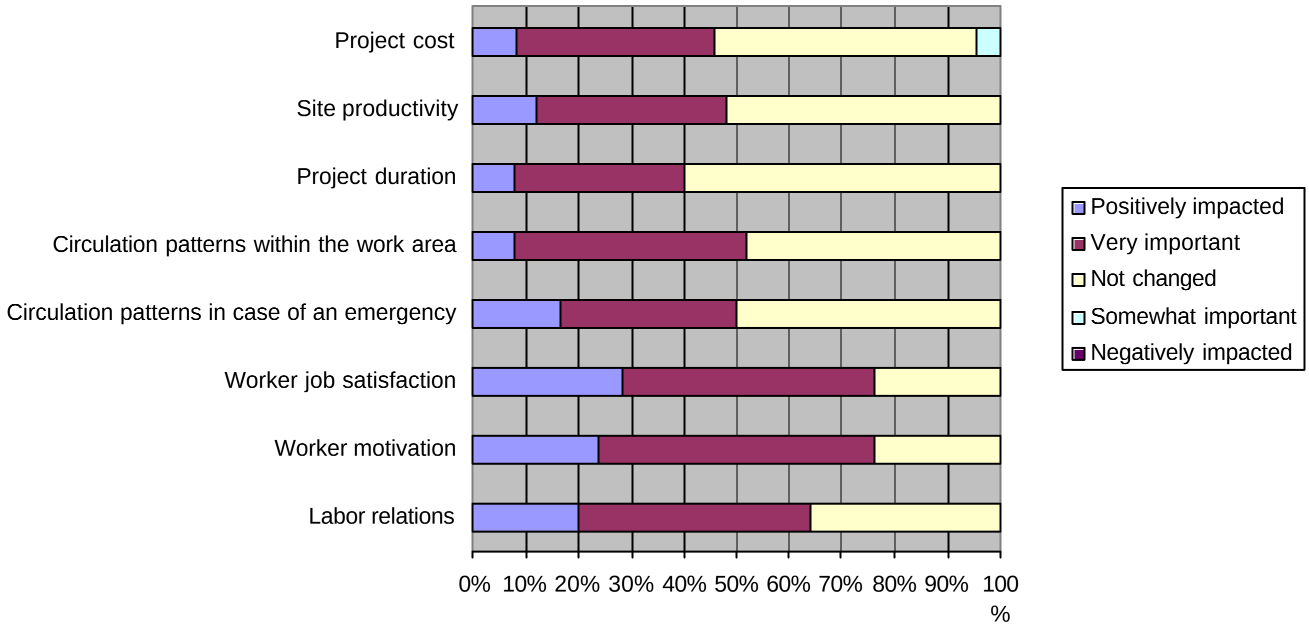


The average ratings and the ranks of the safety garment features are calculated in the following table:

Safety garment features	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Visibility	21	4	0	0	0	96	25	3.84	1
Conspicuity	14	9	1	0	0	85	24	3.54	3
Reflectivity	18	7	0	0	0	93	25	3.72	2
Wearability	8	11	3	3	0	74	25	2.96	6
Durability	3	11	8	3	0	64	25	2.56	8
Comfort	7	13	5	0	0	77	25	3.08	5
Configuration	5	12	4	4	0	68	25	2.72	7
Worker's confidence	16	7	0	1	1	86	25	3.44	4

Visibility of the garment and reflectivity of the retroreflective material are considered to be the two most important features of a safety vest. Visibility and reflectivity are closely related and the results of this questionnaire support that.

- What is the impact of **extremely good nighttime visibility** of workers on the following project factors?

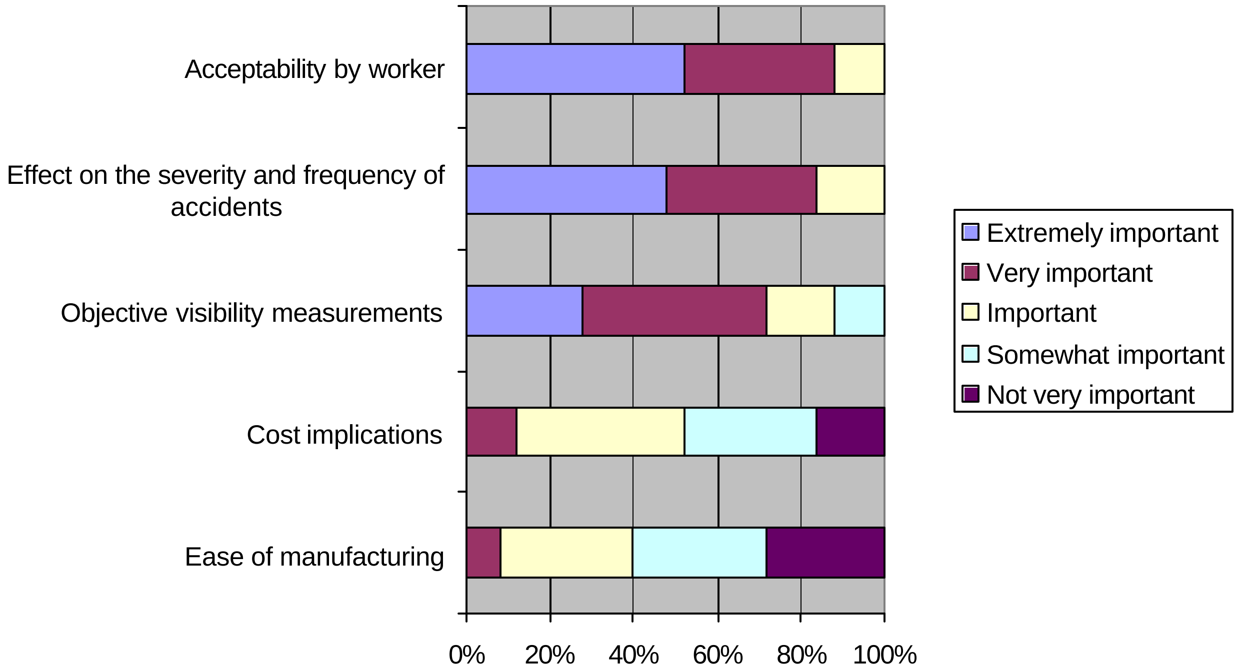


The average ratings and the ranks of the project factors are calculated in the following table:

Project Factors	Positively Impacted (4)	(3)	Not Changed (2)	(1)	Negatively Impact (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Project cost	2	9	12	1	0	60	24	2.50	7
Site productivity	3	9	13	0	0	65	25	2.60	5
Project duration	2	8	15	0	0	62	25	2.48	8
Circulation patterns within the work area	2	11	12	0	0	65	25	2.60	5
Circulation patterns in case of an emergency	4	8	12	0	0	64	24	2.67	4
Worker job satisfaction	7	12	6	0	0	76	25	3.04	1
Worker motivation	6	13	6	0	0	75	25	3.00	2
Labor relations	5	11	9	0	0	71	25	2.84	3

The findings suggest that with a well-designed vest, it is possible to improve worker's job satisfaction, motivation and labor relations a great deal.

- Please rate the importance of the following criteria that should help select a particular type of safety garment. We are seeking **your opinion** rather than the current practice in your organization.



The average ratings and the ranks of selection criteria are calculated in the following table:

Selection criteria	Extremely important (4)	Very important (3)	Important (2)	Somewhat important (1)	Not very important (0)	Total Ranking	Number of respondents	Average Rating	Ranking
Acceptability by worker	13	9	3	0	0	85	25	3.40	1
Effect on the severity and frequency of accidents	12	9	4	0	0	83	25	3.32	2
Objective visibility measurements	7	11	4	3	0	72	25	2.88	3
Cost implications	0	3	10	8	4	37	25	1.48	4
Ease of manufacturing	0	2	8	8	7	30	25	1.20	5

"Acceptability by workers" and "effect on the severity and frequency of accidents" are the most important two criteria the respondents identified for safety garments. The vest should make the worker feel safe and decrease the frequency and severity of the accidents.

5.4 Conclusion

The findings of the surveys administered to IDOT operation personnel, resident engineers and contractors and to departments of transportation of other states than Illinois involved in nighttime construction operations within the past 5 years can be summarized in the following short statements:

- Safety does not seem to be any more of a problem in nighttime than in daytime works. The same attention should be given to safety both in nighttime and daytime works.

- The results show that there are 3 dominant accident types. "Worker struck by through traffic inside the work area" and "Worker struck by construction equipment inside the work area" are the two most common accident types. The dominant nighttime accident types are similar in Illinois and other states.
- The accidents caused by vehicles driving through the work area are more severe and frequent than the accidents caused by construction equipment operating in the work area.
- The main reason for nighttime accidents is the condition of vehicle operators. Poor lighting condition is the second most common reason for these accidents.
- The respondents are mostly concerned with 360° visibility of the safety vests. It is no surprise that ANSI standards make 360° visibility a requirement for safety apparel.
- Visibility of the garment and reflectivity of the retro-reflective material are considered to be the two most important features of a safety vest. Visibility and reflectivity are closely related and the results of this survey support that.
- The findings suggest that with a well-designed vest, it is possible to improve workers' job satisfaction, motivation and labor relations a great deal.
- "Acceptability by workers" and "effect on the severity and frequency of accidents" are the most important two criteria the respondents identified for safety garments. The vest should make the worker feel safe and decrease the frequency and severity of the accidents.
- Last but not least, the data obtained from Illinois respondents and other DOT agencies, are to a great extent, similar. The only difference appears to be in the respondents' opinions concerning the nighttime performance of currently used safety

vests. Respondents from other DOTs are more satisfied with the nighttime performance of the safety garments currently in use on their work areas than IL respondents.

6. FINDINGS AND DISCUSSION OF SITE TESTS

6.1 Site Tests

Four field tests were conducted under different lighting conditions, different weather conditions, and at different locations with different traffic volume. The characteristics of the sites on test nights are presented in Table 6.1. These choices were approved by the project TRP.

Table 6.1 Characteristics of construction sites

	Lighting condition in work zone	Weather condition	Type of setting (urban or rural)	Volume of traffic
1st Site	Medium	Good	Urban	Heavy
2nd Site	Good	Rainy	Urban	Medium
3rd Site	Poor	Clear	Urban	Light
4th Site	Poor	Clear and windy	Rural	Variable

Detailed information associated with the construction sites where tests were conducted is presented in Table 6.2. An example movie that shows the test conducted in the first site was produced and is presented in the CD attached to the report. The movie shows the time of the test as well as the mean luminance values associated with the front face of each safety vest.

Table 6.2 Detailed information about construction sites

Sites	Date of test	Starting time	Ending time	Location	Number of lanes	Number of closed lanes	Speed limit (mph)	Speed limit in work zone (mph)	Background
1st Site	10.22.2002	9:36 PM	12:06 AM	SB IL41-I55 Connection	5	3 central	45	35	Enclosed pedestrian bridge
2nd Site	10.28.2002	10:09 PM	12:41 AM	SB IL41at 31st Street	2	1	45	35	Trees
3rd Site	10.29.2002	9:07 PM	11:44 AM	I55-Franklin Connection	3	1	55	55	Under bridge
4th Site	11.07.2002	9:50 PM	12:26 AM	NB I57 at 159th Street	4	2	55	45	Rural

6.1.1 Descriptive Statistics

The mean luminance values were calculated using the method explained in Chapter 4. Descriptive statistics are run for both front faces and sides of the six vests tested on each of the four construction sites. The results are tabulated in Appendix G.

6.1.2 Normalization of Luminance Values

After running the descriptive statistics of the data collected, the next step is to normalize the mean luminance values of the vests in order to eliminate the effect of different traffic volumes (and therefore the effect of different lighting conditions) recorded during each shift of the tests.

The photometer which was attached to the center stand, recorded the average intensity of light at the test site. There are two sources of light at the test site. First is lighting at the construction site and the second is light generated by passing cars. The photometer calculated the average light intensity at each shift of 10 minutes. So the mean luminance values of the vests were normalized using the photometer readings whenever they were reliable. The photometer used in field tests, calculates mean light intensity in integers, without any decimals. So, when working with very small light intensities, rounding off resulted in inaccurate and unreliable values. For example, the photometer readings on the third and fourth sites varied between 1-2 and 1-3, respectively. So the mean luminance values of the vests obtained at these two sites were normalized using the average traffic volume, a more reliable measure than using average photometer readings. There was no such problem in the first and the second sites where average photometer readings ranged between 16-17 and 48-50, respectively. The mean luminance values obtained at these sites were normalized using average photometer readings for each shift. The normalized mean luminance values are tabulated in Appendix H.

6.1.3 Comparison of Vest Positions in Site Tests

This section is included in the report to show that recording every vest at three positions (stand closest to cones separating the work zone from open lanes, center stand, and stand farthest from the open lane) is reasonable. A statistical analysis was run to see if there is any statistically significant difference between the normalized mean luminance values obtained in these three positions. The normalized values obtained in the first test site for the front face of the IDOT Standard Vest are presented in Table 6.3.

Table 6.3 Descriptive statistics for position comparison

Vest	Position	Mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	96.319	266	2.989	91.34	109.11
	Middle	93.585	251	4.051	78.03	102.11
	Right	88.524	262	4.649	73.78	100.73
	Total	92.816	779	5.114	73.78	109.11

It can be observed in Table 6.3 that the standard deviation and the variance of the means calculated at each of the three positions are different from each other. So Tamhane's T2 test, one of the multiple comparison tests which do not assume equal variance, was used. Dunnett's T3 test, the Games-Howell pair wise comparison test and Dunnett's C test are other multiple comparison tests which do not assume equal variance but Tamhane's T2 test was used in this study because it is a conservative pair wise comparison test based on a t-test. The normalized luminance values of each vest's front face at these three positions are tabulated separately for each site. Tamhane's T2 test was run 24 times, i.e., six vests at four construction sites. A total of 72 significance values were obtained. Only three of the 72 differences were significant at 5%. The results are presented in Appendix I. Table 6.4 presents the results of Tamhane's T2 test for the front face of the IDOT Standard Vest.

Table 6.4 Tamhane's T2 test run for left, middle and right positions

Position (I)	Position (J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	2.734	.315	.000
	Right	7.795	.341	.000
Middle	Left	-2.734	.315	.000
	Right	5.061	.385	.000
Right	Left	-7.795	.341	.000
	Middle	-5.061	.385	.000

The significance values of the pair-wise comparisons are tabulated in the rightmost column of Table 6.4. Since none of the differences were significant at 5%, the null hypothesis, which claims the means are same, is rejected. If one examines the results of the analyses conducted for all the vests at each test site (Appendix I), it can be observed that only 3 of the 72 differences were different at 5%. It can therefore be concluded that the mean luminance values obtained in the three positions are significantly different. This finding justifies the decision to record each vest at each of the three different positions.

6.1.4 Comparison of Vests' Front Faces vs. Sides

According to findings of the survey administered to IDOT operation personnel, resident engineers, contractors and to departments of transportation of other states than Illinois (See Chapter 5), 360° visibility is the most important safety garment design factor. So the sides of the vests were recorded in addition to the front faces of the vests. In this section, the differences between the luminance values of the front faces and the luminance values of the sides of the vests are examined to find out whether these differences are statistically significant or not. Descriptive statistics are presented in tables in Appendix J. T-tests for independent samples were run to determine significance of the differences between the mean luminance values for front faces and sides of vests.

The t-test was run 24 times and 24 significance values were obtained. Only 2 of the 24 differences were found to be significant at 5%. In other words, with a significance level of 5%, 22 out of 24 comparisons confirm that vests' front faces and sides have different mean luminance values, which in turns points to different visibilities. The research team's decision to record both front faces and sides of vests is therefore justified.

6.1.5 Ranking of the Vests

Normalized luminance values of the front faces and of the sides of the six vests tested are presented in Tables 6.5 and 6.6. The vests are ranked according to their normalized mean luminance values.

The next step is to examine the significance of the differences between these means. In other words, is the ranking reliable at a significance level of 5%? Tamhane's T2 test was run for pair-wise comparison of the means. The results of the tests are presented in Appendix K. According to the findings tabulated in Appendix K, the difference between the mean luminance values of the Chami Design Washington Style vest and the Safetyline Minnesota Style vest is not significant at 5% in the first site. Also, the difference between the mean luminance values of the Chami Design Washington Style vest and the Head Lite Roadstar 200 vest is not significant at 5% in the fourth site. So their ranks should be adjusted accordingly. The adjusted rankings based on the performance of vests' front sides are presented in Table 6.7. The rankings based on the performance of vests' sides remain unchanged (Table 6.6) as all the differences between the normalized luminance values of the vests' sides are significant at 5%.

Table 6.8 and 6.9 present the rankings based on the performance of the front faces and sides of vests, respectively at four construction sites. The rankings in the last columns of these tables represent the average of the rankings in the four test sites.

