OSU/State
Agreement No.30530

Research Project Work Plan

for

Use of Additional Lighting for Traffic Control and Speed Reduction in Work Zones

SPR 791

Submitted by:

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1.0 IDENTIFICATION

1.1 Organizations Sponsoring Research:

Oregon Department of Transportation (ODOT)
Research Unit
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Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator (PI):

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1.3 Technical Advisory Committee (TAC) Members:

Jon Lazarus, ODOT Research Unit, Research Coordinator,
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Ernest Kim, ODOT Illumination Engineer , Ernest.C.KIM@odot.state.or.us
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1.4 Project Champion:

Bob Pappe, State Roadway/Traffic Engineer,
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1.5 Friends of the Committee:

TBD....

2.0 PROBLEM STATEMENT

Much of the construction work that occurs on high-speed roadways takes place at night in order to minimize impacts to drivers. Performing work at night exposes workers to hazards that are not present or as great during the daytime, such as the presence of impaired drivers, a lack of sufficient lighting, and icy roadway conditions. As a result, special measures are taken during nighttime work to protect workers and motorists in work zones. Examples of these additional safety controls are: workers wearing reflective clothing, flaggers using lighted STOP/SLOW paddles, and the use of illuminated signs for traffic control.

Working at night also requires illuminating the area where work is taking place in order to provide sufficient lighting for the workers to see their work and the surrounding area. To ensure adequate lighting while conducting work, the Occupational Safety and Health Administration (OSHA), for example, specifies minimum illumination intensities for different types of work operations (OSHA 2015). FHWA (2003) also publishes recommended levels of lighting specifically for roadway work zones. To provide the necessary lighting, construction crews typically employ light towers, balloon lights, or other types of commercially available lighting systems. The actual type of lighting system used for a work operation depends on various factors such as the amount of light needed and the nature of the work operation (e.g., stationary or mobile, and short- or long-term).

Previous research has been conducted related to the illumination of workers on roadways. In 2005, OSU conducted a study for ODOT (SPR 617) to determine optimal illumination of flaggers during nighttime flagging operations (Gambatese and Rajendran 2012; Gambatese 2005). This study led to changes in the ODOT specifications for flagger illumination. Additional research studies conducted across the US that focused on flaggers and work area illumination reveals evidence of the need for sufficient lighting to benefit worker safety, and provides helpful guidance on how to select appropriate light systems, identify needed illumination levels, and orient light systems for optimal worker performance and safety (e.g., Finley et al. 2014; Hassan et al. 2010; El-Rayes et al. 2008; Bryden and Mace 2002; Hanna 1996; Ellis and Amos 1996).

Recent studies conducted by OSU for ODOT (SPR 751 and SPR 769) involved assessments of traffic control measures for pavement preservation project work zones (Gambatese and Zhang 2014, 2015; Gambatese et al. 2013). These studies revealed that motorists tend to slow down next to active work areas containing large pieces of equipment with surrounding work area lighting. As the drivers approach a paver with multiple lights and workers present, for example, vehicle speed reduces to a minimum near the paver and then starts to increase a short distance downstream of the paver. Although not tested as part of the research studies, the reduction in speed is assumed to be due in part to the lighting provided to conduct the work. The lighting makes the workers and equipment more visible and places emphasis on their presence. Consequently, drivers are more aware of the workers, how close the workers are to the travel

lane and, as a result, tend to reduce their speed. The studies did not reveal a similar reduction in speed next to work areas/equipment lacking such illumination.

It is important to note that when conducting highway preservation operations, workers are often located in many different areas of the work zone, not only at the locations of the large pieces of equipment. Project personnel may be working a long distance away from the equipment where light levels are very low. As a result, those workers who are on foot in areas without additional illumination (e.g., traffic control personnel, inspectors, and other contractor personnel) are exposed to safety risk due to both higher vehicle speeds and oftentimes less protection from surrounding equipment. The presence of additional lighting to illuminate these workers is expected to reduce the safety risk exposure of the workers.

