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Research-to-Practice (R2P) Tools for Improving Safety in Nighttime Highway Construction Work Zones

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Abstract

The safety of workers in nighttime roadway work zones has become a major concern for state transportation agencies due to the increase in the number of work zone fatalities. During the last decade, several studies have focused on the improvement of safety in nighttime roadway work zones; but the element that is still missing is a set of tools for translating the research results into practice. This paper discusses: 1) the importance of translating the research results related to the safety of workers and safety planning of nighttime work zones into practice, and 2) examples of tools that can be used for translating the results of such studies into practice. A tool that can propose safety recommendations in nighttime work zones and a web-based safety training tool for workers are presented in this paper. The tools were created as a component of a five-year research study on the assessment of the safety of nighttime roadway construction. The objectives of both tools are explained as well as their functionalities (i.e., what the tools can do for the users); their components (e.g., knowledge base, database, and interfaces); and their structures (i.e., how the components of the tools are organized to meet the objectives). Evaluations by the proposed users of each tool are also presented.

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I. Introduction

Nighttime construction and maintenance work on highways is becoming very common in the U.S. Most of the U.S. highways were built in the 1960s and 1970s with a design life of 30 years, and it is estimated that about 33% of the nation's highways have exceeded their design lives. According to the Federal Highway Administration (FHWA) in 2007, the estimated cost to maintain U.S. highways and bridges in order to ensure an efficient roadway system for the use of the traveling public over the 20-year period from 2005 to 2024 would be about US$78.8 billion, stated in constant 2004 dollars.

Construction and maintenance work on highways is now being performed at night in order to reduce the inconvenience that daytime construction causes for the public, especially the problem of traffic congestion. While beneficial to the traveling public, the practice of conducting nighttime highway operations forces contractors to work in an environment which is very different from their usual daytime operations. Based on the data on fatal accidents in highway work zones in the State of Illinois in the five-year study period of 1996–2001, Arditi et al. (2007) concluded that nighttime construction is about five times more hazardous than daytime construction. Safety is one of the major concerns of the contractor while deciding to work at night, and the work may be performed differently from identical daytime operations due to safety reasons (Hancher and Taylor 2001).

To respond to the safety concerns presented by nighttime highway construction and maintenance operations, several research studies exploring different aspects of the safety of nighttime operations have been conducted. For example, El-Reyes and Hyari (2002) developed a decision support system (DSS) to optimize the lighting variables in work zones; Holguín-Veras (2003) emphasized the significance of lighting for the improvement of safety of nighttime work zones; Ellis et al. (2003) assessed appropriate levels of illumination of nighttime work zones; Bryden and Mace (2002) assessed traffic control practices in nighttime work zones; El-Reyes and Hyari (2005) developed a tool called CONLIGHT to assess the performance of lighting in nighttime work zones; Hyari and El-Reyes (2006) developed a framework for evaluating the lighting requirements of nighttime work zones;

Burgess et al. (2007) assessed the effectiveness of different traffic control strategies for nighttime operations; Miller (2007) and Miller et al. (2009) assessed different speed control practices in nighttime work zones; and Valentin (2007) and Valentin et al. (2010) assessed the effectiveness of various personnel protective equipment (PPE) used in nighttime highway operations. Mostafavi et al (201X) evaluated the impacts of nighttime factors on the productivity of construction projects.

As shown in Figure 1, the knowledge management cycle for new information development includes four fundamental phases: observation and analysis, theory generation, testing and application, and consolidation (Silver and Shakshuki 2002). The last two phases of KM (i.e., testing and application and consolidation) are considered to be the research to practice (R2P) phases and have not gained sufficient attention in the area of safety of nighttime operations. Testing and application refers to the application of the findings of the research studies in practice, and knowledge consolidation refers to the diffusion of new information and knowledge into the current body of knowledge and practice. The information and knowledge generated from research studies should be processed and transferred into practice so that the practitioners benefit from it. So far, many of the research studies on the safety of nighttime highway operations have covered the first two phases of knowledge management (KM) cycle: observation and analysis (e.g., Burgess et al. (2007), Miller (2009), and Valentin (2010)) and theory generation (e.g., Hancher and Taylor (2001), Holguín-Veras (2003), and Arditi et al. (2007)).