Finally, the overall ranking is calculated based on the performance of the front faces (last column of Table 6.8) and the sides (last column of Table 6.9) of vests at four construction sites, each weighed equally. The results are presented in Table 6.10. As it can be observed, the Head Lite Roadstar 200 vest and the Safetyline Minnesota Style vest tie for first rank.

Table 6.5 Normalized mean luminance values and corresponding rankings based on the performance of vests' front faces

Vests	Site 1		Site 2		Site 3		Site 4	
	Normalized mean luminance	Rank	Normalized mean luminance	Rank	Normalized mean luminance	Rank	Normalized mean luminance	Rank
IDOT Standard Vest	92.816	6	99.061	6	50.660	3	44.012	5
IDOT LED Vest	99.975	5	105.718	5	40.529	6	39.827	6
Head Lite Roadstar 200	138.525	1	174.557	3	63.216	1	50.763	2
Iron Horse Texas Style	105.151	4	137.506	4	44.480	5	48.699	4
Chami Design Washington Style	127.156	2	177.067	2	61.154	2	50.750	3
Safetyline Minnesota Style	127.155	3	181.060	1	48.023	4	59.903	1

Table 6.6 Normalized mean luminance values and corresponding rankings based on the performance of vests' sides

Vests	Site 1		Site 2		Site 3		Site 4	
	Normalized mean luminance	Rank	Normalized mean luminance	Rank	Normalized mean luminance	Rank	Normalized mean luminance	Rank
IDOT Standard Vest	85.980	5	85.012	5	52.532	6	48.944	5
IDOT LED Vest	82.913	6	78.169	6	59.481	5	42.144	6
Head Lite Roadstar 200	116.101	2	145.464	2	59.738	4	54.746	3
Iron Horse Texas Style	98.224	4	100.882	4	68.761	2	53.097	4
Chami Design Washington Style	115.142	3	129.915	3	60.392	3	55.884	2
Safetyline Minnesota Style	123.640	1	165.301	1	78.422	1	60.461	1

Table 6.7 Adjusted rankings based on the performance of vests' front faces

Vests	Site 1 Rank	Site 2 Rank	Site 3 Rank	Site 4 Rank
IDOT Standard Vest	6	6	3	5
IDOT LED Vest	5	5	6	6
Head Lite Roadstar 200	1	3	1	2.5
Iron Horse Texas Style	4	4	5	4
Chami Design Washington Style	2.5	2	2	2.5
Safetyline Minnesota Style	2.5	1	4	1

Table 6.8 Ranking based on the performance of vests' front faces

Vests	Site 1 Rank	Site 2 Rank	Site 3 Rank	Site 4 Rank	Total	Ranking
IDOT Standard Vest	6	6	3	5	20	5
IDOT LED Vest	5	5	6	6	22	6
Head Lite Roadstar 200	1	3	1	2.5	7.5	1
Iron Horse Texas Style	4	4	5	4	17	4
Chami Design Washington Style	2.5	2	2	2.5	9	3
Safetyline Minnesota Style	2.5	1	4	1	8.5	2

Table 6.9 Ranking based on the performance of vests' sides

Vests	Site 1 Rank	Site 2 Rank	Site 3 Rank	Site 4 Rank	Total	Ranking
IDOT Standard Vest	5	5	6	5	21	5
IDOT LED Vest	6	6	4	6	22	6
Head Lite Roadstar 200	2	2	4	2.5	10.5	2
Iron Horse Texas Style	4	4	2	4	14	4
Chami Design Washington Style	3	3	4	2.5	12.5	3
Safetyline Minnesota Style	1	1	1	1	4	1

Table 6.10 Ranking based on the combined performance of vests' front faces and sides

Vests	Ranking based on performance of front faces	Ranking based on performance of sides	Ranking based on combined performance of front faces and sides
IDOT Standard Vest	5	5	5
IDOT LED Vest	6	6	6
Head Lite Roadstar 200	1	2	1
Iron Horse Texas Style	4	4	4
Chami Design Washington Style	3	3	3
Safetyline Minnesota Style	2	1	1

6.2 Site Survey

On the first night, 34 students answered the questionnaire (Appendix F) and the photometer reading was 14 lux. The questionnaire was approved by the project TRP. The data presented in Table 6.11 were collected on the first night. On the second night, 17 graduate students evaluated the six vests while the photometer reading was 5 lux. The data presented in Table 6.12 represent the findings of the second night of the survey. The responses obtained on the first and second nights are consolidated and presented in Table 6.13.

Table 6.11 Survey findings (First batch of 34 respondents)

	11.18.02 Batch# 1 Photometer reading 14 lux	Excellent (5)	Very good (4)	OK (3)	Needs improvement (2)	Not acceptable (1)	Total score	Number of respondents	Average score
IDOT Standard Vest	360° visibility	3	3	8	17	3	88	34	2.59
	Conspicuity against background	2	4	12	11	5	89	34	2.62
	Brightness of retro-reflective material	0	6	7	17	4	83	34	2.44
	Configuration (pockets, zipper, etc.)	1	2	12	14	4	81	33	2.45
	Overall perceived effectiveness	2	1	11	14	6	81	34	2.38
IDOT LED Vest	360° visibility	0	9	14	10	1	99	34	2.91
	Conspicuity against background	3	5	13	10	3	97	34	2.85
	Brightness of retro-reflective material	3	7	15	6	3	103	34	3.03
	Configuration (pockets, zipper, etc.)	2	6	15	8	3	98	34	2.88
	Overall perceived effectiveness	1	7	13	10	3	95	34	2.79
Roadstar 200	360° visibility	9	16	8	0	1	134	34	3.94
	Conspicuity against background	12	13	8	1	0	138	34	4.06
	Brightness of retro-reflective material	9	11	11	2	1	127	34	3.74
	Configuration (pockets, zipper, etc.)	4	15	10	5	0	120	34	3.53
	Overall perceived effectiveness	8	12	12	1	1	127	34	3.74
Texas Style	360° visibility	4	15	9	5	1	118	34	3.47
	Conspicuity against background	5	14	8	7	0	119	34	3.50
	Brightness of retro-reflective material	6	14	8	5	1	121	34	3.56
	Configuration (pockets, zipper, etc.)	2	4	22	5	1	103	34	3.03
	Overall perceived effectiveness	4	12	13	5	0	117	34	3.44
Washington Style	360° visibility	9	14	10	1	0	133	34	3.91
	Conspicuity against background	5	19	8	2	0	129	34	3.79
	Brightness of retro-reflective material	9	10	9	4	1	121	33	3.67
	Configuration (pockets, zipper, etc.)	5	14	12	2	0	121	33	3.67
	Overall perceived effectiveness	7	14	10	2	1	126	34	3.71
Minnesota Style	360° visibility	10	14	7	2	1	132	34	3.88
	Conspicuity against background	9	11	9	5	0	126	34	3.71
	Brightness of retro-reflective material	10	16	4	1	3	131	34	3.85
	Configuration (pockets, zipper, etc.)	6	12	11	3	2	119	34	3.50
	Overall perceived effectiveness	7	17	5	4	1	127	34	3.74

Table 6.12 Survey findings (Second batch of 17 respondents)

	11.20.02 Batch# 2 Photometer reading 5 lux	Excellent (5)	Very good (4)	OK (3)	Needs improvement (2)	Not acceptable (1)	Total score	Number of respondents	Average score
IDOT Standard Vest	360° visibility	3	2	6	5	1	52	17	3.06
	Conspicuity against background	0	3	7	6	1	46	17	2.71
	Brightness of retro-reflective material	0	7	4	3	3	49	17	2.88
	Configuration (pockets, zipper, etc.)	0	3	8	3	2	44	16	2.75
	Overall perceived effectiveness	0	3	7	4	2	43	16	2.69
IDOT LED Vest	360° visibility	0	6	8	3	0	54	17	3.18
	Conspicuity against background	0	1	11	5	0	47	17	2.76
	Brightness of retro-reflective material	0	7	5	5	0	53	17	3.12
	Configuration (pockets, zipper, etc.)	1	2	9	4	1	49	17	2.88
	Overall perceived effectiveness	1	3	5	6	2	46	17	2.71
Roadstar 200	360° visibility	11	4	2	0	0	77	17	4.53
	Conspicuity against background	9	7	1	0	0	76	17	4.47
	Brightness of retro-reflective material	7	7	2	0	0	69	16	4.31
	Configuration (pockets, zipper, etc.)	5	8	3	1	0	68	17	4.00
	Overall perceived effectiveness	6	8	2	1	0	70	17	4.12
Texas Style	360° visibility	0	3	7	5	1	44	16	2.75
	Conspicuity against background	1	3	6	7	0	49	17	2.88
	Brightness of retro-reflective material	1	3	5	7	1	47	17	2.76
	Configuration (pockets, zipper, etc.)	0	2	4	9	1	39	16	2.44
	Overall perceived effectiveness	0	2	5	7	3	40	17	2.35
Washington Style	360° visibility	2	11	3	0	0	63	16	3.94
	Conspicuity against background	2	11	3	1	0	65	17	3.82
	Brightness of retro-reflective material	4	7	3	0	0	57	14	4.07
	Configuration (pockets, zipper, etc.)	6	5	4	2	0	66	17	3.88
	Overall perceived effectiveness	4	10	2	1	0	68	17	4.00
Minnesota Style	360° visibility	5	7	4	1	0	67	17	3.94
	Conspicuity against background	8	4	1	2	1	64	16	4.00
	Brightness of retro-reflective material	7	6	1	1	2	66	17	3.88
	Configuration (pockets, zipper, etc.)	5	6	3	3	0	64	17	3.76
	Overall perceived effectiveness	9	1	3	2	2	64	17	3.76

Table 6.13 Survey findings (Consolidated results of all 51 respondents)

	CONSOLIDATED RESULTS	Excellent (5)	Very good (4)	OK (3)	Needs improvement (2)	Not acceptable (1)	Total score	Number of respondents	Average score
IDOT Standard Vest	360° visibility	6	5	14	22	4	140	51	2.75
	Conspicuity against background	2	7	19	17	6	135	51	2.65
	Brightness of retro-reflective material	0	13	11	20	7	132	51	2.59
	Configuration (pockets, zipper, etc.)	1	5	20	17	6	125	49	2.55
	Overall perceived effectiveness	2	4	18	18	8	124	50	2.48
IDOT LED Vest	360° visibility	0	15	22	13	1	153	51	3.00
	Conspicuity against background	3	6	24	15	3	144	51	2.82
	Brightness of retro-reflective material	3	14	20	11	3	156	51	3.06
	Configuration (pockets, zipper, etc.)	3	8	24	12	4	147	51	2.88
	Overall perceived effectiveness	2	10	18	16	5	141	51	2.76
Roadstar 200	360° visibility	20	20	10	0	1	211	51	4.14
	Conspicuity against background	21	20	9	1	0	214	51	4.20
	Brightness of retro-reflective material	16	18	13	2	1	196	50	3.92
	Configuration (pockets, zipper, etc.)	9	23	13	6	0	188	51	3.69
	Overall perceived effectiveness	14	20	14	2	1	197	51	3.86
Texas Style	360° visibility	4	18	16	10	2	162	50	3.24
	Conspicuity against background	6	17	14	14	0	168	51	3.29
	Brightness of retro-reflective material	7	17	13	12	2	168	51	3.29
	Configuration (pockets, zipper, etc.)	2	6	26	14	2	142	50	2.84
	Overall perceived effectiveness	4	14	18	12	3	157	51	3.08
Washington Style	360° visibility	11	25	13	1	0	196	50	3.92
	Conspicuity against background	7	30	11	3	0	194	51	3.80
	Brightness of retro-reflective material	13	17	12	4	1	178	47	3.79
	Configuration (pockets, zipper, etc.)	11	19	16	4	0	187	50	3.74
	Overall perceived effectiveness	11	24	12	3	1	194	51	3.80
Minnesota Style	360° visibility	15	21	11	3	1	199	51	3.90
	Conspicuity against background	17	15	10	7	1	190	50	3.80
	Brightness of retro-reflective material	17	22	5	2	5	197	51	3.86
	Configuration (pockets, zipper, etc.)	11	18	14	6	2	183	51	3.59
	Overall perceived effectiveness	16	18	8	6	3	191	51	3.75

The Head Lite Roadstar 200 vest got the highest scores in four of the five criteria including 360° visibility, conspicuity against background, brightness of retro-reflective material and overall perceived effectiveness. The Chami Design Washington Style vest led only in one criterion, configuration. The matrix in Table 6.14 shows the rankings of the vests in all five categories. The results obtained from the survey indicate that respondents prefer mostly the Head Lite Roadstar 200 vest among the six vests tested.

Table 6.14 Rankings in the Site Survey

	IDOT Standard Vest	IDOT LED Vest	Roadstar 200	Texas Style	Washington Style	Minnesota Style
360° visibility	6	5	1	4	2	3
Conspicuity against background	6	5	1	4	2	2
Brightness of retro-reflective material	6	5	1	4	3	2
Configuration (pockets, zipper, etc.)	6	4	2	5	1	3
Overall perceived effectiveness	6	5	1	4	2	3

The responses for the "overall perceived effectiveness" criterion in the site questionnaire administered to graduate students processed with SPSS. The results of the descriptive statistics and Tamhane's T2 tests are presented in Tables 6.15 and 6.16, respectively.

The following ranking is achieved based on the results of the site survey if significance level is set as 5%:

2- Head Lite Roadstar 200 vest

2- Chami Design Washington Style vest

2- Safetyline Minnesota Style vest

5- Iron Horse Texas Style vest

5- IDOT LED vest

5- IDOT Standard vest

Table 6.15 Descriptive statistics of "overall perceived effectiveness" criterion in site questionnaire

Vests	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	2.48	50	.995	1.00	5.00
IDOT LED Vest	2.76	51	1.012	1.00	5.00
Head Lite Roadstar 200	3.86	51	.939	1.00	5.00
Iron Horse Texas Style	3.08	51	1.036	1.00	5.00
Chami Design Washington Style	3.80	51	.917	1.00	5.00
Safetyline Minnesota Style	3.75	51	1.197	1.00	5.00

Table 6.16 Tamhane's T2 test of "Overall Perceived Effectiveness" criterion in site questionnaire

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	-.285	.200	.923
	Head Lite Roadstar 200	-1.383	.193	.000
	Iron Horse Texas Style	-.598	.202	.056
	Chami Design Washington Style	-1.324	.190	.000
	Safetyline Minnesota Style	-1.265	.219	.000
IDOT LED Vest	IDOT Standard Vest	.285	.200	.923
	Head Lite Roadstar 200	-1.098	.193	.000
	Iron Horse Texas Style	-.314	.203	.865
	Chami Design Washington Style	-1.039	.191	.000
	Safetyline Minnesota Style	-.980	.220	.000
Head Lite Roadstar 200	IDOT Standard Vest	1.383	.193	.000
	IDOT LED Vest	1.098	.193	.000
	Iron Horse Texas Style	.784	.196	.002
	Chami Design Washington Style	.059	.184	1.000
	Safetyline Minnesota Style	.118	.213	1.000
Iron Horse Texas Style	IDOT Standard Vest	.598	.202	.056
	IDOT LED Vest	.314	.203	.865
	Head Lite Roadstar 200	-.784	.196	.002
	Chami Design Washington Style	-.725	.194	.005
	Safetyline Minnesota Style	-.667	.222	.049
Chami Design Washington Style	IDOT Standard Vest	1.324	.190	.000
	IDOT LED Vest	1.039	.191	.000
	Head Lite Roadstar 200	-.059	.184	1.000
	Iron Horse Texas Style	.725	.194	.005
	Safetyline Minnesota Style	.059	.211	1.000
Safetyline Minnesota Style	IDOT Standard Vest	1.265	.219	.000
	IDOT LED Vest	.980	.220	.000
	Head Lite Roadstar 200	-.118	.213	1.000
	Iron Horse Texas Style	.667	.222	.049
	Chami Design Washington Style	-.059	.211	1.000

6.3 Final Ranking

Finally the rankings obtained from site tests and the site survey were combined and the following final ranking is obtained:

1- Head Lite Roadstar 200 vest

1- Safetyline Minnesota Style vest

3- Chami Design Washington Style vest

4- Iron Horse Texas Style vest

5- IDOT Standard vest

6- IDOT LED vest

7. CONCLUSION

7.1 Summary and Conclusion

Many state agencies including IDOT are shifting towards nighttime construction. Nighttime construction mitigates the impact of construction operations on the traveling public, shortens the duration of construction operations and reduces interruptions to construction activities. But nighttime construction operations may be more hazardous for both drivers and construction personnel because of visibility problems at nighttime.