The potentially positive impact that work area lighting can have on vehicle speeds is promising for safety in other areas of a work zone. A work zone may extend for several miles. Adding lighting to areas where the paver and typical work area lighting are currently not present may be a low cost means of making motorists more aware of workers on the roadway, reducing vehicle speeds throughout the work zone, and further protecting workers on the roadway. Further research that utilizes the findings of SPR 617, 751, and 769 is needed to assess whether strategically adding lighting to work zones can lead to lower vehicle speeds, reduced speed variance, and lower speeds where workers on foot are present.

Interest in exploring options for additional lighting exists amongst Oregon contractors and trucking companies. The Engineering Enhancement Taskforce, formed as part of the ODOT Director's Work Zone Strategy Sessions, is made up of representatives from ODOT and the Oregon construction and trucking industries. The goal of the Taskforce is to identify and disseminate ways in which work zone safety can be improved. At its recent meetings in December 2014, the Taskforce identified work zone lighting as a top priority idea for improving safety in work zones.

3.0 STUDY OBJECTIVES

The overall goal of the research study is to assist ODOT with enhancing the safety in its work zones and reducing the exposure of its employees to safety risks. To meet this goal, the proposed research study aims to: (1) determine whether additional lighting added at strategic locations throughout a work zone can benefit work zone safety for both motorists and drivers; and (2) develop recommended practices for strategic use of lighting systems in work zones to help control and reduce vehicle speeds. The following specific objectives are proposed for the study:

1. Document current work area lighting systems and practices in preservation project work zones.
2. Determine the typical work patterns and activities in preservation project operations.
3. Identify potential strategies for additional illumination of work zones using available lighting systems.

4. Select and test one or more lighting strategies in an actual work zone to assess the impacts of the lighting on vehicle speeds, worker safety, contractor operations, and work performance.
5. Develop recommendations for ODOT for additional work zone lighting to enhance work zone safety.

Similar to SPR 751 and 769, the proposed study will focus on preservation projects on high-speed roadways. Specifically, the targeted projects will be re-paving projects on high-speed roadways with two travel lanes in each direction. Projects will be selected that have paving work which extends a long distance to capture the cases when workers are not in the vicinity of well-lit equipment. Additionally, the research will target those lighting systems commonly used and studied in SPR 617 (light tower, balloon light, spotlight, and floodlight). These types of lighting systems are the most commonly used systems in work zones and are initially assumed to be feasible options for providing additional lighting throughout the work zone. Only lighting systems that are currently available to the public will be included; the study does not include designing, fabricating, and testing new or modified lighting systems.

The lighting systems included in the study will be purchased, leased, and/or borrowed as part of the study. In addition, the light system vendors/manufacturers will be contacted to ask about the possibility of the light systems being donated for the use in the study. Equipment used to conduct the testing (e.g., roadway speed sensors, video cameras, etc.) is available for use from previous ODOT studies. New research equipment needed to conduct the testing or replace older equipment will be purchased if needed. The researchers will be able to utilize their experience and knowledge learned from past ODOT studies to efficiently and effectively conduct the present research.

3.1 Benefits

ODOT will benefit from the proposed research by having comprehensive and accurate information about the use of additional lighting systems to improve safety in its work zones. The study will complement the previous work zone safety and flagger illumination studies by providing additional knowledge of the performance of light systems in work zones. The study will also result in recommendations for designing additional light systems into traffic control plans on future projects. Implementation of additional lighting is expected to reduce the risk exposure of workers and motorists, lead to fewer worker injuries and fatalities in work zones, and improve mobility through work zones. Lastly, successful completion of the research and implementation of the research results are expected to strengthen the capability of ODOT to design illumination strategies for its work zones.