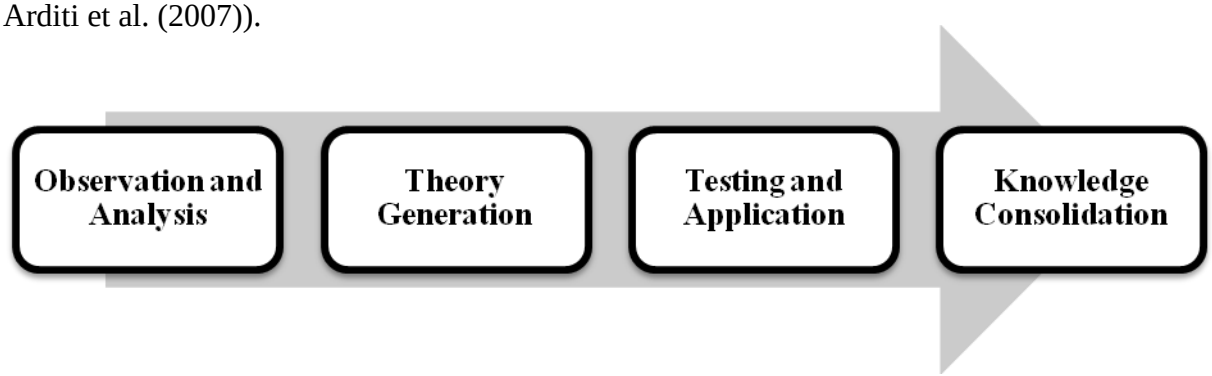

Figure 1- Knowledge management cycle (Silver and Shakshuki 2002)

Knowledge management systems (KMS) have gained popularity in implementation of KM. There are different forms of KMS: knowledge databases, decision support systems, web-

based learning, training tools, etc. KMS are useful in transferring the findings of research studies into practice. This paper discusses three R2P tools that were developed as part of a research study (Grant No.1 R01 0H07553, Safety of Nighttime Construction Operations) funded by the National Institute of Occupational Safety and Health to bridge the gap in the KM cycle in the area of safety of nighttime highway construction and maintenance operations: (1) a tool for developing safety recommendations for nighttime highway operations, (2) a web-based training tool for nighttime highway operations, and (3) course modules for undergraduate students in the area of construction safety. The goals, functionalities (i.e., what the tools can do for the users), the components (e.g., knowledge base, database, and interfaces), the structures (i.e., how the components of the tools are organized to meet the objectives), and the evaluations of each tool are explained in the following sections.

II. Safety Recommendations Tools for Nighttime Highway Operations

The objective of the safety recommendations tool is to provide recommendations regarding the safety of nighttime highway operations based on different project characteristics and activities. The recommendations are a compilation of applicable standards, such as the Manual on Uniform Traffic Control Devices (MUTCD), and the findings of research studies such as Bryden and Mace (2002), Miller (2009), and Valentin (2010). The recommendations tool facilitates the application and consolidation of the findings of prior research studies regarding the safety of nighttime operations into practice. The recommendations provided are based on general conditions typically present at job sites and are not specific to any particular job site. Therefore, it is not intended for the tool to provide a decision for the project engineer, but rather to assist in the consideration of the safety aspects, which are dependent on the type of activities to be performed and on the characteristics of specific projects operating at nighttime. The tool is not intended to replace any existing safety training and/or manuals but to complement them instead.

Structure and components

The safety recommendations tool consists of a knowledge database that stores information in different categories, an interface engine to receive the user input, and a report generating algorithm to print the recommendation reports. Figure 2 shows the structure of the recommendation tool. The tool can provide one of two types of recommendations; (1) site-based and (2) task-based, depending on the type of project, as shown in Figure 3. The site-based recommendations consider the type of site, based on whether maintenance activities or construction activities will be performed during the nighttime operation. Four different activities for both maintenance (i.e., asphalt resurfacing, concrete repair, bridge repair and crack sealing) and construction operations (i.e., hot-mixed asphalt paving, concrete paving, concrete barriers, and bridge construction) were included in the tool. Each one of these activities was divided into sub-activities. Task-based operations consider three typical activities performed as part of highway operations: (1) closing lanes, (2) flagger operations, and (3) shoulder operations.