In this research study, the effects of nighttime construction conditions on worker safety were investigated by studying the statistics provided by the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS) and by seeking the experiences of DOT personnel across the nation; the types of high-visibility garments used by construction workers and IDOT personnel on Illinois highway projects as well as those used in other states were surveyed; and finally, the performance of six high-visibility vests were investigated not in a laboratory setting but on actual construction/maintenance sites that involved different lighting, traffic, and weather conditions. Potential users' perceptions concerning the performance of these six safety vests were also collected by mean of a questionnaire survey. The study shows the following:

- According to data on fatal accidents in highway work zones in the State of Illinois in the five-year study period of 1996-2001, safety does not seem to be any more of a problem in nighttime than in daytime works. The inclusion of a weather parameter into the analysis does not change this finding. The same attention should therefore be given to safety both in nighttime and daytime works. This finding is supported by the responses obtained in a survey of IDOT operations personnel, resident engineers and contractors and by personnel in departments of transportation in other states.

- According to the findings of surveys administered to IDOT operations personnel, resident engineers and contractors and to departments of transportation of other states than Illinois involved in nighttime construction operations within the past 5 years, “worker struck by through traffic inside the work area” and “worker struck by construction equipment inside the work area” are the two most common accident types. The main reason for nighttime accidents is perceived to be the condition of vehicle operators with poor lighting condition being the second most common reason. It appears that investigating visibility issues associated with safety garments at nighttime is justified.

- Consolidated results obtained from the field tests that measured mean luminance values of the front faces and sides of six commonly used safety vests and the perception of potential users of these vests indicated that the Head Lite Roadstar 200 vest and the Safetyline Minnesota Style vest are significantly superior to the other four vests. It is not surprising that these two safety vests tied for first rank as the fabric of the vests and the amount of retroreflective material on each vest are nearly the same. There are two minor differences between the Head Lite Roadstar 200 and

Safetyline Minnesota Style vests: their configuration (zipper and pockets) is different; and the sides of the Safetyline Minnesota Style vest is made of solid fabric, whereas the sides of the Head Lite Roadstar 200 vest is mesh fabric.

- The information obtained in the surveys of Illinois respondents (operations personnel, resident engineers, and contractors) and other DOT agencies, are to a great extent, similar. The only difference appears to be in the respondents' opinions concerning the nighttime performance of currently used safety vests. Illinois respondents are less satisfied with the nighttime performance of the safety garments currently in use on their work areas than respondents from other DOTs. It appears therefore that IDOT's decision to change the specifications and make the Head Lite Roadstar 200 vest mandatory in highway construction/maintenance works performed in Illinois is justified.

7.2 Recommendations for Future Research

The results of the surveys administered to IDOT operations personnel, resident engineers and contractors and to departments of transportation of other states than Illinois, show that construction equipment inside the work area cause as many accidents as through traffic. Research should be conducted to investigate this type of accident in the work areas.

It should also be noted that the six safety vests were tested in only four work areas that had different traffic volume, setting (urban vs. rural), weather (clear and rainy), and lighting conditions. A more rigorous statistical analysis should be possible if the number of test sites were increased.

REFERENCES

Bibliography

3M ® (2000). Retrieved Sep 31, 2001 from 3M Transportation Safety Product Center Database on the World Wide Web: http://www.mmm.com/tcm/wn/story7.html.

AASHTO (1998). *"AASHTO strategic highway safety plan: a compressive plan to substantially reduce vehicle-related fatalities and injuries on the nation's highways."* American Association of State Highway and Transportation Officials, Washington D.C. Part 4, pp. 51-52.

Abd Elrahman, O. and Perry, R. J. (December 1994). *"Nighttime construction operations"* Engineering Research and Development Bureau, New York State Department of Transportation, Albany, NY.

Anders, R. L. (August 2000). *"On-Road Investigation of Fluorescent Sign Colors to Improve Conspicuity."* Virginia Polytechnic and State Institute, Blacksburg, VA.

ANSI/ISEA 107-1999. (June 1999). *"American National Standard for High-Visibility Safety Apparel."* International Safety Equipment Association, Arlington, VA.

AS/NZS 1906.4:1997. (1997). *"Australian/New Zealand Standard: Retroreflective materials and devices for road traffic control purposes.- Part 4: High-Visibility materials for safety garments."* Jointly published by Standards Australia, Homebush, Australia; and Standards New Zealand, Welling, New Zealand.

AS/NZS 4602:1999. (1999). *"Australian/New Zealand Standard: High-Visibility safety garments."* Jointly published by Standards Australia, Homebush, Australia; and Standards New Zealand, Welling, New Zealand.

ASTM, Designation: F 923-00. (February 2001). *"Standard Guide to Properties of High Visibility Materials Used to Improve Individual Safety"*

Birch, S. E. (December 1998). *"The Effects of Nighttime Work on Highway Construction Site Safety in Arizona."* Arizona State University, AZ.

Brackett, Q. and Stuart, M. (October 1982). *"High Visibility Garments for Use in Work Zones."* Research Report 262-4. Texas Transportation Institute, TX.

Brackett, Q., Stuart, M., Carnahan, T. and Stealy, S. (October 1985). *"High Visibility Garments for Use in Work Zones."* Research Report 330-1. Texas Transportation Institute, TX.

Bradley, J. C. (2001). *"Columns – Workplace Solutions – Can you clarify the conspicuity?"* Safety & Health, 163(1), 66.

BS EN 471. (1994). *"Specification for High-Visibility Warning Clothing."* British Standards Institute, London, UK.

Ellis, R. D, Jr. and Herbsman, Z. (1996). *"Illumination Guideline for Nighttime Highway Work"* NCHRP Report 5-13, Transportation Research Board, National Research Council, Washington, DC.

Ellis, R. D. Jr. and Amos, S. J. (1995). *"Development of Work Zone Lighting Standards for Nighttime Highway Work."* Transportation Research Record, 1529, 35-42.

Ellis, R. D. Jr. and Kumar, A. (1993). *"Influence of Nighttime Operations on Construction Cost and Productivity."* Transportation Research Record, 1389, 31-37.

Ha, T. J. and Z. A. Nemeth (1995). *"Detailed study of accident experience in construction and maintenance zones."* Transportation Research Record, 1509. National Research Council. 38-45.

Hancher, D. E. and Taylor, T. R. B. (2001). *"Nighttime Construction Issues."* Transportation Research Board (TRB) 80th Annual Meeting, 7-11.

Anonymous. (November 1997). *"Assessing the visibility of clothing."* High Performance Textiles, Lausanne, Switzerland, 163, 6.

Hinze J. W. and Carlisle, D. (February 1990). *"An Evaluation of the important Variables in Nighttime Construction."* Transportation Northwest, Dept. of Civil Engineering, University of Washington, Seattle, WA.

http://international.3m.com/intl/CA/english/centres/safety/personal_safety/. Retrieved September 31, 2001 from Personal Safety Products site of 3M Safety and Security System Division, Issue 3, Winter 2000.

http://ops.fhwa.dot.gov/wz/wzguidbk/Documents/hp-ia1.htm. Retrieved September 31, 2001 from FHWA Database, Barb Mallon, Safety Coordinator, Iowa DOT, Tel: 515- 239-1594.

http://ops.fhwa.dot.gov/wz/wzguidbk/Documents/hp-mn11.htm. Retrieved September 31, 2001 from FHWA Database, Bill Servatius, MN/DOT Construction Programs Coordinator, Tel: 651- 296-2721.

http://www.dot.ca.gov/hq/traffops/signtech/signdel/flagging/flagging.htm. Retrieved September 31, 2001 from Ca/DOT Website, *"Flagging Instruction Handbook."* April, 1999.

http://www.dot.state.ia.us/morgue/06239704.htm. Retrieved September 31, 2001 from Iowa DOT Database, Contact: Fred Walker, Tel: 515-239-1646. *"DOT testing new safety clothing for road workers - The bright way to save lives."* June 23, 1997.

http://www.headlitescorp.com/Page10.html. Retrieved August 30, 2001 from HeadLights Corporation website. *"Reflective Material; How much is Enough?"*

http://www-fars.nhtsa.dot.gov/. Retrieved October 10, 2001 from VDOT Database, *"Fatality Analysis Reporting Syatem (FARS) Web-Based Encyclopedia"*.

Isler, R., Kirk, P., Bradford S. J. and Parker, R. J. (1997). *"Testing the relative conspicuity of Safety garments for New Zealand forestry workers."* Applied Ergonomics, 28(5-6), 323.

Janson, M. H. and Smith, G. M. (1976). *"Reflectorized Flagman Vests."* Research Report R- 1021. Michigan Department of State Highways and Transportation, Lansing, MI.

Janson, M. H. and Smith, G. M. (July 1973). *"Reflectorization of Fluorescent Flagman Vests."* Research Report R-873. Michigan Department of State Highways and Transportation, Lansing, MI.

Layfield, R. G. (1988). *"Nightwork comparison."* Memorandum/report by resident engineer. Florida Department of Transportation, Tallahassee, FL.

Lesley, G. (April 1995). *"Enhancing the Daytime Conspicuity of Pedestrians Through the Usage of Fluorescent Materials."* Color Research and Applications, 20(2), 117-123.

Levitt, R. E. and Samelson, N. M. (1993). *"Construction Safety Management"*. Second edition, Wiley, New York, NY.

Michigan Manual of Uniform Traffic Control Devices. (1994, revised in 2001). Part 6 – Construction and Maintenance. Michigan State Advisory Committee, Michigan Department of Transportation, Lansing, MI.

Michon, J. A., Eernst, J. T. and Koutstaal. G. A. (1969). *"Safety Clothing for Human Traffic Obstacles."* Ergonomics, 12(1), 61-70.

MIL-S-43753C. (August 1998). *"MIL-S-43753C: Military Specification Safety Clothing, High Visibility."* U.S Army Natick Research, Development and Engineering Center, Natick, MA.

MUTCD 2000 - Manual of Uniform Traffic Control Devices. (1993, revised in 2000). Millennium edition, Part 6 – Work Zones, Chapter 6D – Pedestrian and Worker Safety. FHWA, U.S. DOT, Washington, DC.

Pal, R. and Sinha, K. C. (1996). *"Evaluation of Crossover and Partial Lane Closure Strategies for Interstate Work Zones in Indiana."* Transportation Research Record, TRB, 1529, 10-18.

Pratt, S. G., Fosbroke D. E. and Marsh, S. M. (April 2001). *"Building Safer Highway Work Zones: Measures to Prevent Worker Injuries From Vehicles and Equipment."* Department of Health and Human Services, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, Cincinnati, OH (http://www.cdc.gov/niosh/pdfs/01-128.pdf).

Report 98–S-50. (April 26, 1999). *"Department of Transportation, Nighttime construction program."* State of New York, Office of the State Comptroller - Division of Management Audit and State Financial Service, Albany, NY. http://nysosc3.osc.state.ny.us/audits/allaudits/093099/98s50.htm http://nysosc3.osc.state.ny.us/audits/audits/9899/98s50.pdf

"Safety Vest Task Force." (December 1999). Washington State Department of Transportation, Seattle, WA.

Shepard, F. D. and Cottrell, B. H., Jr. (1985). *"Benefits and Safety Impact of Night Work Zone Activities."* Virginia Highway and Transportation Research Council, Springfield, VA .

Turner, J. D., Simmons, C. J. and Graham, J. R. *"High-Visibility Clothing for Daytime Use in Work Zones."* Transportation Research Record, TRB, 1585, 1-8.

www.wsdot.wa.gov/fossc/cons/contaa/bulletin/wkzonebulaug.pdf. Retrieved October 30, 2001 from WsDOT Database, *"New emergency rules for flaggers."*

Wang, J., Hughes, W. E., Council, F. M. and Paniati, J. F. (1996). *"Investigation of Highway Work Zone Crashes: What We Know and What We Don't Know."* Transportation Research Record, TRB, 1529, 54-62.

Additional Bibliography

A Policy on Geometric Design of Highways and Streets. (1984). AASHTO, American Association of State Highway and Transportation Officials

Arens, J. B., Saremi, A. R. and Simmons, C. J. (1991). *"Color Recognition of Retroreflective Traffic Signs Under Various Lighting Conditions."* *Public Roads*, 55(1), 1-7.

Burns, D. M. and Johnson, N. L. (1997). *"Characterizing the visual performance of fluorescent retro-reflective signing materials using the fluorescent luminance factor."* In

Proceedings of the 8th Congress of the International Colors Association, Vol. 1, pp. 359-362, Kyoto, Japan.

Burns D. M. and Johnson, N. L. (1999). *"Methodology of fluorescent retroreflective materials and its relationship to their daytime visibility."* Analytica Chimica Acta, 380(2), 211.

Cole, B. and Hughes, P. (1984). *"A field trial of attention and search conspicuity."* Human Factors, 26(3), 299-313.

Cornsweet, T. N. (1974). *"Visual Perception."* Academic Press, Inc., New York, NY.

Crant, P. S. and Townsend, G. B. (1961). *"Colour Television"* Iliffe Books LTD, London, UK

Freund, J. E., Livermore, P. E. and Miller, I. (1962). *"Manual of Experimental Statistics"* Prentice-Hall Inc., Englewood Cliffs, NJ

Hanson, D. R. and Dickson, A. D. (1963). *"Significant Visual Properties of Some Fluorescent Pigments."* Highway Research Record, 49, HRB, National Research Council, Washington, DC.

Jacobs, G. F., Hedblom, T. P., Bradshaw, T. I., Hodson, N. A. and Austin, R. L. *"Detectability of Pavement Markings Under Stationary and Dynamic Conditions as a Function of Retroreflective Brightness."* Transportation Research Record, TRB, 1495, 68-76.

Jenkins, S. E. and Cole, B. L. (1986). *"Daytime conspicuity of road traffic control devices."* Transportation Research Record, TRB, 1093, 74-80.

Jenssen, G. D. and Brekke, B. (1997). *"A comprehensive evaluation of fluorescent retroreflective traffic control devices based on human factors and traffic engineering data."* 7th International Vision in Vehicles Conference, Marseilles, France

Jenssen, G. D. and Brekke, B. (1998). *"A Study of the Visibility and Effectiveness of Fluorescent Retroreflective Traffic Control Signing in Work Zone Applications."* (Report No. VTI konferens 9A part 6). Swedish National Road and Transport Research Institute, S-581 95 Linkoping, Sweden

Johnson, N. L. and Leone F. C. (1964). *"Statistical and Experimental Design in Engineering and the Physical Sciences"* John Wiley & Sons Inc., New York

Maxwell, A. E. (1961). *"Analysing Qualitative Data"* John Wiley & Sons Inc, New York

Mortimer, R. G. and Fell, J. C. (1989). *"Older drivers: their night fatal crash involvement and risk."* *Accident Analysis and Prevention*, 21(3), 273-282, National Research Council, Transportation Research Board.

Nam, D., Lee, J., Dunston, P. and Mannering, F. Paper No. 99-0072.,*"Analysis of the Impacts of Freeway Reconstruction Closures in Urban Area."* Transportation Research Record, TRB, 1654, 161-170.

Olson, P. L. and Bernstein, A. (1979). *"The nighttime legibility of highway signs as a function of their luminance characteristics."* Human Factors, 21(2), 145-160.

Olzak, Owsley, C. E. and Sloan, M. E. (1987). *"Contrast sensitivity, acuity, and the perception of "real-world" targets."* British Journal of Ophthalmology, 71, 791-796.

Price, D. A. (1986). Report No.CDH-DTP-R-86-6, *"Nighttime Paving."* Colorado Department of Highways, Denver, CO.

Senter, R. J. (1969). *"Analysis of Data"* Scott, Foresman and Company, Glenview, IL

Shibuya, S., Nakatsuji, T., Fujiwara, T. and Matsuyama, E. *"Traffic Control at Flagger-Operated Work Zones on Two-Lane Roads."* Transportation Research Record, TRB, 1529, 3-9.

Smith, H. J. (1980). *"Daylight Fluorescent Color - The Color That Shouts."* Transportation Research Circular 229, TRB, National Research Council, Washington, D.C., 15-16.

Spiegel, M. R. (1961). *"Scahum's Outline of Theory and Problems of Statistics"* McGraw-Hill Inc., New York

Sullivan, E. C. (1989). *"Accident rates during nighttime construction."* Research Report UCB-ITS-RR-89-11, Institute of Transportation Studies, University of California at Berkeley, CA.

Ullman, G. L. *"Queuing and Natural Diversion at Short term Freeway Work Zone lane Closures."* Transportation Research Record, TRB, 1529, 19-26.

Zwahlen, H. T. and Schnell, T. (1997). *"Visual detection and recognition of fluorescent color targets versus non-fluorescent color targets as a function of peripheral viewing angle and target size."* Transportation Research Record, TRB, 1605, 28-40.

Zwahlen, H. T., Li, Q. and Yu, J. *"Luminance Measurements of Retroreflective Warnign Signs at Night Using the CalCalc System."* Transportation Research Record, TRB, 1316, 31-38.