4.0 IMPLEMENTATION

The product of the research will be a report that describes the identification and testing of lighting systems that are feasible and effective in illuminating workers and provides guidelines and recommendations for their use in practice. The results and product of the research will be used by the Statewide Construction and Maintenance Offices for planning construction and

maintenance work. The research output will also be used by the Transportation Safety Division, and by the Transportation Safety Coordinators in each Region, as a resource for effectively designing work zones and planning construction and maintenance operations.

5.0 RESEARCH TASKS

To conduct the study, the researchers will perform multiple tasks involving collecting information about the targeted lighting systems and evaluating the performance of each lighting system. Data collected will be based on prior research, experiential input and advice from ODOT staff and construction practitioners, and field testing of the lighting systems under controlled conditions and in active work zones. The following table presents the tasks that will be undertaken to conduct the entire research study. The order in which the tasks will be conducted and their timing are shown in Section 6.0. The actual timing and duration of the live testing (Task 6) may vary depending on the construction schedule and progress of case study projects selected for this research and the lighting systems selected for inclusion in the testing. It is expected that the selected case study projects will be undertaken in the 2016 construction season.

ID	Task
1.	**Documentation of Lighting Systems** The researchers will collect and review archival literature on the types and capabilities of currently available lighting systems that have high potential for being used for additional lighting in work zones. To collect the literature, the researchers will conduct a comprehensive search of archival publications and the Internet using on-line search engines. All documents found that are germane to the research topic will be accessed and reviewed. Task 1 will lead to the creation of a catalog of the available lighting systems for use during the research and in the future by ODOT. The catalog will contain a description of each light system along with associated benefits, limitations to its use, and summaries of findings from prior research on the technology. *Cost*: \$6,090 *Duration*: 2 months (Fall 2015) *Deliverable*: Interim report to the TAC describing the results of Tasks 1, 2, and 3. Final report (see Task 8) which includes a description of the results of Task 1. *TAC Decision/Action*: TAC shall meet with the PI at the completion of Tasks 1, 2, and 3, to review the results of these tasks and identify potential lighting strategies for pilot testing. TAC shall also meet with the PI at the completion of the study to review and provide input on the results of this task and final report.

2.	**Survey of Current Practice** The researchers will conduct a survey of state DOTs and state-wide construction and traffic control contractors to document current and recommended practices, barriers, enablers, and impacts associated with work zone lighting systems. The survey instrument will be a questionnaire. The researchers will create a questionnaire that addresses the aims listed above. The TAC will be asked to review the questionnaire and provide feedback prior to its dissemination. The questionnaire will be revised to incorporate the TAC's input, and then distributed by the researchers to the entities listed above. The survey sample will be developed based on input from the TAC, the researcher's personal contacts, and the companies and organizations identified in Task 1. The researchers will collect, record, and analyze the responses to the survey. Task 2 will lead to the identification of the status quo of the construction industry and its current best practices in terms of work zone lighting and the use of lighting systems. *Cost*: \$7,846 *Duration*: 3 months (Fall 2015) *Deliverable*: Interim report to the TAC describing the results of Tasks 1, 2, and 3. Final report (see Task 8) which includes a description of the results of Task 2. *TAC Decision/Action*: TAC shall meet with the PI at the completion of Tasks 1, 2, and 3, to review the results of these tasks and identify potential lighting strategies for pilot testing. TAC shall also meet with the PI at the completion of the study to review and provide input on the results of this task and final report.
3.	**Documentation of Work Operations** This task is intended to provide an understanding of typical work patterns and lighting needs on highway preservation projects. In consultation with the TAC, the researchers will select 2-3 current ODOT preservation projects to study. The researchers will visit the projects and monitor the work operations, especially with regard to those workers who are on the roadway a long distance from lighting and large equipment. The researchers will record the operations, monitor worker movements and locations, and document the equipment utilized and reflective clothing worn by the workers. The researchers will also measure the level of illumination at the work locations. This task is expected to reveal situations in which workers are especially in need of additional lighting and opportunities for additional lighting. *Cost*: \$6,090 *Duration*: 3 months (Winter 2015/Early 2016) *Deliverable*: Interim report to the TAC describing the results of Tasks 1, 2, and 3. Final report (see Task 8) which includes a description of the results of Task 3.