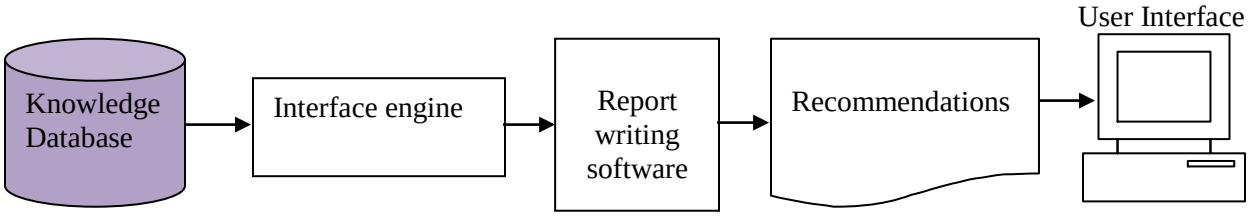

Figure 2. Structure of the tool for safety recommendations

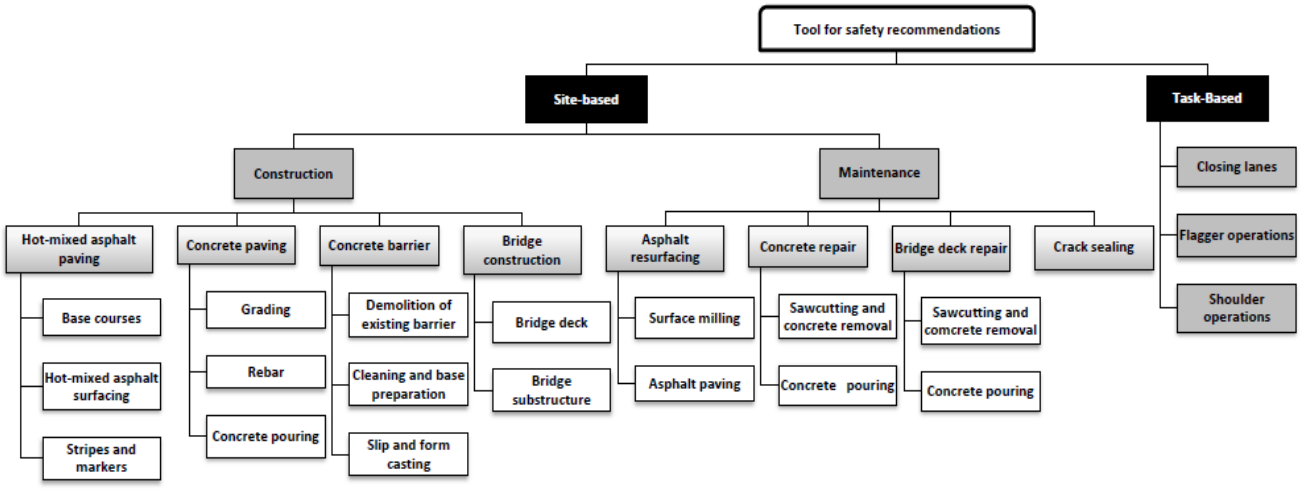

Figure 3. Categories and sub-categories of site-based and task-based recommendations

The content of the database is easily editable so that the database can be adapted to the needs of the user and the applicable regulations. The recommendations tool consists of five main consecutive screens, which are described in Table 1. In each screen, the user enters specific inputs, which are used to refine the information to be used in the recommendations. In the *project information* screen, the user enters project information such as the name, contract number, and duration of the project, which identifies the project, and the safety recommendations. In the *project type* screen, the user enters input regarding the type of work site and activities performed. In the *project characteristics* screen, the user enters input regarding the characteristics (e.g., number of workers, length of the work zone, original speed limit, etc.) of the project for which safety recommendations are sought. Figure 4 is a screenshot of the "Project Characteristics" screen. The input here is used in the selection of the safety information available in the database to match the specified project type and characteristics. For instance, when a user defines the original speed limit of the highway in which the work zone is set up, the safety recommendations will be tailored based on the specified speed limit. The output of the safety recommendations tool is grouped within four main categories: (1) lighting, (2) traffic control, (3) personal protective equipment, and (4) general awareness. Within each category, and when applicable, recommendations are given in each one of the sub-categories listed in Table 2.