Zwahlen, H. T. and Vel, U. D. (1994). *"Conspicuity in Terms of Peripheral Visual Detection and Recognition of Fluorescent Color Targets Versus Nonfluorescent Color Targets Against Different Backgrounds in Daytime."* Transportation Research Record, TRB, 1456, 125-138.

APPENDIX A

LIST OF SAFETY GARMENT MANUFACTURERS AND DISTRIBUTORS

MANUFACTURERS AND DISTRIBUTORS OF SAFETY GARMENTS

Name of The Company	Web Address	***E-mail***	**Telephone**	**Contact Person**	**Location of the headquarter**
Brenton Safety Inc.	www.brentonsafety.com	sales@brentonsafety.com	800-733-4333	Maria F. Smith	San Francisco, CA
Carolina Safety Sports	www.cssport.com	info@cssport.com	336-474-8000	Philip Young	North Carolina
Columbia Gorge Center	www.cgc-direct.com	cgc@gorge.net	866-424-2669	Sam Windsheimer	OR
CTC Accessories Inc.	www.ctcaccessories.com	info@ctcaccessories.com	360-802-4738	Brad Golphenee	WA
Doublet Manufacturing Inc.	www.doublet.com	doublet@doublet.com	800-624-4198	Micheal Medici	San Francisco, CA
Conney Safety Products	www.conney.com	tvaughan@conney.com	888-356-9100	Tom Vaughan	Madison, WI
Estex Manufacturing Co. Inc.	www.estexmfg.com	sales@estexmfg.com	770-964-3322	Brent Wilkes	Georgia
Harris Industries Inc.	www.harrisind.com	info@harrisind.com	714-898-8048	Bob Saylor	CA
Harris Manufacturing	www.harrismanufacturingco.com	Dharris765@aol.com	609-393-3717	David Harris	NJ
Head Lites Corp.	www.headlitescorp.com		800-777-5630	David Saatzer	MN
I. Spiewak & Sons Inc.	www.spiewak.com	uniformsupport@spiewak.com	800-223-6850	Sol Jacobs	New York, NY

Industries for the Blind of New York State	www.ibnys.com	custserv@ibnys.org	518-456-8671	Larry Clever	Albany, NY
Infinity Products Inc.	www.infinityproducts.com	iproducts@indy.rr.com	317-272-3435	Linda Chambers	IN
Iron Horse Safety Specialties	www.reflectivefabric.com	sales@reflectivefabric.com	800-323-5889	David Harvey	Dallas, TX
MJN Enterprises Inc.	www.safety-vest.com	orders@safety-vest.com	417-967-1654	Mike Hoth	MO
Mifflin Valley Reflective Apparel	www.mifflinvalley.com	info@mifflinvalley.com	888-775-5209	Mike Gallen	PA
M. L. Kishigo Manufacturing Co.	www.mlkishigo.com	info@mlkishigo.com	800-338-9480	Kaye Clark	Santa Ana, CA
Pacific Safety Supply Inc.	www.pacsaf.com	sales@pacsaf.com	800-333-5641	Brad Dye	Oregon
Nasco Industries	www.nascoinc.com	info@nascoinc.com	800-767-4288	Jeff Smith	IN
Radiator Specialty	www.gunk.com	safety@gunk.com	704-377-6555	John Gonzalez	Charlotte, NC
Rehab Plus Safety	www.rehabplus.com	sharris@rehabplus.com	806-791-2288	Pat Cox	TX
River City Protective Wear	www.protectivewear.com	RKnox@protectivewear.com	901-794-3321	Rick Knox	Memphis, TN
R&B Fabrications Inc.	www.rbfab.com	info@rbfab.com	800-553-1911	Don Eakins	OH
Safe	www.safereflections.com	reflectivesales@safereflections.com	800-773-8199	Katie	Saint Paul,

Reflections Inc.				Mahoney	MN
American All Safe	www.americanallsafe.com	info@americanallsafe.com	800-231-1332	Sharon Whitfield	NY
Serving & Materials	www.servmat.com	servmat@jacksonproducts.com	800-216-2969	Jackie Reed	MO
TTB Products Inc.	www.ttbproducts.com	info@ttbproducts.com	888-970-7192	Bob Wielenga	CA
Vantech Safety Line	www.safetyline.co m	vantech@safetyline.com	800-872-3359	Liz Vega	CA
Vogue Safety Flag	www.safetyflag.com	mail@safetyflag.com	800-556-7584	Norm Benson	Rhode Island
ERB Industries Inc.	www.e-erb.com	customerservice@e-erb.com	800-800-6522		GA
La Crosse Rainfair Safety Products	www.lacrosserainfair.com	general@lacrosserainfair.com	800-557-7246	Julianne Hlavka	WI
Seton Identification and Safety Experts	www.seton.com	Custsvc_SetonUS@seton.com	800-571-2596		CT
Direct Safety	www.directsafety.com	Customer.Service@directsafety.com	800-528-7405	Tom Reine	Arizona
Dritex	www.dritex.com	rainman@dritex.com	847-437-2141		IL

APPENDIX B

PICTURES OF VESTS TESTED

PICTURES OF THE VESTS USED IN FIELD TESTS

IODT Standard Vest

IDOT LED Vest

Head Lite Roadstar 200 Vest

Iron Horse Texas Style Vest

Chami Design Washington Style Vest

Safetyline Minnesota Style Vest

APPENDIX C

IDOT SURVEY INSTRUMENT

ILLINOIS INSTITUTE OF TECHNOLOGY
Transforming Lives.Inventing the Future.www.iit.edu

DEPARTMENT OF CIVIL AND ARCHITECTURAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT PROGRAM

Worker Safety Issues in Nighttime Highway Construction in Illinois

Questionnaire Survey

Name: ……………………………………..

Position: ……………………………………

Organization: ………………………………

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

Do you think safety is more of a problem during nighttime or during daytime on Illinois highway construction/rehabilitation/maintenance work areas?

❑ Nighttime ❑ Daytime ❑ No difference

How would you characterize the typical nighttime accident involving through traffic or construction equipment in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

Type of nighttime accident in work areas	Type of work area	
	Construction/ Rehabilitation	Maintenance
Worker struck by through traffic inside the work area		
Worker struck by through traffic outside the work area		
Worker struck by construction equipment inside the work area		
Worker struck by construction equipment outside the work area		
Others (Specify the type ________________________________)		

How severe was the worst worker-related nighttime accident caused by **vehicles driving through** any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work areas you are familiar with)

Type of highway work area	Very severe (involves fatality)	Severe (involves injury but no fatality)	Less severe (only property damage)
Construction/ Rehabilitation			
Maintenance			

How severe was the worst worker-related nighttime accident caused by **construction equipment** operating on any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very severe (involves fatality)	Severe (involves injury but no fatality)	Not severe (only property damage)
Construction/ Rehabilitation			
Maintenance			

How frequent (on the average) were the worker-related nighttime accidents caused by **vehicles driving through** any of your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very frequent (more than 1 accident/project)	Frequent (1 accident/project)	Less frequent (less than1 accident/project)
Construction/ Rehabilitation			
Maintenance			

How frequent (on the average) were the worker-related nighttime accidents caused by **construction equipment** operating on your IDOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very frequent (more than 1 accident/project)	Frequent (1 accident/project)	Not frequent (less than1 accident/project)
Construction/ Rehabilitation			
Maintenance			

What are the major factors contributing to worker-related nighttime accidents in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

Factors contributing to nighttime accidents in work areas	Type of work area	
	Construction/ Rehabilitation	Maintenance
Poor lighting conditions		
Unfavorable weather conditions		
Poor performance of safety garment		
Workers not wearing safety garments		
Condition of vehicle operator (sleepy, DUI, age, etc.)		
Others (Specify:________________________________)		

II. Evaluation of existing safety garments

Describe the safety garments that are currently being used at nighttime on your highway work areas:

Manufacturer: ………………. ……… Model: ………………………….
Color of vest: ………………..……… Description: ……………………
Color of retro-reflective material: …………………………………………….

From which source are you providing safety garments for your site?

Please specify (____)

How would you characterize the **nighttime performance** of the safety garments currently in use on your work areas? (Refer to Table 1 for definitions)

Condition		Performance Factors	Excellent	Very good	OK	Needs improvement	Not acceptable
Background	Urban Area	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
	Rural Area	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
Weather	Dry	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
	Wet	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
Others		Wearability	5	4	3	2	1
		Durability	5	4	3	2	1
		Comfort	5	4	3	2	1
		Configuration	5	4	3	2	1
		Perceived effectiveness	5	4	3	2	1

Table 1. Performance factors of safety garments (Modified from ASTM; Designation: F923-00, 3M)

Factors	Definitions
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
Conspicuity	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
Reflectivity	The measure of brightness of retro-reflective material used in workers' garments making the garments more visible at nighttime.
Wearability	The qualities of the garments that provide good fit, up-to-date look, likable colors and shapes, and weather protection.
Durability	The ability of garments to retain their original characteristics after many wears and washes.
Comfort	Garments' features that prevent the worker from perspiring, being cold or hot, getting wet, or limiting their movements.
Configuration	The exterior and interior design of safety garments such as size, number and function of pockets, use of buttons/zippers/Velcro.
Perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

III. Safety garment design factors and features

What is the importance of the following design factors in the use of retro-reflective materials to enhance the nighttime visibility of your safety garments? (Refer to Table 2 for definitions).

Design Factors	Extremely important	Very important	Important	Somewhat important	Not very important
Definability of the human form	5	4	3	2	1
Locations of retro-reflective materials on the garment	5	4	3	2	1
360° visibility	5	4	3	2	1
Amount of retro-reflective material	5	4	3	2	1
Brightness of the retro-reflective material	5	4	3	2	1
Acceptable loss of color and brightness after repeated wear and washing	5	4	3	2	1

Table 2. Design Factors that Enhance Nighttime Visibility (Modified from 3M)

Factors	Definitions
Definability of the human form	The retro-reflective material on a garment being the only component visible to a driver at nighttime, it should make the driver recognize the object as a worker.
Location of retro-reflective materials on the garment	The appropriate location of the retro-reflective material on a safety garment should enhance its visibility by drawing the human eye to the moving object as the worker moves.
360° visibility	The human form should be detected from all directions regardless of the human form, movement, location, and situation.
Amount of retro-reflective material	The amount of retro-reflective material applied should increase a worker's visibility.
Brightness of the retro-reflective material	The brightness of retro-reflective material should increase a worker's visibility.
Acceptable loss of color and brightness after repeated wear and washing	The garment should be resistant to wear and washing such that the garment maintains its color and brightness longer.

How important do you consider the following features of safety garments used in nighttime construction? (See Table 1 for definitions)

Safety garment features	Extremely important	Very important	Important	Somewhat important	Not very important
Visibility	5	4	3	2	1
Conspicuity	5	4	3	2	1
Reflectivity	5	4	3	2	1
Wearability	5	4	3	2	1
Durability	5	4	3	2	1
Comfort	5	4	3	2	1
Configuration	5	4	3	2	1
Worker's confidence that he/she will be visible	5	4	3	2	1

What is the impact of **extremely good nighttime visibility** of workers on the following project factors?

Project Factors	Positively impacted		Not changed		Negatively impacted
Project cost	5	4	3	2	1
Site productivity	5	4	3	2	1
Project duration	5	4	3	2	1
Circulation patterns within the work area	5	4	3	2	1
Circulation patterns in case of an emergency	5	4	3	2	1
Worker job satisfaction	5	4	3	2	1
Worker motivation	5	4	3	2	1
Labor relations	5	4	3	2	1

Please rate the importance of the following criteria that should help select a particular type of safety garment. We are seeking **your opinion** rather than the current practice in your organization.

Selection criteria	Extremely important	Very important	Important	Somewhat important	Not very important
Acceptability by worker	5	4	3	2	1
Effect on the severity and frequency of accidents	5	4	3	2	1
Objective visibility measurements	5	4	3	2	1
Cost implications	5	4	3	2	1
Ease of manufacturing	5	4	3	2	1

**** Thanks for your time and effort in filling out this questionnaire****

Please return by email
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You can also return it by regular mail
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Chicago, IL 60616

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APPENDX D

OTHER DOTs SURVEY INSTRUMENT

ILLINOIS INSTITUTE OF TECHNOLOGY
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DEPARTMENT OF CIVIL AND ARCHITECTURAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT PROGRAM

Worker Safety Issues in Nighttime Highway Construction

Questionnaire Survey

Name: ……………………………………..

Position: ……………………………………

Organization: ………………………………

I. Type, severity, and frequency of nighttime accidents involving workers in work areas

Do you think safety is more of a problem during nighttime or during daytime on highway construction/rehabilitation/maintenance work areas?

❑ Nighttime ❑ Daytime ❑ No difference

How would you characterize the typical nighttime accident involving through traffic or construction equipment in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

Type of nighttime accident in work areas	Type of work area	
	Construction/ Rehabilitation	Maintenance
Worker struck by through traffic inside the work area		
Worker struck by through traffic outside the work area		
Worker struck by construction equipment inside the work area		
Worker struck by construction equipment outside the work area		
Others (Specify the type ______________________________)		

How severe was the worst worker-related nighttime accident caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work areas you are familiar with)

Type of highway work area	Very severe (involves fatality)	Severe (involves injury but no fatality)	Less severe (only property damage)
Construction/ Rehabilitation			
Maintenance			

How severe was the worst worker-related nighttime accident caused by **construction equipment** operating on any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very severe (involves fatality)	Severe (involves injury but no fatality)	Not severe (only property damage)
Construction/ Rehabilitation			
Maintenance			

How frequent (on the average) were the worker-related nighttime accidents caused by **vehicles driving through** any of your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very frequent (more than 1 accident/project)	Frequent (1 accident/project)	Less frequent (less than1 accident/project)
Construction/ Rehabilitation			
Maintenance			

How frequent (on the average) were the worker-related nighttime accidents caused by **construction equipment** operating on your DOT work areas in the last 5 years? (Answer only for the type(s) of work area you are familiar with)

Type of highway work area	Very frequent (more than 1 accident/project)	Frequent (1 accident/project)	Not frequent (less than1 accident/project)
Construction/ Rehabilitation			
Maintenance			

What are the major factors contributing to worker-related nighttime accidents in work areas? (Mark as many as appropriate but only for the type(s) of work area you are familiar with)

Factors contributing to nighttime accidents in work areas	Type of work area	
	Construction/ Rehabilitation	Maintenance
Poor lighting conditions		
Unfavorable weather conditions		
Poor performance of safety garment		
Workers not wearing safety garments		
Condition of vehicle operator (sleepy, DUI, age, etc.)		
Others (Specify:________________________________)		

II. Evaluation of existing safety garments

Describe the safety garments that are currently being used at nighttime on your highway work areas:

Manufacturer: ………………. ……… Model: ………………………….
Color of vest: ………………..……… Description: ……………………
Color of retro-reflective material: ……………………………………….

From which source are you providing safety garments for your site?

Please specify (____)

How would you characterize the **nighttime performance** of the safety garments currently in use on your work areas? (Refer to Table 1 for definitions)

Condition		Performance Factors	Excellent	Very good	OK	Needs improvement	Not acceptable
Background	Urban Area	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
	Rural Area	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
Weather	Dry	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
	Wet	Visibility	5	4	3	2	1
		Conspicuity	5	4	3	2	1
		Reflectivity	5	4	3	2	1
Others		Wearability	5	4	3	2	1
		Durability	5	4	3	2	1
		Comfort	5	4	3	2	1
		Configuration	5	4	3	2	1
		Perceived effectiveness	5	4	3	2	1

Table 1. Performance factors of safety garments (Modified from ASTM; Designation: F923-00, 3M)

Factors	Definitions
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
Conspicuity	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
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Comfort	Garments' features that prevent the worker from perspiring, being cold or hot, getting wet, or limiting their movements.
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Perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

III. Safety garment design factors and features

What is the importance of the following design factors in the use of retro-reflective materials to enhance the nighttime visibility of your safety garments? (Refer to Table 2 for definitions).

Design Factors	Extremely important	Very important	Important	Somewhat important	Not very important
Definability of the human form	5	4	3	2	1
Locations of retro-reflective materials on the garment	5	4	3	2	1
360° visibility	5	4	3	2	1
Amount of retro-reflective material	5	4	3	2	1
Brightness of the retro-reflective material	5	4	3	2	1
Acceptable loss of color and brightness after repeated wear and washing	5	4	3	2	1

Table 2. Design Factors that Enhance Nighttime Visibility (Modified from 3M)

Factors	Definitions
Definability of the human form	The retro-reflective material on a garment being the only component visible to a driver at nighttime, it should make the driver recognize the object as a worker.
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Brightness of the retro-reflective material	The brightness of retro-reflective material should increase a worker's visibility.
Acceptable loss of color and brightness after repeated wear and washing	The garment should be resistant to wear and washing such that the garment maintains its color and brightness longer.