	TAC Decision/Action: TAC shall meet with the PI at the completion of Tasks 1, 2, and 3, to review the results of these tasks and identify potential lighting strategies for pilot testing. TAC shall also meet with the PI at the completion of the study to review and provide input on the results of this task and final report.
4.	**Identify Potential Lighting Strategies** Task 4 will involve conducting focus group sessions with ODOT personnel and construction contractors. The objective of this task to identify and develop promising lighting strategies to implement and test in an active work zone. For example, one lighting strategy may be to have 250-watt, tripod-mounted flood lights set up where quality control personnel check pavement densities upstream of the rollers. The flood lights would be oriented and located such that they illuminate the personnel for on-coming traffic yet do not create disabling glare for the drivers. Another example, if sufficient shoulder width is available, may be to have a dedicated truck towing a portable light tower that follows the quality control personnel and illuminates the personnel as they conduct their work on the roadway. The TAC will be asked to recommend focus group participants from within ODOT and construction companies. The researchers will plan, schedule, and conduct the focus group sessions. A total of 2-3 focus group sessions is assumed. Prior to the focus group meetings, the researchers will develop possible strategies for additional lighting to present at the meetings. In each session, feedback on each of the lighting systems will be solicited. The evaluation of possible strategies will consider lighting system availability, cost, ease of implementation, potential for improving safety, and potential for incorporating the strategies in typical traffic control plans. Those lighting strategies that are deemed promising by the focus group participants, and fit within the research budget, will be selected for testing. *Cost*: $18,680 *Duration*: 3 months (Spring 2016, following completion of Task 3) *Deliverable*: Final report (see Task 8) which includes a description of the results of Task 4. *TAC Decision/Action*: TAC shall meet with the PI at the completion of the study to review and provide input on the results and final report.
5.	**Pilot Testing of Lighting Strategies** Those lighting strategies selected will be pilot tested under controlled, off-roadway conditions to further assess their feasibility and performance. Lighting systems used in the testing will be purchased, leased, borrowed, or if possible, acquired through donations. Each selected lighting strategy will be assessed to evaluate its potential for efficient and economic implementation, its ability to provide effective lighting to illuminate workers,

	and associated limitations to its implementation. As part of the testing, the researchers will determine optimal location and orientation of the light systems, along with an effective amount of light emitted to illuminate the workers without creating disabling glare for drivers. Light meters will be used to measure the amount of illumination in the work area and on the worker. Standard reflective clothing will be worn by participants involved in the testing to simulate working conditions. In conjunction with the pilot testing, the researchers will consult with ODOT to select upcoming preservation projects on which to test each of the strategies as described in Task 6. The case study projects are expected to be paving projects located on high-speed roadways with two lanes in each direction. A total of four case study projects are anticipated for the research study. ODOT will contact the paving contractor(s) regarding conducting the research on the projects, and make the needed contracting or change order requirements necessary to incorporate the research work into the paving projects. Cost impacts to the contractor(s) for conducting the work, if any, are not included in the research budget and are expected to be paid by ODOT directly to the contractor. *Cost*: $46,140 *Duration*: 4 months (Spring/Summer 2016, following completion of Task 4) *Deliverable*: Interim report to the TAC describing the results of Task 5. Final report (see Task 8) which includes a description of the results of Task 5. *TAC Decision/Action*: TAC shall meet with the PI at the completion of this task to review the results of Task 5 and plan the performance of Task 6. TAC shall also meet with the PI at the completion of the study to review and provide input on the results and final report.
6.	**Implement and Test Selected Lighting Strategies** For Task 6, the researchers will implement one or more of the selected lighting strategies on each case study project. The researchers will consult with the TAC to determine which lighting strategies to implement on each project. Depending on the case study projects selected, it is planned to apply the lighting strategies under different work zone and traffic conditions (e.g., A-lane and B-lane, within a straight roadway section and near a horizontal curve, and different days of the week). Each selected lighting strategy will be implemented during actual work operations. The researchers will monitor the installation, use, and removal of the light systems, videotape the operations, and monitor vehicle speeds as needed to assess each lighting strategy. For example, one night of testing will be conducted without the light systems used (baseline case for comparison) and the next night of testing will have the light systems implemented and turned on. The testing results of each technology will be evaluated and compared based on a variety of criteria including: ease of implementation and use, and the impacts on vehicle speeds, speed variability, visibility of workers, worker productivity, and implementation cost. Upon the completion of testing, feedback on each