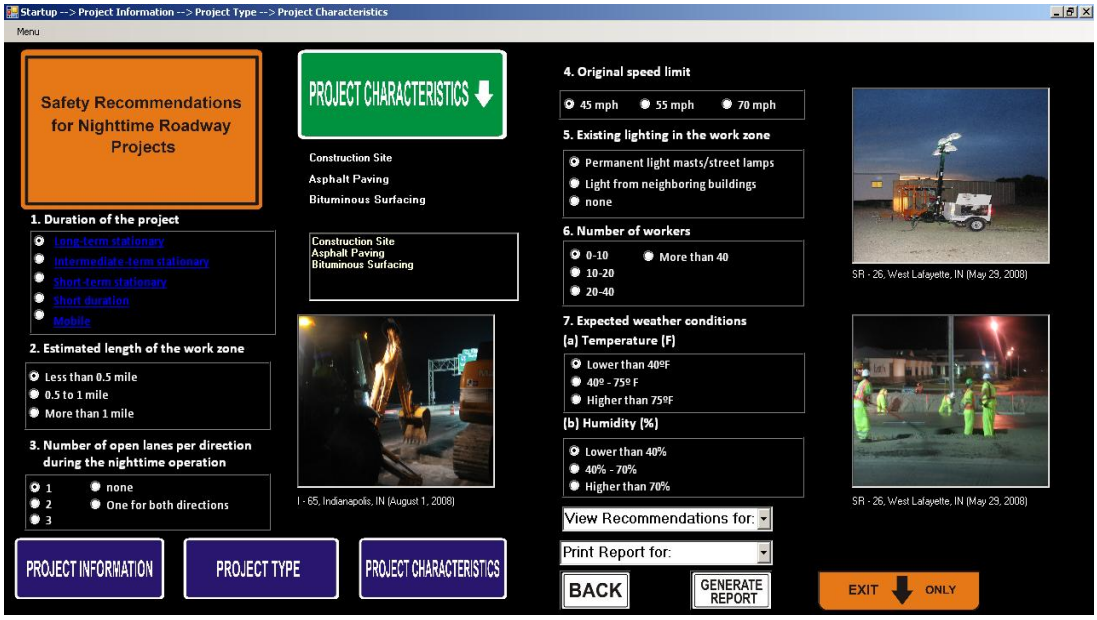

Figure 4. Graphic user interface of the project characteristics screen

Table 1. Description of the screens in the tool for safety recommendations

Screen Name	**User Input**	**Additional information**
Introductory screen	N/A	- Provides access to credits and references used in the output of the tool. - Refers to the grant received from NIOSH. - States the disclaimer for using the tool.
Project information	- Project name - Project location - Project duration (start and end dates) - Contract number	This information is used to record the project and the safety recommendations
Project type	Activity-related characteristics: - Type of recommendation (site-based, task-based) - Type of site - Activity to be performed - Sub-activity to be performed	The program, upon the user's request, provides a definition and a figure of each sub-activity
Project characteristics	Project- related characteristics: - Duration of the project (as defined by the 2009 MUTCD) - Estimated length of the work zone - Number of open lanes per direction - Original speed limit - Existing lighting in the work zone - Number of workers - Expected weather conditions: (a) temperature (b) humidity	The user has the option to view the recommendations in a new screen or to print out a report
Recommendations	N/A	In this screen the user is able to access the recommendations applicable to the set of characteristics without having to print out a report

Table 2. Recommendation categories in the tool for safety recommendations

Recommendation Category	**Sub-categories**
Lighting	▪ Minimum illuminance level ▪ General lighting ▪ Task lighting ▪ Lighting layout
Traffic Control	▪ Speed control ▪ Signing ▪ Channelizing devices ▪ Safety equipment
Personal Protective Equipment	▪ High visibility protection ▪ Head protection ▪ Hands and arm protection ▪ Hearing protection ▪ Eye and face protection ▪ Foot and leg protection ▪ Respiratory protection
Recommendations Regarding General Awareness	▪ Awareness and accidents

Evaluation of the tool

During nine on-site validation/evaluation meetings, nine groups of potential stakeholders (64 individuals total) evaluated the tool; see Table 3 for more details about the groups. After the nighttime safety recommendations tool was briefly demonstrated, evaluation questionnaires were distributed to each group. The individuals in each group had the opportunity to use the tool and obtain safety recommendations for a specified project before completing a questionnaire about the features and content of the tool and any recommendations the users had on improving the tool. Figure 5 shows the results of the evaluation of the tool for each of the evaluated categories. After each validation meeting, the recommendations received from the stakeholders were reviewed and used to improve the content, presentation screens, and output of the tool.