How important do you consider the following features of safety garments used in nighttime construction? (See Table 1 for definitions)

Safety garment features	Extremely important	Very important	Important	Somewhat important	Not very important
Visibility	5	4	3	2	1
Conspicuity	5	4	3	2	1
Reflectivity	5	4	3	2	1
Wearability	5	4	3	2	1
Durability	5	4	3	2	1
Comfort	5	4	3	2	1
Configuration	5	4	3	2	1
Worker's confidence that he/she will be visible	5	4	3	2	1

What is the impact of **extremely good nighttime visibility** of workers on the following project factors?

Project Factors	Positively impacted		Not changed		Negatively impacted
Project cost	5	4	3	2	1
Site productivity	5	4	3	2	1
Project duration	5	4	3	2	1
Circulation patterns within the work area	5	4	3	2	1
Circulation patterns in case of an emergency	5	4	3	2	1
Worker job satisfaction	5	4	3	2	1
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Please rate the importance of the following criteria that should help select a particular type of safety garment. We are seeking **your opinion** rather than the current practice in your organization.

Selection criteria	Extremely important	Very important	Important	Somewhat important	Not very important
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Effect on the severity and frequency of accidents	5	4	3	2	1
Objective visibility measurements	5	4	3	2	1
Cost implications	5	4	3	2	1
Ease of manufacturing	5	4	3	2	1

**** Thanks for your time and effort in filling out this questionnaire****

Please return by email
arditi@iit.edu

You can also return it by regular mail
Professor David Arditi
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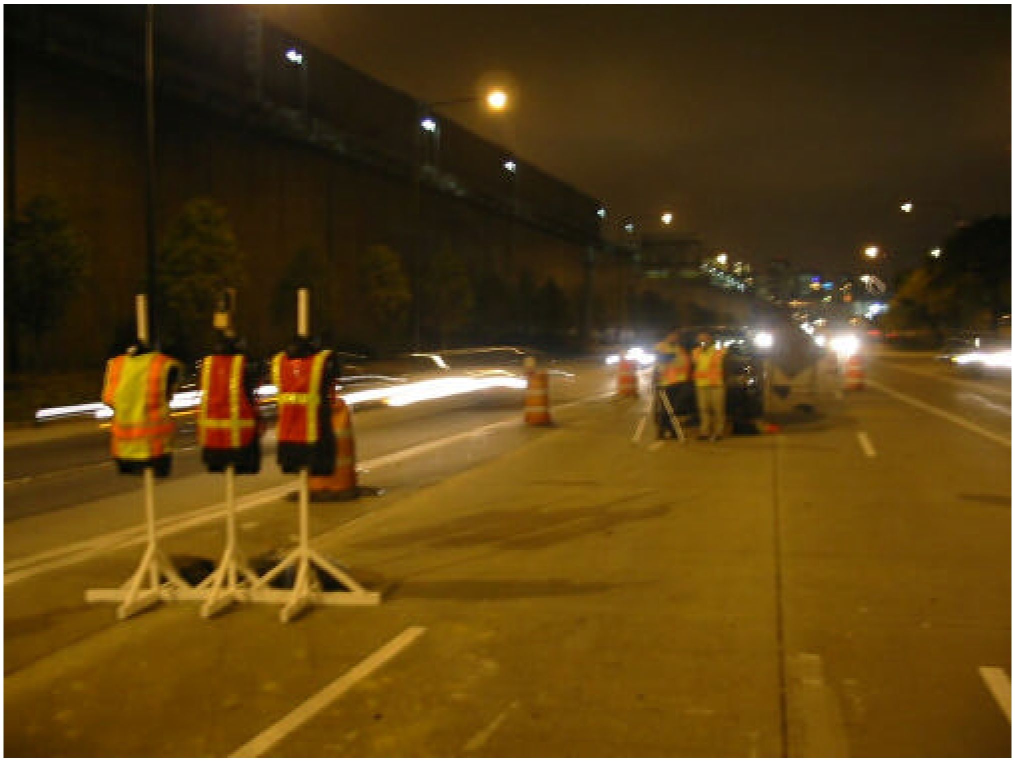
(312) 567-3519

APPENDIX E

PHOTOGRAPHS FROM FIELD TESTS

PHOTOGRAPHS FROM FIELD TESTS

Site 1



Site 2

Site 3

APPENDIX F

SITE SURVEY INSTRUMENT

Please rate the safety garments' design factors and features.

Vest no	Design Factors & features	Excellent	Very good	OK	Needs improvement	Not acceptable
I	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					
II	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					
III	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					

Vest no	Design Factors & features	Excellent	Very good	OK	Needs improvement	Not acceptable
IV	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					
V	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					
VI	360° visibility					
	Conspicuity against background					
	Brightness of retro-reflective material					
	Configuration (Pockets, zipper, etc.)					
	Overall perceived effectiveness					

Factors	**Definition**
Visibility	Transmission of light waves from workers' garments to the eye of the driver of through traffic or equipment operators.
360° visibility	The human form should be detected from all directions regardless of the human form, movement, location and situation.
Conspicuity against background	The characteristics that a worker's garment will come to the attention of a driver or operator by means of sharp contrast with the background.
Brightness of retro-reflective material	Brightness of retro-reflective material should increase a worker's visibility.
Configuration	The exterior and interior design of safety garments such as size, number and function of pockets, use of buttons/zippers/Velcro.
Overall perceived effectiveness	The worker's confidence that the garment he/she is wearing is visible to drivers and operators and that he/she can move around with no fear of being struck by a vehicle.

APPENDIX G

DESCRIPTIVE STATISTICS

MEAN VALUES FOR FRONT FACES AND SIDES ON FOUR TEST SITES

Front Faces / First Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	90.653	266	2.813	85.97	102.69
	Middle	88.080	251	3.813	73.44	96.10
	Right	83.317	262	4.376	69.44	94.80
	Total	87.357	779	4.814	69.44	102.69
IDOT LED Vest	Left	92.680	251	4.572	77.52	104.35
	Middle	98.742	262	4.819	84.47	113.73
	Right	90.850	266	3.796	84.56	116.89
	Total	94.094	779	5.562	77.52	116.89
Head Lite Roadstar 200	Left	130.152	262	6.483	114.61	151.08
	Middle	137.246	266	5.991	128.43	163.42
	Right	123.331	251	6.311	106.65	141.41
	Total	130.377	779	8.443	106.65	163.42
Iron Horse Texas Style	Left	105.538	252	6.809	85.99	123.28
	Middle	107.195	255	5.663	87.46	124.16
	Right	96.599	246	7.261	82.39	123.92
	Total	103.179	753	8.061	82.39	124.16
Chami Design Washington Style	Left	126.122	246	7.682	111.53	155.71
	Middle	125.225	252	6.279	107.33	143.61
	Right	122.459	255	5.427	104.75	138.02
	Total	124.581	753	6.692	104.75	155.71
Safetyline Minnesota Style	Left	127.923	255	7.020	108.14	151.87
	Middle	127.145	246	8.773	110.91	163.39
	Right	118.631	252	6.957	99.59	139.65
	Total	124.559	753	8.699	99.59	163.39

Front Faces / Second Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	94.390	254	3.969	50.74	104.06
	Middle	98.841	197	4.487	47.45	108.31
	Right	101.738	311	2.789	96.08	110.98
	Total	98.540	762	4.852	47.45	110.98
IDOT LED Vest	Left	100.878	197	4.736	52.45	111.93
	Middle	108.523	311	2.925	101.96	117.83
	Right	104.439	254	3.308	99.14	117.66
	Total	105.185	762	4.737	52.45	117.83
Head Lite Roadstar 200	Left	171.490	311	4.660	161.77	188.48
	Middle	174.846	254	5.193	135.90	189.21
	Right	175.444	197	8.548	79.00	195.32
	Total	173.631	762	6.313	79.00	195.32
Iron Horse Texas Style	Left	126.004	202	3.569	117.68	144.32
	Middle	137.522	213	5.177	119.93	152.83
	Right	137.779	200	5.512	120.15	155.47
	Total	133.822	615	7.296	117.68	155.47
Chami Design Washington Style	Left	171.890	200	4.037	156.73	186.29
	Middle	169.756	202	3.219	160.44	180.83
	Right	175.274	213	4.485	158.66	186.05
	Total	172.361	615	4.568	156.73	186.29
Safetyline Minnesota Style	Left	178.585	213	6.166	159.85	199.85
	Middle	178.141	200	4.752	163.42	194.35
	Right	171.862	202	5.505	158.89	204.33
	Total	176.232	615	6.305	158.89	204.33

Front Faces / Third Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	49.456	272	4.294	29.08	68.95
	Middle	32.101	264	6.253	26.48	51.56
	Right	30.555	277	4.567	26.78	54.74
	Total	37.380	813	9.985	26.48	68.95
IDOT LED Vest	Left	32.517	262	4.851	27.78	51.63
	Middle	41.361	275	6.832	27.97	57.28
	Right	31.378	258	5.892	23.90	50.63
	Total	35.207	795	7.440	23.90	57.28
Head Lite Roadstar 200	Left	44.281	264	8.502	34.93	83.05
	Middle	38.677	277	6.950	32.04	76.45
	Right	56.669	272	6.388	32.15	97.10
	Total	46.516	813	10.515	32.04	97.10
Iron Horse Texas Style	Left	37.002	258	6.019	29.97	55.63
	Middle	34.401	262	4.964	29.08	54.44
	Right	43.578	275	7.183	29.08	65.10
	Total	38.419	795	7.268	29.08	65.10
Chami Design Washington Style	Left	40.188	277	7.037	33.64	79.70
	Middle	55.902	272	6.654	29.97	98.29
	Right	38.796	264	7.691	30.33	71.48
	Total	44.993	813	10.535	29.97	98.29
Safetyline Minnesota Style	Left	47.892	275	8.026	32.15	75.32
	Middle	38.624	258	7.456	29.85	62.18
	Right	37.890	262	6.507	29.97	61.81
	Total	41.588	795	8.676	29.85	75.32

Front Faces / Fourth Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	36.455	302	7.039	30.08	73.24
	Middle	31.379	270	2.960	27.90	47.20
	Right	28.256	279	2.627	25.42	42.20
	Total	32.156	851	5.859	25.42	73.24
IDOT LED Vest	Left	34.777	285	3.772	29.20	56.37
	Middle	32.172	274	3.398	27.20	53.74
	Right	46.045	270	4.043	37.20	62.11
	Total	37.586	829	7.053	27.20	62.11
Head Lite Roadstar 200	Left	62.669	270	6.897	49.75	90.62
	Middle	43.363	285	6.443	34.45	86.05
	Right	38.105	274	4.843	31.38	62.11
	Total	47.913	829	12.140	31.38	90.62
Iron Horse Texas Style	Left	38.328	270	4.606	32.97	60.51
	Middle	33.417	279	3.340	28.78	47.97
	Right	35.225	302	8.716	27.90	86.38
	Total	35.617	851	6.422	27.90	86.38
Chami Design Washington Style	Left	44.331	274	5.037	37.53	70.93
	Middle	58.653	270	6.488	46.76	86.07
	Right	40.789	285	10.925	30.98	87.61
	Total	47.778	829	11.058	30.98	87.61
Safetyline Minnesota Style	Left	42.703	279	4.893	36.34	63.85
	Middle	48.245	302	14.734	34.34	129.31
	Right	37.897	270	6.413	30.68	72.21
	Total	43.145	851	10.760	30.68	129.31

Sides / First Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	86.817	269	2.828	79.42	103.63
	Middle	85.908	209	1.829	83.41	94.07
	Right	81.905	327	2.380	78.16	91.90
	Total	84.586	805	3.297	78.16	103.63
IDOT LED Vest	Left	71.406	209	1.375	68.82	79.25
	Middle	86.350	327	2.511	82.52	100.54
	Right	84.207	269	2.951	76.93	99.53
	Total	81.754	805	6.662	68.82	100.54
Head Lite Roadstar 200	Left	116.181	327	3.979	111.26	139.35
	Middle	116.724	269	4.435	107.33	143.11
	Right	108.398	209	2.953	103.48	120.44
	Total	114.342	805	5.262	103.48	143.11
Iron Horse Texas Style	Left	96.686	269	3.241	92.47	126.47
	Middle	100.770	253	3.912	85.16	119.91
	Right	97.395	278	3.265	93.24	122.30
	Total	98.224	800	3.890	85.16	126.47
Chami Design Washington Style	Left	118.943	278	3.571	114.23	135.48
	Middle	118.924	269	3.515	114.23	135.20
	Right	106.945	253	4.025	91.04	132.08
	Total	115.142	800	6.693	91.04	135.48
Safetyline Minnesota Style	Left	122.838	253	5.359	105.06	147.18
	Middle	126.720	278	4.786	120.77	153.23
	Right	121.211	269	4.388	115.40	140.01
	Total	123.640	800	5.380	105.06	153.23

Sides / Second Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	84.863	268	2.169	81.50	93.15
	Middle	80.643	273	6.661	52.52	92.52
	Right	84.420	279	1.783	81.75	90.81
	Total	83.307	820	4.575	52.52	93.15
IDOT LED Vest	Left	76.776	279	2.103	73.22	85.69
	Middle	75.420	268	1.889	72.52	82.99
	Right	77.462	273	6.512	61.06	88.54
	Total	76.561	820	4.179	61.06	88.54
Head Lite Roadstar 200	Left	128.813	273	8.176	68.66	150.21
	Middle	148.095	279	4.162	143.52	171.78
	Right	151.072	268	3.683	146.82	167.27
	Total	142.648	820	11.386	68.66	171.78
Iron Horse Texas Style	Left	94.713	180	7.706	84.87	113.56
	Middle	98.221	194	3.697	91.97	113.88
	Right	106.528	208	7.692	94.97	125.42
	Total	100.105	582	8.299	84.87	125.42
Chami Design Washington Style	Left	118.656	208	7.270	94.91	137.54
	Middle	135.127	180	6.865	126.73	150.70
	Right	134.556	194	2.750	126.53	143.45
	Total	129.050	582	9.803	94.91	150.70
Safetyline Minnesota Style	Left	163.031	194	4.320	153.09	179.57
	Middle	167.149	208	7.136	155.90	187.50
	Right	161.669	180	7.337	151.05	186.57
	Total	164.081	582	6.817	151.05	187.50

Sides / Third Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	45.448	266	1.857	25.60	51.56
	Middle	46.720	249	1.879	44.30	55.63
	Right	44.816	277	1.353	42.71	53.26
	Total	45.627	792	1.876	25.60	55.63
IDOT LED Vest	Left	25.715	147	.986	22.89	31.07
	Middle	36.472	138	3.073	23.19	41.07
	Right	29.123	241	7.055	22.11	39.89
	Total	30.099	526	6.479	22.11	41.07
Head Lite Roadstar 200	Left	53.612	249	4.762	49.15	79.14
	Middle	52.126	277	3.527	48.74	83.80
	Right	49.650	266	3.024	28.97	60.93
	Total	51.761	792	4.140	28.97	83.80
Iron Horse Texas Style	Left	42.202	138	3.687	27.78	53.03
	Middle	34.996	241	7.566	27.26	49.73
	Right	27.215	147	1.507	23.96	33.37
	Total	34.712	526	7.802	23.96	53.03
Chami Design Washington Style	Left	53.280	277	4.295	49.74	94.13
	Middle	51.663	266	3.485	31.04	63.78
	Right	51.645	249	3.954	46.97	68.25
	Total	52.223	792	4.001	31.04	94.13
Safetyline Minnesota Style	Left	41.265	241	8.349	32.15	77.44
	Middle	33.473	147	3.118	29.15	50.07
	Right	43.042	138	4.128	28.44	53.63
	Total	39.554	526	7.342	28.44	77.44

Sides / Fourth Site

Vest	Settlement	Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	49.404	276	2.477	45.48	63.51
	Middle	46.931	273	1.317	44.01	51.56
	Right	46.082	271	1.566	42.71	55.63
	Total	47.483	820	2.332	42.71	63.51
IDOT LED Vest	Left	30.775	265	3.763	25.71	45.37
	Middle	25.063	262	1.332	22.83	33.26
	Right	23.418	261	1.089	21.23	27.60
	Total	26.439	788	3.965	21.23	45.37
Head Lite Roadstar 200	Left	36.475	262	3.410	31.74	53.00
	Middle	33.457	261	2.871	28.56	44.52
	Right	33.579	265	4.646	27.08	55.88
	Total	34.501	788	3.970	27.08	55.88
Iron Horse Texas Style	Left	54.770	273	2.781	49.37	65.33
	Middle	52.172	271	3.394	46.48	78.44
	Right	48.052	276	1.997	44.60	58.26
	Total	51.650	820	3.925	44.60	78.44
Chami Design Washington Style	Left	36.120	261	2.501	32.57	43.89
	Middle	37.462	265	6.156	29.68	80.41
	Right	32.048	262	3.531	28.27	70.20
	Total	35.218	788	4.922	28.27	80.41
Safetyline Minnesota Style	Left	65.639	271	5.963	54.64	97.61
	Middle	54.450	276	4.121	48.56	76.31
	Right	56.405	273	4.989	46.67	74.95
	Total	58.799	820	7.033	46.67	97.61