	lighting system will be collected directly from the construction personnel involved in each case study project. The live testing on multiple case study projects is expected to entail multiple days of observations. For budget purposes, it is assumed that the data collection will be conducted over three days on four different occasions (total of 12 days of testing). This testing is expected to require researcher travel to, and overnight accommodations at, the case study locations due to the proximity of the case study projects relative to Corvallis, OR. This task will use the light systems obtained in Task 5; no additional technologies will be acquired. *Cost*: $57,793 *Duration*: 5 months (Summer/Fall 2016; following completion of Task 5) *Deliverable*: Final report (see Task 8) which includes a description of the results of Task 6. *TAC Decision/Action*: TAC shall meet with the PI at the completion of the study to review and provide input on the results and final report.
7.	**Data Analysis** The data collected from the case study projects will be analyzed to determine the effectiveness of each of the lighting strategies tested. The researchers will compare the vehicle speeds, speed variability, visibility of the workers, worker productivity, and implementation cost associated with the baseline case (without the lighting system) to that when the light system is implemented and turned on. Where appropriate, multi criteria decision analysis will be applied to rank order the effectiveness of each light strategy. Such comparisons are expected to lead to a determination of the relative benefits provided by each light system in effectively and efficiently illuminating construction personnel. *Cost*: $18,347 *Duration*: 3 months (Fall 2016, together with the completion of Task 6) *Deliverable*: Final report (see Task 8) which includes a description of the results of Task 7. *TAC Decision/Action*: TAC shall meet with the PI at the completion of the study to review and provide input on the results and final report.
8.	**Documentation and Dissemination** The researchers will prepare and submit a draft final research report to ODOT for review and comment. The draft report will present the findings of the research and provide recommendations to ODOT for implementation in practice. Following ODOT's review, the draft final research report will be revised based on the comments received from ODOT, and a final research report will be prepared and submitted to ODOT for publication.

	Cost:	$14,014
	Duration:	3 months (Spring 2017, following the completion of Task 7)
	Deliverable:	Final report which includes a description of the results of Tasks 1-7.
	TAC Decision/Action:	TAC shall meet with the PI at the completion of the study to review and provide input on the results and final report.

5.1 Reporting

All reports will be produced in the standard ODOT Research Section report format provided to the Project Investigator by the Research Coordinator unless some other format is deemed to be more appropriate. The Project Investigator will be responsible for submitting reports of professional-level written composition equivalent to the writing standards of peer-reviewed journals. These writing considerations include grammar, spelling, syntax, organization, and conciseness.

The Project Investigator, in consultation with the TAC and Research Coordinator, will deliver to ODOT in electronic format the data produced during the project. The Project Investigator will ensure the data is labeled and organized to facilitate future access. ODOT shall warehouse the data.

5.2 Safety and Related Training

Prior to accessing ODOT right-of-way (ROW), all personnel who will work on ODOT ROW will complete safety training appropriate to the work to be performed within the ROW. The Project Investigator will notify Project Coordinator in writing (email accepted) prior to the first day of work within the ROW that all project personnel who will access ODOT ROW have been trained. Until all ROW work is completed, the Project Investigator shall notify Project Coordinator in writing (email accepted) annually that an active safety training appropriate to the work to be performed within the ROW has been completed by all personnel who will work on ODOT ROW.