Table 3.Groups involved in validation of the Safety Recommendations tool

Group	**Number of Evaluators**	**Date**
Indiana Department of Transportation (INDOT),	1	04/09/2009
INDOT LaPorte Highway SubDistrict Office	2	04/17/2009
INDOT Work Zone Safety Division	6	05/05/2009
INDOT's Indianapolis Subdistrict Office Nighttime Crew	13	05/05/2009
INDOT Safety Directors	7	05/13/2009
Indiana Contractors Association (ICA)**,** Indiana Department of Transportation (INDOT), Indiana Division of the Occupational Safety and Health Administration (IOSHA), and the Indiana State Police (ISP) Safety Joint Cooperative Committee	18	05/13/2009
La Porte Sub-District Office - Safety Review Meeting	12	09/10/2009
Faculty members from U.S. universities	5	02/09/2011

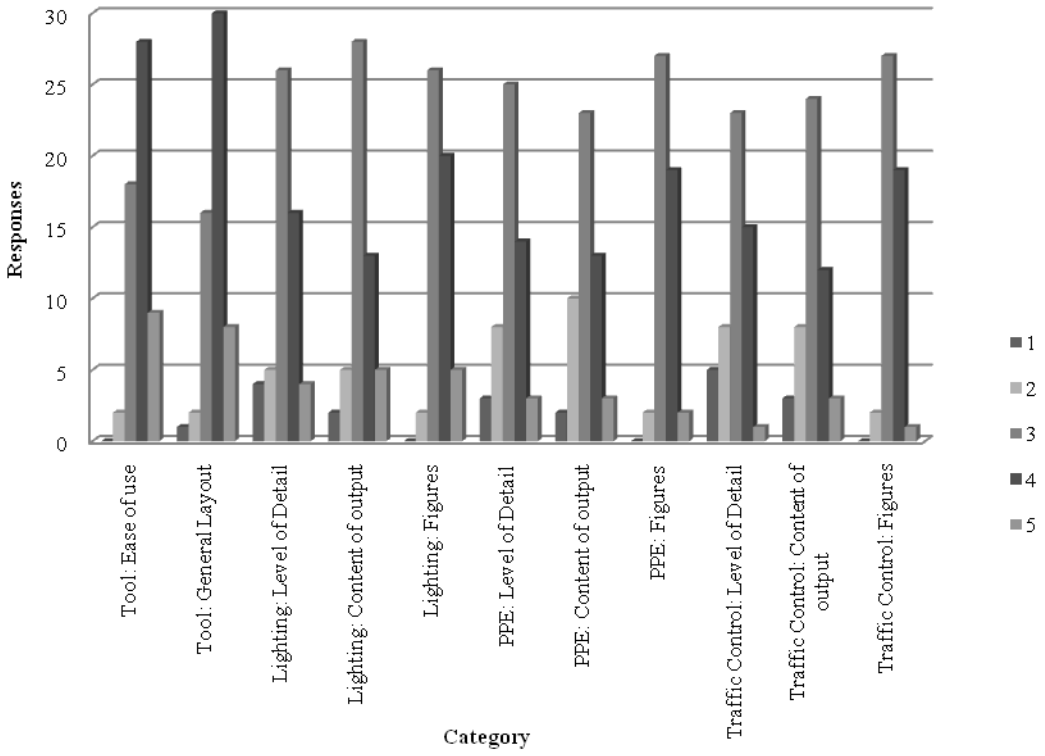

Figure 5. Results from the evaluations (1- Needs improvement, 2 - Needs minor changes, 3 – Good enough, 4- Very good, 5 – Excellent) (y- axis – Number of responses)

III. Safety Course Modules

According to Usmen (1994), the role of engineers is to seek opportunities to eliminate or minimize unsafe acts and conditions through their roles in design, management, and training. The objective of the course modules in construction safety is to provide training to future and current engineers about the importance of safety in project goals, devising safety strategies, and good and poor safety practices at the job site.

Structure and components

The course modules consist of three PowerPoint presentations: (1) Construction Safety: An Overview, (2) Construction Safety: Focus on Highway Construction, (3) Construction Safety: Focus on Nighttime Operations. The content of each module is summarized in Table 4.