APPENDIX H

DESCRIPTIVE STATISTICS

NORMALIZED MEAN VALUES FOR FRONT FACES AND SIDES ON FOUR TEST SITES

Front Faces / First Site

Vest	Position	Mean photometer reading	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	16	90.653	96.319	266	2.989	91.34	109.11
	Middle	16	88.080	93.585	251	4.051	78.03	102.11
	Right	16	83.317	88.524	262	4.649	73.78	100.73
	Weighted Total (4)		87.357	92.816	779	5.114	73.78	109.11
IDOT LED Vest	Left	16	92.680	98.473	251	4.857	82.37	110.87
	Middle	16	98.742	104.913	262	5.120	89.75	120.84
	Right	16	90.850	96.528	266	4.033	89.85	124.20
	Weighted Total (4)		94.094	99.975	779	5.909	82.37	124.20
Head Lite Roadstar 200	Left	16	130.152	138.287	262	6.888	121.77	160.52
	Middle	16	137.246	145.824	266	6.366	136.46	173.63
	Right	16	123.331	131.039	251	6.705	113.32	150.25
	Weighted Total (4)		130.377	138.525	779	8.971	113.32	173.63
Iron Horse Texas Style	Left	17	105.538	105.538	252	6.809	85.99	123.28
	Middle	17	107.195	107.195	255	5.663	87.46	124.16
	Right	16	96.599	102.636	246	7.714	87.54	131.67
	Weighted Total (4)		103.179	105.151	753	7.017	85.99	131.67
Chami Design Washington Style	Left	16	126.122	134.004	246	8.162	118.50	165.44
	Middle	17	125.225	125.225	252	6.279	107.33	143.61
	Right	17	122.459	122.459	255	5.427	104.75	138.02
	Weighted Total (4)		124.581	127.156	753	8.300	104.75	165.44
Safetyline Minnesota Style	Left	17	127.923	127.923	255	7.020	108.14	151.87
	Middle	16	127.145	135.092	246	9.321	117.84	173.60
	Right	17	118.631	118.631	252	6.957	99.59	139.65
	Weighted Total (4)		124.559	127.155	753	10.308	99.59	173.60

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max photometer reading) / (Photometer reading)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Front Faces / Second Site

Vest	Position	Average photometer reading	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	50	94.390	94.390	254	3.969	50.74	104.06
	Middle	49	98.841	100.858	197	4.579	48.42	110.52
	Right	50	101.738	101.738	311	2.789	96.08	110.98
	Weighted Total (4)		98.540	99.061	762	4.985	48.42	110.98
IDOT LED Vest	Left	49	100.878	102.937	197	4.832	53.52	114.21
	Middle	50	108.523	108.523	311	2.925	101.96	117.83
	Right	50	104.439	104.439	254	3.308	99.14	117.66
	Weighted Total (4)		105.185	105.718	762	4.348	53.52	117.83
Head Lite Roadstar 200	Left	50	171.490	171.490	311	4.660	161.77	188.48
	Middle	50	174.846	174.846	254	5.193	135.90	189.21
	Right	49	175.444	179.025	197	8.723	80.61	199.31
	Weighted Total (4)		173.631	174.557	762	6.816	80.61	199.31
Iron Horse Texas Style	Left	49	126.004	128.575	202	3.642	120.08	147.27
	Middle	49	137.522	140.329	213	5.283	122.38	155.95
	Right	48	137.779	143.519	200	5.742	125.16	161.95
	Weighted Total (4)		133.822	137.506	615	8.090	120.08	161.95
Chami Design Washington Style	Left	48	171.890	179.052	200	4.205	163.26	194.05
	Middle	49	169.756	173.221	202	3.285	163.71	184.52
	Right	49	175.274	178.851	213	4.576	161.90	189.85
	Weighted Total (4)		172.361	177.067	615	4.873	161.90	194.05
Safetyline Minnesota Style	Left	49	178.585	182.230	213	6.292	163.11	203.93
	Middle	48	178.141	185.563	200	4.950	170.23	202.45
	Right	49	171.862	175.369	202	5.617	162.13	208.50
	Weighted Total (4)		176.232	181.060	615	7.048	162.13	208.50

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max photometer reading) / (Photometer reading)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Front Faces / Third Site

Vest	Position	Average traffic volume (veh/min)	Original Mean Luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	12.36	49.456	63.620	272	5.523	37.41	88.70
	Middle	11.47	32.101	44.499	264	8.668	36.71	71.47
	Right	11.09	30.555	43.808	277	6.548	38.40	78.48
	Weighted Total (4)		37.380	50.660	813	11.564	36.71	88.70
IDOT LED Vest	Left	13.63	32.517	37.933	262	5.659	32.41	60.23
	Middle	15.90	41.361	41.361	275	6.832	27.97	57.28
	Right	11.80	31.378	42.280	258	7.939	32.20	68.22
	Weighted Total (4)		35.207	40.529	795	7.106	27.97	68.22
Head Lite Roadstar 200	Left	11.47	44.281	61.383	264	11.786	48.42	115.13
	Middle	11.09	38.677	55.453	277	9.965	45.94	109.61
	Right	12.36	56.669	72.900	272	8.217	41.36	124.91
	Weighted Total (4)		46.516	63.216	813	12.423	41.36	124.91
Iron Horse Texas Style	Left	11.80	37.002	49.858	258	8.110	40.38	74.96
	Middle	13.63	34.401	40.130	262	5.791	33.92	63.51
	Right	15.90	43.578	43.578	275	7.183	29.08	65.10
	Weighted Total (4)		38.419	44.480	795	8.127	29.08	74.96
Chami Design Washington Style	Left	11.09	40.188	57.618	277	10.089	48.23	114.27
	Middle	12.36	55.902	71.913	272	8.560	38.55	126.44
	Right	11.47	38.796	53.780	264	10.661	42.04	99.09
	Weighted Total (4)		44.993	61.154	813	12.513	38.55	126.44
Safetyline Minnesota Style	Left	15.90	47.892	47.892	275	8.026	32.15	75.32
	Middle	11.80	38.624	52.044	258	10.047	40.22	83.78
	Right	13.63	37.890	44.200	262	7.591	34.96	72.10
	Weighted Total (4)		41.588	48.023	795	9.161	32.15	83.78

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max traffic volume) / (Traffic volume)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Front Faces / Fourth Site

Vest	Position	Average traffic volume (veh/min)	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	21.06	36.455	49.195	302	9.499	40.59	98.84
	Middle	25.78	31.379	34.592	270	3.263	30.76	52.03
	Right	16.90	28.256	47.517	279	4.418	42.75	70.97
	Weighted Total (4)		32.156	44.012	851	9.136	30.76	98.84
IDOT LED Vest	Left	28.42	34.777	34.777	285	3.772	29.20	56.37
	Middle	25.69	32.172	35.591	274	3.759	30.09	59.45
	Right	26.46	46.045	49.455	270	4.343	39.96	66.71
	Weighted Total (4)		37.586	39.827	829	7.785	29.20	66.71
Head Lite Roadstar 200	Left	26.46	62.669	67.311	270	7.407	53.44	97.33
	Middle	28.42	43.363	43.363	285	6.443	34.45	86.05
	Right	25.69	38.105	42.154	274	5.358	34.71	68.71
	Weighted Total (4)		47.913	50.763	829	13.198	34.45	97.33
Iron Horse Texas Style	Left	25.78	38.328	42.252	270	5.078	36.35	66.71
	Middle	16.90	33.417	56.195	279	5.617	48.40	80.67
	Right	21.06	35.225	47.536	302	11.762	37.65	116.57
	Weighted Total (4)		35.617	48.699	851	9.980	36.35	116.57
Chami Design Washington Style	Left	25.69	44.331	49.042	274	5.572	41.52	78.47
	Middle	26.46	58.653	62.998	270	6.969	50.22	92.45
	Right	28.42	40.789	40.789	285	10.925	30.98	87.61
	Weighted Total (4)		47.778	50.750	829	12.288	30.98	92.45
Safetyline Minnesota Style	Left	16.90	42.703	71.812	279	8.228	61.11	107.37
	Middle	21.06	48.245	65.106	302	19.884	46.34	174.50
	Right	25.78	37.897	41.777	270	7.070	33.82	79.60
	Weighted Total (4)		43.145	59.903	851	18.398	33.82	174.50

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max traffic volume) / (Traffic volume)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Sides / First Site

Vest	Position	Average photometer reading	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	17	86.817	86.817	269	2.828	79.42	103.63
	Middle	16	85.908	91.277	209	1.943	88.62	99.95
	Right	17	81.905	81.905	327	2.380	78.16	91.90
	Weighted Tota171 (4)		84.586	85.980	805	4.497	78.16	103.63
IDOT LED Vest	Left	16	71.406	75.869	209	1.461	73.12	84.20
	Middle	17	86.350	86.350	327	2.511	82.52	100.54
	Right	17	84.207	84.207	269	2.951	76.93	99.53
	Weighted Total (4)		81.754	82.913	805	4.927	73.12	100.54
Head Lite Roadstar 200	Left	17	116.181	116.181	327	3.979	111.26	139.35
	Middle	17	116.724	116.724	269	4.435	107.33	143.11
	Right	16	108.398	115.172	209	3.137	109.95	127.97
	Weighted Total (4)		114.342	116.101	805	3.985	107.33	143.11
Iron Horse Texas Style	Left	17	96.686	96.686	269	3.241	92.47	126.47
	Middle	17	100.770	100.770	253	3.912	85.16	119.91
	Right	17	97.395	97.395	278	3.265	93.24	122.30
	Weighted Total (4)		98.224	98.224	800	3.890	85.16	126.47
Chami Design Washington Style	Left	17	118.943	118.943	278	3.571	114.23	135.48
	Middle	17	118.924	118.924	269	3.515	114.23	135.20
	Right	17	106.945	106.945	253	4.025	91.04	132.08
	Weighted Total (4)		115.142	115.142	800	6.693	91.04	135.48
Safetyline Minnesota Style	Left	17	122.838	122.838	253	5.359	105.06	147.18
	Middle	17	126.720	126.720	278	4.786	120.77	153.23
	Right	17	121.211	121.211	269	4.388	115.40	140.01
	Weighted Total (4)		123.640	123.640	800	5.380	105.06	153.23

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max photometer reading) / (Photometer reading)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Sides / Second Site

Vest	Position	Average photometer reading	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	50	84.863	84.863	268	2.169	81.50	93.15
	Middle	48	80.643	84.003	273	6.938	54.71	96.38
	Right	49	84.420	86.143	279	1.819	83.42	92.66
	Weighted Total (4)		83.307	85.012	820	4.408	54.71	96.38
IDOT LED Vest	Left	49	76.776	78.343	279	2.145	74.71	87.44
	Middle	50	75.420	75.420	268	1.889	72.52	82.99
	Right	48	77.462	80.690	273	6.783	63.60	92.23
	Weighted Total (4)		76.561	78.169	820	4.755	63.60	92.23
Head Lite Roadstar 200	Left	48	128.813	134.180	273	8.517	71.52	156.47
	Middle	49	148.095	151.117	279	4.247	146.45	175.29
	Right	50	151.072	151.072	268	3.683	146.82	167.27
	Weighted Total (4)		142.648	145.464	820	9.913	71.52	175.29
Iron Horse Texas Style	Left	50	94.713	94.713	180	7.706	84.87	113.56
	Middle	50	98.221	98.221	194	3.697	91.97	113.88
	Right	49	106.528	108.702	208	7.849	96.91	127.98
	Weighted Total (4)		100.105	100.882	582	8.990	84.87	127.98
Chami Design Washington Style	Left	49	118.656	121.077	208	7.418	96.85	140.35
	Middle	50	135.127	135.127	180	6.865	126.73	150.70
	Right	50	134.556	134.556	194	2.750	126.53	143.45
	Weighted Total (4)		129.050	129.915	582	8.956	96.85	150.70
Safetyline Minnesota Style	Left	50	163.031	163.031	194	4.320	153.09	179.57
	Middle	49	167.149	170.560	208	7.281	159.08	191.33
	Right	50	161.669	161.669	180	7.337	151.05	186.57
	Weighted Total (4)		164.081	165.301	582	7.575	151.05	191.33

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max photometer reading) / (Photometer reading)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Sides / Third Site

Vest	Position	Average traffic volume (veh/min)	Original mean luminance (1)	Normalized Luminance Values				
				Mean(2)	N(3)	Std. Deviation	Min	Max
IDOT Standard Vest	Left	11.10	45.448	47.741	266	1.951	26.89	54.16
	Middle	11.66	46.720	46.720	249	1.879	44.30	55.63
	Right	8.38	44.816	62.357	277	1.882	59.43	74.11
	Weighted Total (4)		45.627	52.532	792	7.468	26.89	74.11
IDOT LED Vest	Left	6.32	25.715	47.443	147	1.820	42.23	57.32
	Middle	6.10	36.472	69.715	138	5.874	44.33	78.50
	Right	5.57	29.123	60.965	241	14.769	46.28	83.50
	Weighted Total (4)		30.099	59.481	526	13.370	42.23	83.50
Head Lite Roadstar 200	Left	11.66	53.612	53.612	249	4.762	49.15	79.14
	Middle	8.38	52.126	72.529	277	4.907	67.82	116.60
	Right	11.10	49.650	52.154	266	3.177	30.43	64.00
	Weighted Total (4)		51.761	59.738	792	10.360	30.43	116.60
Iron Horse Texas Style	Left	6.10	42.202	80.668	138	7.047	53.10	101.37
	Middle	5.57	34.996	73.258	241	15.839	57.06	104.10
	Right	6.32	27.215	50.209	147	2.781	44.20	61.57
	Weighted Total (4)		34.712	68.761	526	16.514	44.20	104.10
Chami Design Washington Style	Left	8.38	53.280	74.135	277	5.975	69.21	130.97
	Middle	11.10	51.663	54.269	266	3.661	32.61	67.00
	Right	11.66	51.645	51.645	249	3.954	46.97	68.25
	Weighted Total (4)		52.223	60.392	792	11.166	32.61	130.97
Safetyline Minnesota Style	Left	5.57	41.265	86.383	241	17.478	67.30	162.11
	Middle	6.32	33.473	61.756	147	5.752	53.78	92.38
	Right	6.10	43.042	82.274	138	7.890	54.36	102.51
	Weighted Total (4)		39.554	78.422	526	16.609	53.78	162.11

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max traffic volume) / (Traffic volume)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

Sides / Fourth Site

Vest	Position	Average traffic volume (veh/min)	Original mean luminance [1]	Normalized Luminance Values				
				Mean[2]	N[3]	Std. Deviation	Min	Max
IDOT Standard Vest	Left	17.77	49.404	53.269	276	2.671	49.04	68.48
	Middle	19.16	46.931	46.931	273	1.317	44.01	51.56
	Right	18.96	46.082	46.568	271	1.582	43.16	56.22
	Weighted Total [3]		47.483	48.944	820	3.649	43.16	68.48
IDOT LED Vest	Left	11.50	30.775	51.273	265	6.270	42.84	75.59
	Middle	11.98	25.063	40.084	262	2.130	36.51	53.19
	Right	12.84	23.418	34.944	261	1.625	31.68	41.19
	Weighted Total [3]		26.439	42.144	788	7.889	31.68	75.59
Head Lite Roadstar 200	Left	11.98	36.475	58.336	262	5.453	50.76	84.76
	Middle	12.84	33.457	49.925	261	4.283	42.62	66.43
	Right	11.50	33.579	55.945	265	7.740	45.12	93.10
	Weighted Total [3]		34.501	54.746	788	6.964	42.62	93.10
Iron Horse Texas Style	Left	19.16	54.770	54.770	273	2.781	49.37	65.33
	Middle	18.96	52.172	52.723	271	3.430	46.97	79.27
	Right	17.77	48.052	51.811	276	2.153	48.09	62.82
	Weighted Total [3]		51.650	53.097	820	3.089	46.97	79.27
Chami Design Washington Style	Left	12.84	36.120	53.898	261	3.732	48.60	65.49
	Middle	11.50	37.462	62.415	265	10.256	49.45	133.97
	Right	11.98	32.048	51.256	262	5.647	45.21	112.27
	Weighted Total [3]		35.218	55.884	788	8.559	45.21	133.97
Safetyline Minnesota Style	Left	18.96	65.639	66.332	271	6.026	55.22	98.64
	Middle	17.77	54.450	58.709	276	4.444	52.36	82.28
	Right	19.16	56.405	56.405	273	4.989	46.67	74.95
	Weighted Total [3]		58.799	60.461	820	6.693	46.67	98.64