6.0 TIME SCHEDULE

This section specifies the timeline for the project, as shown in the table below, listing the task headings and showing monthly time blocks in which each task will be accomplished. Also shown are interim and final deliverables. The proposed research is expected to take 18 months of effort, and for the purposes of this work plan, the starting date is planned for October 1, 2015. As indicated above, the duration and completion of Task 6 will depend on the schedule and progress of the case study projects selected for this research. The timeline shown below assumes that the case study projects will be conducted in the summer and fall of 2016. The timeline may change if the case studies are conducted at later dates.

Project Tasks	FY2016									FY2017								
	Q2			Q3			Q4			Q1			Q2			Q3		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Task 1: Documentation of Lighting Systems Duration: 2 months Deliverable: Interim report (with Tasks 2 and 3), and final report describing results of Task 1																		
Task 2: Survey of Current Practice Duration: 3 months Deliverable: Interim report (with Tasks 1 and 3), and final report describing results of Task 2																		
Task 3: Documentation of Work Operations Duration: 3 months Deliverable: Interim report (with Tasks 1 and 2), and final report describing results of Task 3				* †														
Task 4: Identify Potential Lighting Strategies Duration: 3 months Deliverable: Final report describing results of Task 4																		
Task 5: Pilot Testing of Lighting Strategies Duration: 4 months Deliverable: Interim report and final report describing results of Task 5										* †								
Task 6: Implement and Test Selected Lighting Strategies Duration: 5 months Deliverable: Final report describing results of Task 6																		
Task 7: Data Analysis Duration: 3 months Deliverable: Final report describing results of Task 7																		
Task 8: Documentation and Dissemination Duration: 3 months Deliverable: Draft and final reports describing entire research study																		* †

* = Deliverable
† = TAC Meetings

7.0 BUDGET ESTIMATE

The itemized budget for the research study is shown in the table below. The table presents the expenditures for each item by fiscal year and the total anticipated expenditures. ODOT Administration expenses will be charged internally to the appropriate Expenditure Account (EA), which may involve ODOT staff time on-site, travel expenses, and deliverable review.[1,2] An estimated amount of $20,000 is included in the budget to cover the cost of renting and/or purchasing the lighting systems tested in the study and other needed research equipment. This amount may be less depending on the lighting systems selected in Task 4.

Item	FY2016	FY2017	Total
Personnel			
John Gambatese, OSU (PI)	$13,696	$8,218	$21,914
Graduate Student Researchers, OSU (3)	$32,610	$18,756	$51,366
Undergraduate Student Researchers, OSU	$0	$0	$0
Total Salaries	$46,306	$26,974	$73,280
Fringe Benefits			
Faculty	$7,122	$4,438	$11,560
Graduate Student Researchers (3)	$4,585	$2,766	$7,351
Undergraduate Student Researchers	$0	$0	$0
Total Fringe Benefits	$11,707	$7,204	$18,911
Total Personnel Costs (Salaries + Benefits)	$58,013	$34,178	$92,191
Travel to project site	$2,410	$7,230	$9,640
Services/Supplies	$1,000	$998	$1,998
Minor Equipment	$15,000	$3,000	$18,000
Total Direct Costs for OSU (sum of personnel costs, travel, services/supplies, and equipment)	$76,423	$45,406	$121,829
Indirect Costs for OSU Activity (26.0% of Total Direct Costs)	$19,870	$11,806	$31,676
Student Tuition	$15,960	$5,535	$21,495
Subtotal – OSU	$112,253	$62,747	$175,000
ODOT Administration	$10,000	$8,000	$18,000
Total Estimated Costs	**$122,253**	**$70,747**	**$193,000**

8.0 REFERENCES

[1] ODOT administration includes overtime for on-site participation during in-field site visits.
[2] The indirect cost rate for this study is 26% regardless of the source of funds.

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