Validation

In spring 2010, the course modules were presented to a total of 54 undergraduate students at Purdue University in West Lafayette, Indiana as part of the course "CE 497- Life Cycle Engineering and Management of Constructed Facilities." After the modules were presented, the students were asked to complete an evaluation survey. In addition, the course modules were evaluated by five faculty members from U.S. universities. Based on the recommendations of the faculty members and the students, additional photos and videos were included in the tool, and the text in some of the slides was enhanced.

Table 4.Summary of the content of the course modules

Course Module	Sections	Content
Construction Safety: An Overview	Role of safety	- Construction project metrics - Examples of impacts of safety violations - Occupational and fatal injuries statistics - Fatal falls
	Accidents in construction	- What is an accident - Causes of accidents - Examples of unsafe acts - Examples of unsafe conditions - Worker's poor attitudes and behavior - Other issues affecting safety
	Motivation for safety practices	- Statistics - Impacts of injuries and fatalities
	Metrics	- Safety metrics - Factors motivating safe job site practices
	Regulations	- Federal legislations and regulations - OSHA requirements - Application of the OSHA law - Application of state and federal OSHA provisions
	Strategies	- Working safely - OSHA training - Safety program
Construction Safety: Focus on Highway Construction	Violations in highway construction	- Examples of impacts of safety violations
	Statistics	- Statistics on injuries and fatalities in highway operations.
	Causes of accidents	- Hazards leading to serious or fatal occupational injuries in work zone - Typical behavioral causes of safety incidents in work zones - Typical accident events in work zones
	Legislation and regulations	- MUTCD - Worker visibility (23CFR634.1)
	Safety strategies	- National Highway Work Zone Safety Information Clearinghouse - Components of a temporary traffic control zone - Type of roadway operations considering duration - Examples of safety strategies
Construction Safety: Focus on Nighttime Operations	Introduction	- Nighttime operations statistics - Why nighttime operations - Advantages and issues - Noise control - Speed
	Lighting	- Lighting issues - Factors affecting illumination requirements - Lighting equipment alternatives - Recommended illuminance levels
	Traffic Control	- Factors considered when establishing temporary signing - Speed control methods - Work zone implementation
	Personal Protective Equipment	- Importance - Factors that determine the effectiveness of PPE - Additional information - ANSI-ISEA 107 2004 - Retroreflectivity (cd/lx*m^2)
	Awareness and Training	- Role of the engineer - Unsafe practices

IV. Nighttime Safety Web-based Training Tool

The objective of the web-based training tool for nighttime highway operations is to provide preliminary training to workers and engineers who are new to nighttime highway construction operations. The training tool is designed to be used by organizations, personnel, and workers who are involved in nighttime highway construction and maintenance operations to provide basic safety training. Similar to the tool for safety recommendations discussed in Section II, the intent of this training tool is not to replace any applicable or existing guideline or training material, but rather to complement them. The materials provided in the tool are based on general conditions typically present on jobsites, and are not specific to any particular job site.

Structure and components

The tool was developed using HTML language and consists of the three major components shown in Figure 6: network database, content database, and quiz database. The databases were developed using Microsoft Access tables and are stored on a Purdue University server (http://rebar.ecn.purdue.edu/nighttime/index.aspx). The function of the network database is to store the information about the trainees (e.g., trainee name, name of organization, username and password, and the information related to completion of quizzes. The first time a user accesses the tool, setting up a login is necessary in order to access to the tool (Figure 7). The login information is stored in the network database. The network database is a dynamic database which is updated as a trainee progresses through the quizzes related to the learning modules. The function of the content database is to store the learning modules. The learning modules are created in the form of web pages in HTML language. The function of the quiz database is to store the question banks. For each learning module, there is a quiz to be completed by the trainees. The questions presented in the quizzes are randomly chosen from question banks related to the learning modules. Therefore, when a trainee retakes a quiz, a different set of questions is presented.