(1) The original means are obtained from descriptive statistics tables in Appendix E
(2) Normalized Mean = (Original mean) × (Max traffic volume) / (Traffic volume)
(3) N = Number of data frames
(4) Weighted Total = Weighted average of three positions (left, middle and right) using N

APPENDIX I

DESCRIPTIVE STATISTICS

COMPARISON OF VEST POSITIONS IN SITE TESTS

Front Face of IDOT Standard Vest / First Site

Descriptive Statistics

Vest	Position	Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	96.319	266	2.989	91.34	109.11
	Middle	93.585	251	4.051	78.03	102.11
	Right	88.524	262	4.649	73.78	100.73
	Total	92.816	779	5.114	73.78	109.11

Tamhane's T2 Test Results

Position (I)	Position (J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	2.734	.315	.000
	Right	7.795	.341	.000
Middle	Left	-2.734	.315	.000
	Right	5.061	.385	.000
Right	Left	-7.795	.341	.000
	Middle	-5.061	.385	.000

Front Face of IDOT LED Vest / First Site

Descriptive Statistics

Vest	Position	Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT LED Vest	Left	98.473	251	4.857	82.37	110.87
	Middle	104.913	262	5.120	89.75	120.84
	Right	96.528	266	4.033	89.85	124.20
	Total	99.975	779	5.909	82.37	124.20

Tamhane's T2 Test Results

Position (I)	Position (J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-6.441	.441	.000
	Right	1.945	.394	.000
Middle	Left	6.441	.441	.000
	Right	8.385	.401	.000
Right	Left	-1.945	.394	.000
	Middle	-8.385	.401	.000

Front Face of Head Lite Roadstar 200 Vest / First Site

Descriptive Statistics

Vest	Position	Mean	N	Std. Deviation	Minimum	Maximum
Head Lite Roadstar 200	Left	138.287	262	6.888	121.77	160.52
	Middle	145.824	266	6.366	136.46	173.63
	Right	131.039	251	6.705	113.32	150.25
	Total	138.525	779	8.971	113.32	173.63

Tamhane's T2 Test Results

Position (I)	Position (J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-7.537	.577	.000
	Right	7.248	.600	.000
Middle	Left	7.537	.577	.000
	Right	14.785	.576	.000
Right	Left	-7.248	.600	.000
	Middle	-14.785	.576	.000

Front Face of Iron Horse Texas Style Vest / First Site

Descriptive Statistics

Vest	Position	Mean	N	Std. Deviation	Minimum	Maximum
Iron Horse Texas Style	Left	105.538	252	6.809	85.99	123.28
	Middle	107.195	255	5.663	87.46	124.16
	Right	102.636	246	7.714	87.54	131.67
	Total	105.151	753	7.017	85.99	131.67

Tamhane's T2 Test Results

Position (I)	Position (J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-1.657	.557	.009
	Right	2.902	.653	.000
Middle	Left	1.657	.557	.009
	Right	4.559	.606	.000
Right	Left	-2.902	.653	.000
	Middle	-4.559	.606	.000

Front Face of Chami Design Washington Style Vest / First Site

Descriptive Statistics

Vest	Position	Mean	N	Std. Deviation	Minimum	Maximum
Chami Design Washington Style	Left	134.004	246	8.162	118.50	165.44
	Middle	125.225	252	6.279	107.33	143.61
	Right	122.459	255	5.427	104.75	138.02
	Total	127.156	753	8.300	104.75	165.44

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	8.780	.654	.000
	Right	11.546	.622	.000
Middle	Left	-8.780	.654	.000
	Right	2.766	.521	.000
Right	Left	-11.546	.622	.000
	Middle	-2.766	.521	.000

Front Face of Safetyline Minnesota Style Vest / First Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Safetyline Minnesota Style	Left	127.923	255	7.020	108.14	151.87
	Middle	135.092	246	9.321	117.84	173.60
	Right	118.631	252	6.957	99.59	139.65
	Total	127.155	753	10.308	99.59	173.60

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-7.169	.739	.000
	Right	9.292	.621	.000
Middle	Left	7.169	.739	.000
	Right	16.461	.738	.000
Right	Left	-9.292	.621	.000
	Middle	-16.461	.738	.000

Front Face of IDOT Standard Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	94.390	254	3.969	50.74	104.06
	Middle	100.858	197	4.579	48.42	110.52
	Right	101.738	311	2.789	96.08	110.98
	Total	99.061	762	4.985	48.42	110.98

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-6.468	.410	.000
	Right	-7.348	.295	.000
Middle	Left	6.468	.410	.000
	Right	-.880	.363	.047
Right	Left	7.348	.295	.000
	Middle	.880	.363	.047

Front Face of IDOT LED Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT LED Vest	Left	102.937	197	4.832	53.52	114.21
	Middle	108.523	311	2.925	101.96	117.83
	Right	104.439	254	3.308	99.14	117.66
	Total	105.718	762	4.348	53.52	117.83

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-5.586	.382	.000
	Right	-1.502	.402	.001
Middle	Left	5.586	.382	.000
	Right	4.084	.266	.000
Right	Left	1.502	.402	.001
	Middle	-4.084	.266	.000

Front Face of Head Lite Roadstar 200Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Head Lite Roadstar 200	Left	171.490	311	4.660	161.77	188.48
	Middle	174.846	254	5.193	135.90	189.21
	Right	179.025	197	8.723	80.61	199.31
	Total	174.557	762	6.816	80.61	199.31

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-3.357	.420	.000
	Right	-7.535	.675	.000
Middle	Left	3.357	.420	.000
	Right	-4.178	.702	.000
Right	Left	7.535	.675	.000
	Middle	4.178	.702	.000

Front Face of Iron Horse Texas Style Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Iron Horse Texas Style	Left	128.575	202	3.642	120.08	147.27
	Middle	140.329	213	5.283	122.38	155.95
	Right	143.519	200	5.742	125.16	161.95
	Total	137.506	615	8.090	120.08	161.95

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-11.754	.444	.000
	Right	-14.944	.480	.000
Middle	Left	11.754	.444	.000
	Right	-3.190	.544	.000
Right	Left	14.944	.480	.000
	Middle	3.190	.544	.000

Front Face of Chami Design Washington Style Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Chami Design Washington Style	Left	179.052	200	4.205	163.26	194.05
	Middle	173.221	202	3.285	163.71	184.52
	Right	178.851	213	4.576	161.90	189.85
	Total	177.067	615	4.873	161.90	194.05

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	5.831	.377	.000
	Right	.201	.432	.954
Middle	Left	-5.831	.377	.000
	Right	-5.630	.390	.000
Right	Left	-.201	.432	.954
	Middle	5.630	.390	.000

Front Face of Safetyline Minnesota Style Vest / Second Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Safetyline Minnesota Style	Left	182.230	213	6.292	163.11	203.93
	Middle	185.563	200	4.950	170.23	202.45
	Right	175.369	202	5.617	162.13	208.50
	Total	181.060	615	7.048	162.13	208.50

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-3.334	.555	.000
	Right	6.860	.585	.000
Middle	Left	3.334	.555	.000
	Right	10.194	.528	.000
Right	Left	-6.860	.585	.000
	Middle	-10.194	.528	.000

Front Face of IDOT Standard Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	63.620	272	5.523	37.41	88.70
	Middle	44.499	264	8.668	36.71	71.47
	Right	43.808	277	6.548	38.40	78.48
	Total	50.660	813	11.564	36.71	88.70

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	19.121	.630	.000
	Right	19.812	.517	.000
Middle	Left	-19.121	.630	.000
	Right	.691	.663	.654
Right	Left	-19.812	.517	.000
	Middle	-.691	.663	.654

Front Face of IDOT LED Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT LED Vest	Left	37.933	262	5.659	32.41	60.23
	Middle	41.361	275	6.832	27.97	57.28
	Right	42.280	258	7.939	32.20	68.22
	Total	40.529	795	7.106	27.97	68.22

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-3.428	.540	.000
	Right	-4.347	.605	.000
Middle	Left	3.428	.540	.000
	Right	-.919	.643	.394
Right	Left	4.347	.605	.000
	Middle	.919	.643	.394

Front Face of Head Lite Roadstar 200 Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Head Lite Roadstar 200	Left	61.383	264	11.786	48.42	115.13
	Middle	55.453	277	9.965	45.94	109.61
	Right	72.900	272	8.217	41.36	124.91
	Total	63.216	813	12.423	41.36	124.91

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	5.931	.941	.000
	Right	-11.517	.880	.000
Middle	Left	-5.931	.941	.000
	Right	-17.447	.779	.000
Right	Left	11.517	.880	.000
	Middle	17.447	.779	.000

Front Face of Iron Horse Texas Style Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Iron Horse Texas Style	Left	49.858	258	8.110	40.38	74.96
	Middle	40.130	262	5.791	33.92	63.51
	Right	43.578	275	7.183	29.08	65.10
	Total	44.480	795	8.127	29.08	74.96

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	9.728	.619	.000
	Right	6.281	.665	.000
Middle	Left	-9.728	.619	.000
	Right	-3.447	.562	.000
Right	Left	-6.281	.665	.000
	Middle	3.447	.562	.000

Front Face of Chami Design Washington Style Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Chami Design Washington Style	Left	57.618	277	10.089	48.23	114.27
	Middle	71.913	272	8.560	38.55	126.44
	Right	53.780	264	10.661	42.04	99.09
	Total	61.154	813	12.513	38.55	126.44

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-14.295	.798	.000
	Right	3.838	.893	.000
Middle	Left	14.295	.798	.000
	Right	18.133	.837	.000
Right	Left	-3.838	.893	.000
	Middle	-18.133	.837	.000

Front Face of Safetyline Minnesota Style Vest / Third Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Safetyline Minnesota Style	Left	47.892	275	8.026	32.15	75.32
	Middle	52.044	258	10.047	40.22	83.78
	Right	44.200	262	7.591	34.96	72.10
	Total	48.023	795	9.161	32.15	83.78

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-4.152	.791	.000
	Right	3.692	.674	.000
Middle	Left	4.152	.791	.000
	Right	7.845	.782	.000
Right	Left	-3.692	.674	.000
	Middle	-7.845	.782	.000

Front Face of IDOT Standard Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Left	49.195	302	9.499	40.59	98.84
	Middle	34.592	270	3.263	30.76	52.03
	Right	47.517	279	4.418	42.75	70.97
	Total	44.012	851	9.136	30.76	98.84

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	14.603	.582	.000
	Right	1.678	.607	.018
Middle	Left	-14.603	.582	.000
	Right	-12.925	.331	.000
Right	Left	-1.678	.607	.018
	Middle	12.925	.331	.000

Front Face of IDOT LED Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
IDOT LED Vest	Left	34.777	285	3.772	29.20	56.37
	Middle	35.591	274	3.759	30.09	59.45
	Right	49.455	270	4.343	39.96	66.71
	Total	39.827	829	7.785	29.20	66.71

Tamhane’s T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-.814	.319	.032
	Right	-14.678	.346	.000
Middle	Left	.814	.319	.032
	Right	-13.864	.348	.000
Right	Left	14.678	.346	.000
	Middle	13.864	.348	.000

Front Face of Head Lite Roadstar 200 Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Head Lite Roadstar 200	Left	67.311	270	7.407	53.44	97.33
	Middle	43.363	285	6.443	34.45	86.05
	Right	42.154	274	5.358	34.71	68.71
	Total	50.763	829	13.198	34.45	97.33

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	23.948	.591	.000
	Right	25.157	.555	.000
Middle	Left	-23.948	.591	.000
	Right	1.209	.500	.047
Right	Left	-25.157	.555	.000
	Middle	-1.209	.500	.047

Front Face of Iron Horse Texas Style Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Iron Horse Texas Style	Left	42.252	270	5.078	36.35	66.71
	Middle	56.195	279	5.617	48.40	80.67
	Right	47.536	302	11.762	37.65	116.57
	Total	48.699	851	9.980	36.35	116.57

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-13.943	.457	.000
	Right	-5.283	.744	.000
Middle	Left	13.943	.457	.000
	Right	8.660	.756	.000
Right	Left	5.283	.744	.000
	Middle	-8.660	.756	.000

Front Face of Chami Design Washington Style Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Chami Design Washington Style	Left	49.042	274	5.572	41.52	78.47
	Middle	62.998	270	6.969	50.22	92.45
	Right	40.789	285	10.925	30.98	87.61
	Total	50.750	829	12.288	30.98	92.45

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	-13.955	.541	.000
	Right	8.254	.729	.000
Middle	Left	13.955	.541	.000
	Right	22.209	.774	.000
Right	Left	-8.254	.729	.000
	Middle	-22.209	.774	.000

Front Face of Safetyline Minnesota Style Vest / Fourth Site

Descriptive Statistics

Vest		Mean	N	Std. Deviation	Minimum	Maximum
Safetyline Minnesota Style	Left	71.812	279	8.228	61.11	107.37
	Middle	65.106	302	19.884	46.34	174.50
	Right	41.777	270	7.070	33.82	79.60
	Total	59.903	851	18.398	33.82	174.50

Tamhane's T2 Test Results

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Left	Middle	6.706	1.246	.000
	Right	30.034	.654	.000
Middle	Left	-6.706	1.246	.000
	Right	23.329	1.222	.000
Right	Left	-30.034	.654	.000
	Middle	-23.329	1.222	.000

APPENDIX J

DESCRIPTIVE STATISTICS

COMPARISON OF VESTS' FRONT FACES VS. SIDES

First Site

Descriptive Statistics

Vest		Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Front	92.817	779	5.114	73.78	109.11
	Side	85.980	805	4.497	78.16	103.63
IDOT LED Vest	Front	99.975	779	5.909	82.37	124.20
	Side	82.913	805	4.927	73.12	100.54
Head Lite Roadstar 200	Front	138.525	779	8.971	113.32	173.63
	Side	116.101	805	3.985	107.33	143.11
Iron Horse Texas Style	Front	105.151	753	7.017	85.99	131.67
	Side	98.224	800	3.890	85.16	126.47
Chami Design Washington Style	Front	127.156	753	8.300	104.75	165.44
	Side	115.142	800	6.693	91.04	135.48
Safetyline Minnesota Style	Front	127.155	753	10.308	99.59	173.60
	Side	123.640	800	5.380	105.06	153.23

Results of t-Tests

Vest	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IDOT Standard Vest	28.219	1542.258	.000	6.837	.242
IDOT LED Vest	62.310	1513.873	.000	17.062	.274
Head Lite Roadstar 200	63.930	1065.811	.000	22.424	.351
Iron Horse Texas Style	23.857	1158.792	.000	6.927	.290
Chami Design Washington Style	31.284	1444.844	.000	12.014	.384
Safetyline Minnesota Style	8.347	1117.938	.000	3.515	.421

Second Site

Descriptive Statistics

Vest		Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Front	99.061	762	4.985	48.42	110.98
	Side	85.012	820	4.408	54.71	96.38
IDOT LED Vest	Front	105.718	762	4.348	53.52	117.83
	Side	78.169	820	4.755	63.60	92.23
Head Lite Roadstar 200	Front	174.557	762	6.816	80.61	199.31
	Side	145.464	820	9.913	71.52	175.29
Iron Horse Texas Style	Front	137.506	615	8.090	120.08	161.95
	Side	100.882	582	8.990	84.87	127.98
Chami Design Washington Style	Front	177.067	615	4.873	161.90	194.05
	Side	129.915	582	8.956	96.85	150.70
Safetyline Minnesota Style	Front	181.060	615	7.048	162.13	208.50
	Side	165.301	582	7.575	151.05	191.33

Results of t-Tests

Vest	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IDOT Standard Vest	59.207	1521.941	.000	14.049	.2373
IDOT LED Vest	120.372	1579.588	.000	27.549	.229
Head Lite Roadstar 200	68.423	1458.129	.000	29.093	.425
Iron Horse Texas Style	73.948	1165.171	.000	36.624	.495
Chami Design Washington Style	112.254	886.355	.000	47.152	.420
Safetyline Minnesota Style	37.211	1176.021	.000	15.760	.424

Third Site
Descriptive Statistics

Vest		Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Front	50.660	813	11.564	36.71	88.70
	Side	52.532	792	7.468	26.89	74.11
IDOT LED Vest	Front	40.529	795	7.106	27.97	68.22
	Side	59.481	526	13.370	42.23	83.50
Head Lite Roadstar 200	Front	63.216	813	12.423	41.36	124.91
	Side	59.738	792	10.360	30.43	116.60
Iron Horse Texas Style	Front	44.480	795	8.127	29.08	74.96
	Side	68.761	526	16.514	44.20	104.10
Chami Design Washington Style	Front	61.154	813	12.513	38.55	126.44
	Side	60.392	792	11.166	32.61	130.97
Safetyline Minnesota Style	Front	48.023	795	9.161	32.15	83.78
	Side	78.422	526	16.609	53.78	162.11