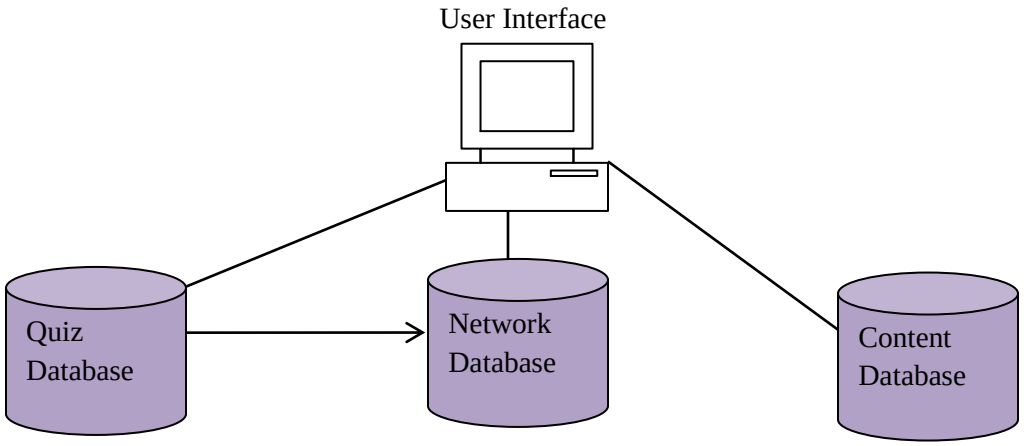

Figure 6. Structure of the Training Tool

Figure 7. Login set up for the first time users

Learning Modules

There are four main topics covered in the training tool: traffic control, lighting, personal protective equipment (PPE), and awareness. Each of these topics includes different learning modules. The list of learning modules is presented in Table 5. The *nighttime work zones* module discusses the parts and planning issues of nighttime work zones. Important considerations in planning the layout of nighttime work zones, internal traffic control plans, and external traffic control plans are discussed in this module.

The *channelizing devices* module discusses the purpose of channelizing devices. and their layout and spacing considerations are explained. The *work zone signs* module discusses the

use of temporary signs for traffic control in work zones. The characteristics of different temporary signs, such as warning signs, regulatory signs, and information signs and their locations in nighttime work ones, are presented. The *speed control module* discusses the key features of speed control techniques typically used in nighttime work zones. The *lighting in nighttime work* module discusses the different aspects of lighting in nighttime work zones. The minimum illuminance levels for different construction operations are discussed, and lighting design considerations are explained. The *lighting equipment* module discusses the key features of temporary lighting equipment as well as lighting sources and different configurations of lighting systems. The *Personal protective equipment (PPE)* module discusses the different types and applications of protective equipment and addresses issues related to the selection of PPE for nighttime operations. The *Awareness* module discusses the main causes of accidents in nighttime work zones. The module explains the importance of awareness in nighttime work zones and provides examples of good practices and poor practices using photographs.

Table 5. Learning Modules

Topic	**Learning Module**
Traffic Control	Nighttime Work Zones
	Channelizing Devices
	Work Zone Signs
	Speed Control
Lighting	Lighting in Nighttime Work
	Lighting Equipment
PPE	PPE Types and Applications
Awareness	Awareness Issues

The content of the learning modules includes: 1) the findings of the research studies in the area of safety in nighttime construction operations, such as the findings related to safety management strategies, speed control, traffic control, PPE, and lighting considerations; and 2) information from relevant guidelines and specifications, such as the MUTCD, and information from the current nighttime safety literature (e.g., Bryden and Mace (2002), Burgess et al. (2007), Miller (2009) and Valentin (2010)) is also used. The references are also provided in order that a trainee can refer to them for more information. Figure 8 shows a screenshot of a learning module.

Figure 8. A screenshot of a learning module

Quizzes

There is a quiz associated with each learning module. The questions in each quiz are randomly chosen from the question bank related to the learning module. The questions are designed to ensure that trainees "learn" the materials presented in the modules. The passing grade for each quiz is 80%. If a trainee fails to complete the quiz satisfactorily, reviewing the learning module again and retaking the quiz are possible. To ensure the learning process, the questions in each quiz are randomly changed each time. The information related to the trainee's progress related to the completion of the quizzes is stored in the network module. Trainees can track their progress at the quiz progress page (Figure 9).