Results of t-Tests

Vest	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IDOT Standard Vest	-3.861	1393.896	.000	-1.871	.485
IDOT LED Vest	-29.841	722.911	.000	-18.952	.635
Head Lite Roadstar 200	6.096	1565.938	.000	3.477	.570
Iron Horse Texas Style	-31.307	694.930	.000	-24.281	.776
Chami Design Washington Style	1.288	1590.841	.198	.762	.592
Safetyline Minnesota Style	-38.300	737.870	.000	-30.400	.794

Fourth Site

Descriptive Statistics

Vest		Normalized mean luminance	N	Std. Deviation	Minimum	Maximum
IDOT Standard Vest	Front	44.012	851	9.136	30.76	98.84
	Side	48.944	820	3.649	43.16	68.48
IDOT LED Vest	Front	39.827	829	7.785	29.20	66.71
	Side	42.144	788	7.889	31.68	75.59
Head Lite Roadstar 200	Front	50.763	829	13.198	34.45	97.33
	Side	54.746	788	6.964	42.62	93.10
Iron Horse Texas Style	Front	48.699	851	9.980	36.35	116.57
	Side	53.097	820	3.089	46.97	79.27
Chami Design Washington Style	Front	50.750	829	12.288	30.98	92.45
	Side	55.884	788	8.559	45.21	133.97
Safetyline Minnesota Style	Front	59.903	851	18.398	33.82	174.50
	Side	60.461	820	6.693	46.67	98.64

Results of t-Tests

Vest	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IDOT Standard Vest	-14.587	1122.857	.000	-4.932	.338
IDOT LED Vest	-5.943	1608.419	.000	-2.318	.390
Head Lite Roadstar 200	-7.641	1269.516	.000	-3.983	.521
Iron Horse Texas Style	-12.263	1016.971	.000	-4.399	.359
Chami Design Washington Style	-9.788	1482.627	.000	-5.134	.525
Safetyline Minnesota Style	-.830	1078.387	.407	-.558	.673

APPENDIX K

SIGNIFICANCE TESTS OF RANKINGS

Ranking of Front Faces / First Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	-7.158	.280	.000
	Head Lite Roadstar 200	-45.709	.370	.000
	Iron Horse Texas Style	-12.335	.315	.000
	Chami Design Washington Style	-34.340	.354	.000
	Safetyline Minnesota Style	-34.339	.418	.000
IDOT LED Vest	IDOT Standard Vest	7.158	.280	.000
	Head Lite Roadstar 200	-38.550	.385	.000
	Iron Horse Texas Style	-5.176	.332	.000
	Chami Design Washington Style	-27.181	.369	.000
	Safetyline Minnesota Style	-27.180	.431	.000
Head Lite Roadstar 200	IDOT Standard Vest	45.709	.370	.000
	IDOT LED Vest	38.550	.385	.000
	Iron Horse Texas Style	33.374	.411	.000
	Chami Design Washington Style	11.369	.441	.000
	Safetyline Minnesota Style	11.370	.494	.000
Iron Horse Texas Style	IDOT Standard Vest	12.335	.315	.000
	IDOT LED Vest	5.176	.332	.000
	Head Lite Roadstar 200	-33.374	.411	.000
	Chami Design Washington Style	-22.005	.396	.000
	Safetyline Minnesota Style	-22.004	.454	.000
Chami Design Washington Style	IDOT Standard Vest	34.340	.354	.000
	IDOT LED Vest	27.181	.369	.000
	Head Lite Roadstar 200	-11.369	.441	.000
	Iron Horse Texas Style	22.005	.396	.000
	Safetyline Minnesota Style	.001	.482	1.000
Safetyline Minnesota Style	IDOT Standard Vest	34.339	.418	.000
	IDOT LED Vest	27.180	.431	.000
	Head Lite Roadstar 200	-11.370	.494	.000
	Iron Horse Texas Style	22.004	.454	.000
	Chami Design Washington Style	-.001	.482	1.000

Ranking of Front Faces / Second Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	-6.656	.240	.000
	Head Lite Roadstar 200	-75.495	.306	.000
	Iron Horse Texas Style	-38.445	.373	.000
	Chami Design Washington Style	-78.006	.267	.000
	Safetyline Minnesota Style	-81.999	.337	.000
IDOT LED Vest	IDOT Standard Vest	6.656	.240	.000
	Head Lite Roadstar 200	-68.839	.293	.000
	Iron Horse Texas Style	-31.788	.362	.000
	Chami Design Washington Style	-71.349	.252	.000
	Safetyline Minnesota Style	-75.343	.325	.000
Head Lite Roadstar 200	IDOT Standard Vest	75.495	.306	.000
	IDOT LED Vest	68.839	.293	.000
	Iron Horse Texas Style	37.051	.409	.000
	Chami Design Washington Style	-2.510	.316	.000
	Safetyline Minnesota Style	-6.504	.376	.000
Iron Horse Texas Style	IDOT Standard Vest	38.445	.373	.000
	IDOT LED Vest	31.788	.362	.000
	Head Lite Roadstar 200	-37.051	.409	.000
	Chami Design Washington Style	-39.561	.381	.000
	Safetyline Minnesota Style	-43.554	.433	.000
Chami Design Washington Style	IDOT Standard Vest	78.006	.267	.000
	IDOT LED Vest	71.349	.252	.000
	Head Lite Roadstar 200	2.510	.316	.000
	Iron Horse Texas Style	39.561	.381	.000
	Safetyline Minnesota Style	-3.993	.346	.000
Safetyline Minnesota Style	IDOT Standard Vest	81.999	.337	.000
	IDOT LED Vest	75.343	.325	.000
	Head Lite Roadstar 200	6.504	.376	.000
	Iron Horse Texas Style	43.554	.433	.000
	Chami Design Washington Style	3.993	.346	.000

Ranking of Front Faces / Third Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	10.131	.477	.000
	Head Lite Roadstar 200	-12.555	.595	.000
	Iron Horse Texas Style	6.181	.498	.000
	Chami Design Washington Style	-10.494	.598	.000
	Safetyline Minnesota Style	2.638	.520	.000
IDOT LED Vest	IDOT Standard Vest	-10.131	.477	.000
	Head Lite Roadstar 200	-22.686	.503	.000
	Iron Horse Texas Style	-3.950	.383	.000
	Chami Design Washington Style	-20.625	.506	.000
	Safetyline Minnesota Style	-7.493	.411	.000
Head Lite Roadstar 200	IDOT Standard Vest	12.555	.595	.000
	IDOT LED Vest	22.686	.503	.000
	Iron Horse Texas Style	18.736	.522	.000
	Chami Design Washington Style	2.061	.618	.013
	Safetyline Minnesota Style	15.193	.544	.000
Iron Horse Texas Style	IDOT Standard Vest	-6.181	.498	.000
	IDOT LED Vest	3.950	.383	.000
	Head Lite Roadstar 200	-18.736	.522	.000
	Chami Design Washington Style	-16.675	.525	.000
	Safetyline Minnesota Style	-3.543	.434	.000
Chami Design Washington Style	IDOT Standard Vest	10.494	.598	.000
	IDOT LED Vest	20.625	.506	.000
	Head Lite Roadstar 200	-2.061	.618	.013
	Iron Horse Texas Style	16.675	.525	.000
	Safetyline Minnesota Style	13.132	.546	.000
Safetyline Minnesota Style	IDOT Standard Vest	-2.638	.520	.000
	IDOT LED Vest	7.493	.411	.000
	Head Lite Roadstar 200	-15.193	.544	.000
	Iron Horse Texas Style	3.543	.434	.000
	Chami Design Washington Style	-13.132	.546	.000

Ranking of Front Faces / Fourth Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	4.185	.414	.000
	Head Lite Roadstar 200	-6.751	.555	.000
	Iron Horse Texas Style	-4.687	.464	.000
	Chami Design Washington Style	-6.738	.529	.000
	Safetyline Minnesota Style	-15.891	.704	.000
IDOT LED Vest	IDOT Standard Vest	-4.185	.414	.000
	Head Lite Roadstar 200	-10.936	.532	.000
	Iron Horse Texas Style	-8.872	.436	.000
	Chami Design Washington Style	-10.923	.505	.000
	Safetyline Minnesota Style	-20.076	.686	.000
Head Lite Roadstar 200	IDOT Standard Vest	6.751	.555	.000
	IDOT LED Vest	10.936	.532	.000
	Iron Horse Texas Style	2.065	.572	.005
	Chami Design Washington Style	.013	.626	1.000
	Safetyline Minnesota Style	-9.140	.780	.000
Iron Horse Texas Style	IDOT Standard Vest	4.687	.464	.000
	IDOT LED Vest	8.872	.436	.000
	Head Lite Roadstar 200	-2.065	.572	.005
	Chami Design Washington Style	-2.051	.547	.003
	Safetyline Minnesota Style	-11.204	.717	.000
Chami Design Washington Style	IDOT Standard Vest	6.738	.529	.000
	IDOT LED Vest	10.923	.505	.000
	Head Lite Roadstar 200	-.013	.626	1.000
	Iron Horse Texas Style	2.051	.547	.003
	Safetyline Minnesota Style	-9.153	.762	.000
Safetyline Minnesota Style	IDOT Standard Vest	15.891	.704	.000
	IDOT LED Vest	20.076	.686	.000
	Head Lite Roadstar 200	9.140	.780	.000
	Iron Horse Texas Style	11.204	.717	.000
	Chami Design Washington Style	9.153	.762	.000

Ranking of Sides / First Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	3.067	.235	.000
	Head Lite Roadstar 200	-30.121	.212	.000
	Iron Horse Texas Style	-12.244	.210	.000
	Chami Design Washington Style	-29.163	.285	.000
	Safetyline Minnesota Style	-37.661	.248	.000
IDOT LED Vest	IDOT Standard Vest	-3.067	.235	.000
	Head Lite Roadstar 200	-33.188	.223	.000
	Iron Horse Texas Style	-15.311	.222	.000
	Chami Design Washington Style	-32.230	.294	.000
	Safetyline Minnesota Style	-40.728	.258	.000
Head Lite Roadstar 200	IDOT Standard Vest	30.121	.212	.000
	IDOT LED Vest	33.188	.223	.000
	Iron Horse Texas Style	17.877	.197	.000
	Chami Design Washington Style	.958	.275	.008
	Safetyline Minnesota Style	-7.540	.236	.000
Iron Horse Texas Style	IDOT Standard Vest	12.244	.210	.000
	IDOT LED Vest	15.311	.222	.000
	Head Lite Roadstar 200	-17.877	.197	.000
	Chami Design Washington Style	-16.918	.274	.000
	Safetyline Minnesota Style	-25.416	.235	.000
Chami Design Washington Style	IDOT Standard Vest	29.163	.285	.000
	IDOT LED Vest	32.230	.294	.000
	Head Lite Roadstar 200	-.958	.275	.008
	Iron Horse Texas Style	16.918	.274	.000
	Safetyline Minnesota Style	-8.498	.304	.000
Safetyline Minnesota Style	IDOT Standard Vest	37.661	.248	.000
	IDOT LED Vest	40.728	.258	.000
	Head Lite Roadstar 200	7.540	.236	.000
	Iron Horse Texas Style	25.416	.235	.000
	Chami Design Washington Style	8.498	.304	.000

Ranking of Sides / Second Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	6.843	.226	.000
	Head Lite Roadstar 200	-60.452	.379	.000
	Iron Horse Texas Style	-15.870	.403	.000
	Chami Design Washington Style	-44.903	.402	.000
	Safetyline Minnesota Style	-80.289	.350	.000
IDOT LED Vest	IDOT Standard Vest	-6.843	.226	.000
	Head Lite Roadstar 200	-67.295	.384	.000
	Iron Horse Texas Style	-22.713	.408	.000
	Chami Design Washington Style	-51.746	.407	.000
	Safetyline Minnesota Style	-87.132	.355	.000
Head Lite Roadstar 200	IDOT Standard Vest	60.452	.379	.000
	IDOT LED Vest	67.295	.384	.000
	Iron Horse Texas Style	44.582	.509	.000
	Chami Design Washington Style	15.548	.508	.000
	Safetyline Minnesota Style	-19.837	.467	.000
Iron Horse Texas Style	IDOT Standard Vest	15.870	.403	.000
	IDOT LED Vest	22.713	.408	.000
	Head Lite Roadstar 200	-44.582	.509	.000
	Chami Design Washington Style	-29.034	.526	.000
	Safetyline Minnesota Style	-64.419	.487	.000
Chami Design Washington Style	IDOT Standard Vest	44.903	.402	.000
	IDOT LED Vest	51.746	.407	.000
	Head Lite Roadstar 200	-15.548	.508	.000
	Iron Horse Texas Style	29.034	.526	.000
	Safetyline Minnesota Style	-35.385	.486	.000
Safetyline Minnesota Style	IDOT Standard Vest	80.289	.350	.000
	IDOT LED Vest	87.132	.355	.000
	Head Lite Roadstar 200	19.837	.467	.000
	Iron Horse Texas Style	64.419	.487	.000
	Chami Design Washington Style	35.385	.486	.000

Ranking of Sides / Third Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	-6.950	.641	.000
	Head Lite Roadstar 200	-7.207	.454	.000
	Iron Horse Texas Style	-16.229	.767	.000
	Chami Design Washington Style	-7.860	.477	.000
	Safetyline Minnesota Style	-25.891	.771	.000
IDOT LED Vest	IDOT Standard Vest	6.950	.641	.000
	Head Lite Roadstar 200	-.257	.689	1.000
	Iron Horse Texas Style	-9.279	.926	.000
	Chami Design Washington Style	-.911	.705	.963
	Safetyline Minnesota Style	-18.941	.930	.000
Head Lite Roadstar 200	IDOT Standard Vest	7.207	.454	.000
	IDOT LED Vest	.257	.689	1.000
	Iron Horse Texas Style	-9.022	.809	.000
	Chami Design Washington Style	-.654	.541	.979
	Safetyline Minnesota Style	-18.684	.812	.000
Iron Horse Texas Style	IDOT Standard Vest	16.229	.767	.000
	IDOT LED Vest	9.279	.926	.000
	Head Lite Roadstar 200	9.022	.809	.000
	Chami Design Washington Style	8.369	.822	.000
	Safetyline Minnesota Style	-9.662	1.021	.000
Chami Design Washington Style	IDOT Standard Vest	7.860	.477	.000
	IDOT LED Vest	.911	.705	.963
	Head Lite Roadstar 200	.654	.541	.979
	Iron Horse Texas Style	-8.369	.822	.000
	Safetyline Minnesota Style	-18.030	.826	.000
Safetyline Minnesota Style	IDOT Standard Vest	25.891	.771	.000
	IDOT LED Vest	18.941	.930	.000
	Head Lite Roadstar 200	18.684	.812	.000
	Iron Horse Texas Style	9.662	1.021	.000
	Chami Design Washington Style	18.030	.826	.000

Ranking of Sides / Fourth Site

Results of Tamhane's T2 Tests

(I) Vest	(J) Vest	Mean Difference (I-J)	Std. Error	Sig.
IDOT Standard Vest	IDOT LED Vest	6.800	.309	.000
	Head Lite Roadstar 200	-5.802	.279	.000
	Iron Horse Texas Style	-4.153	.167	.000
	Chami Design Washington Style	-6.940	.330	.000
	Safetyline Minnesota Style	-11.517	.266	.000
IDOT LED Vest	IDOT Standard Vest	-6.800	.309	.000
	Head Lite Roadstar 200	-12.602	.375	.000
	Iron Horse Texas Style	-10.953	.301	.000
	Chami Design Washington Style	-13.740	.415	.000
	Safetyline Minnesota Style	-18.317	.366	.000
Head Lite Roadstar 200	IDOT Standard Vest	5.802	.279	.000
	IDOT LED Vest	12.602	.375	.000
	Iron Horse Texas Style	1.649	.271	.000
	Chami Design Washington Style	-1.138	.393	.056
	Safetyline Minnesota Style	-5.715	.341	.000
Iron Horse Texas Style	IDOT Standard Vest	4.153	.167	.000
	IDOT LED Vest	10.953	.301	.000
	Head Lite Roadstar 200	-1.649	.271	.000
	Chami Design Washington Style	-2.787	.323	.000
	Safetyline Minnesota Style	-7.364	.257	.000
Chami Design Washington Style	IDOT Standard Vest	6.940	.330	.000
	IDOT LED Vest	13.740	.415	.000
	Head Lite Roadstar 200	1.138	.393	.056
	Iron Horse Texas Style	2.787	.323	.000
	Safetyline Minnesota Style	-4.577	.384	.000
Safetyline Minnesota Style	IDOT Standard Vest	11.517	.266	.000
	IDOT LED Vest	18.317	.366	.000
	Head Lite Roadstar 200	5.715	.341	.000
	Iron Horse Texas Style	7.364	.257	.000
	Chami Design Washington Style	4.577	.384	.000