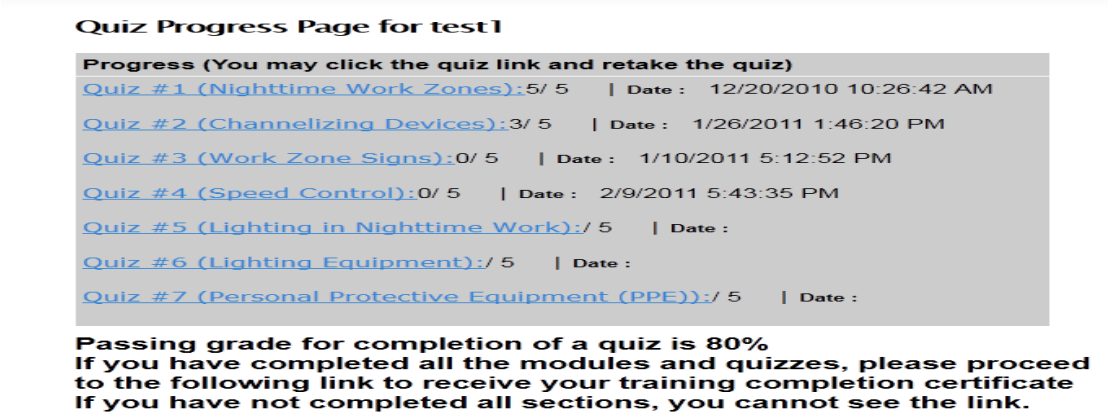

Figure 9. A screenshot of the trainee's quiz progress page

When all of the learning modules and related quizzes are completed successfully by a trainee, a completion certificate is presented to the trainee, and this certificate can be printed. Figure 10 shows the completion certificate.

NIGHTTIME CONSTRUCTION SAFETY TRAINING TOOL – COMPLETION REPORT

This is to certify that Mr. / Ms. test1 test1 has completed the Nighttime Construction Safety Training tool.
The tool provided web-based training regarding safety in nighttime construction operations*.
The summary of the trainee's completion of the training modules is presented in the following table:

Progress (You may click the quiz link and retake the quiz)			
Module	**Completion Date**	**Score obtained and Percentage**	**Completion Status**
Quiz #1 (Nighttime Work Zones):	12/20/2010 10:26:42 AM	5/ 5, 100%	COMPLETED
Quiz #2 (Channelizing Devices):	3/12/2011 11:33:16 AM	4/ 5, 80%	COMPLETED
Quiz #3 (Work Zone Signs):	3/12/2011 11:34:03 AM	5/ 5, 100%	COMPLETED
Quiz #4 (Speed Control):	3/12/2011 11:38:04 AM	4/ 5, 80%	COMPLETED
Quiz #5 (Lighting in Nighttime Work):	3/12/2011 11:39:20 AM	5/ 5, 100%	COMPLETED
Quiz #6 (Lighting Equipment):	3/12/2011 11:41:04 AM	5/ 5, 100%	COMPLETED
Quiz #7 (Personal Protective Equipment (PPE)):	3/12/2011 11:42:37 AM	4/ 5, 80%	COMPLETED

Figure 10. A screenshot of the training completion certificate

Validation of the Safety Training Tool

The initial version of the training tool was tested by four faculty members in construction engineering from different universities in the U.S. who have conducted extensive research related to the safety of construction operations. They evaluated the training tool in terms of the content of the learning modules and quizzes and the structure of the tool. Table 6 summarizes the faculty members' evaluations of the tool, where the number in each cell represents the number of faculty members who rated a specific characteristic of the tool.

Table 6.Summary of the evaluation of the Safety Training Tool

Web-based Nighttime Safety Training Tool					
Characteristics of the Tools	**Evaluation**				
	Needs Improvement		**Good**		**Excellent**
	1	**2**	**3**	**4**	**5**
Comprehensiveness of the Topics			2	2	
User Interface			2	2	
Graphics and figures		1	2	2	
User friendliness			3	1	
Organization of Modules			3	1	
Depth of Contents			3	1	
Structure of Quizzes			3	1	
Structure of the Tool			3	1	
Functionality			3	1	
	Not of Value		**Moderate Level of Value**		**Significant Value**
Value to Safety personnel in Industry			1	2	1
Overall Evaluation of Modules			1	2	1
Overall Evaluation of Quizzes			1	3	

V. Summary and Conclusions

Research-to-practice tools are needed to facilitate application and consolidation of the new knowledge created in research studies related to the safety of nighttime highway operations. Three research-to-practice tools related to the safety of nighttime highway operations were presented in this paper, and their objectives, components, structures, and functionalities were discussed in detail. These tools have the potential to facilitate diffusion of research findings related to the safety of nighttime operations into practice and enhance the knowledge consolidation in this area.

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