Research Project Work Plan

for

LIDAR FOR MAINTENANCE OF PAVEMENT REFLECTIVE MARKINGS AND RETRO-REFLECTIVE SIGNS

SPR 799

Submitted by

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for

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Research Section
555 13th Street NE
Salem, OR 97301 Phone: (503) 986-2700

Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator (ODOT requests only one per institution or firm)

Michael J. Olsen, Associate Professor
School of Civil and Construction Engineering
Oregon State University
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Corvallis, OR 97331
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1.1 Associate Investigator(s)

Christopher Parrish
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Oregon State University
Email: Phone: (541)737-XXX

1.2 Technical Advisory Committee (TAC) Members

Joel Fry, ODOT Maintenance, Pavement Marketing Committee Chair, joel.d.fry@odot.state.or.us
Eric Leaming, ODOT Traffic Devices Engineer, Eric.s.leaming@odot.state.or.us
Dennis Hackney, ODOT Assistant District Manager, D 13 , Region 5, Dennis.a.Hackney@odot.state.or.us
ODOT LiDAR Technical Expert, TBD
FHWA member, TBD

1.3 Friends of the Committee (if any)

None identified at this time

1.4 Research Coordinator

Jon Lazarus, ODOT Research Coordinator, *TAC Chair*
Email: jon.m.lazarus@odot.state.or.us,
Phone: (503) 986-2852

1.5 Project Champion

Ron Singh, Oregon DOT,

2.0 Problem Statement

ODOT currently tracks several metrics for compliance of pavement markings, including appearance and retro-reflectivity. The Maintenance Section of ODOT uses a van, which travels the state every summer, to capture retro-reflectivity values on lane markings, which are analyzed and used in creating a plan of action for maintenance (e.g., vendor replacement if covered under warranty, or in house or contracted maintenance). Unfortunately, issues arise due to the timing and frequency of the data acquisition. Often, individual hand-held reflectometer readings are required after winter months to recheck compliance, which may be risky (roadside) and staff time intensive. Sign retro-reflectivity evaluations suffer from similar limitations, and are more cumbersome for crews in making the retro-reflectivity measurements.

Mobile lidar scans of state highways are now being conducted on a regular basis through ODOT Geometronics. This technology supports a wide range of transportation applications [Olsen et al., 2013] within a single dataset that is acquired more safely and efficiently than conventional methods. In addition to capturing geometric information along the highways, a side product of lidar scans is intensity (return signal strength), which can be calibrated to produce estimates of reflectivity. Research is currently needed to: a) develop and test operational procedures for generating retro-reflectivity data from ODOT's mobile scanner, and b) evaluate the effects of challenging conditions, including rain and ice, which are commonly encountered in the winter/spring seasons after plowing when crews evaluate lines for summer work.

2.1 Background and Significance of Work

Recent research has investigated the potential use of mobile lidar for retro-reflectivity evaluation [Olsen et al., 2013; Ai and Tsai, 2016]. While this work appears promising, detailed studies are needed to assess the operational feasibility of these methods for state DOTs and to develop production-ready procedures. Additionally, since some aspects of the lidar intensity calibration are specific to a

particular system and configuration, it is important to modify and test these procedures using data directly from ODOT's system.

Figures 1 and 2 show examples of retro-reflective pavement markings and street signs captured in a mobile lidar point cloud. The colors are representative of uncorrected intensity values and are able to clearly distinguish pavement markings. The challenge of this research will be to transform these values into representative readings of retro-reflectivity so that markings can be compared and evaluated for compliance. This transformation requires corrections for acquisition geometry and environmental conditions, as well as system parameters.

Figure 1- Sample point cloud collected on the ODOT mobile test course of lane markings. Note that the markings can be distinguished well in the uncorrected intensity.

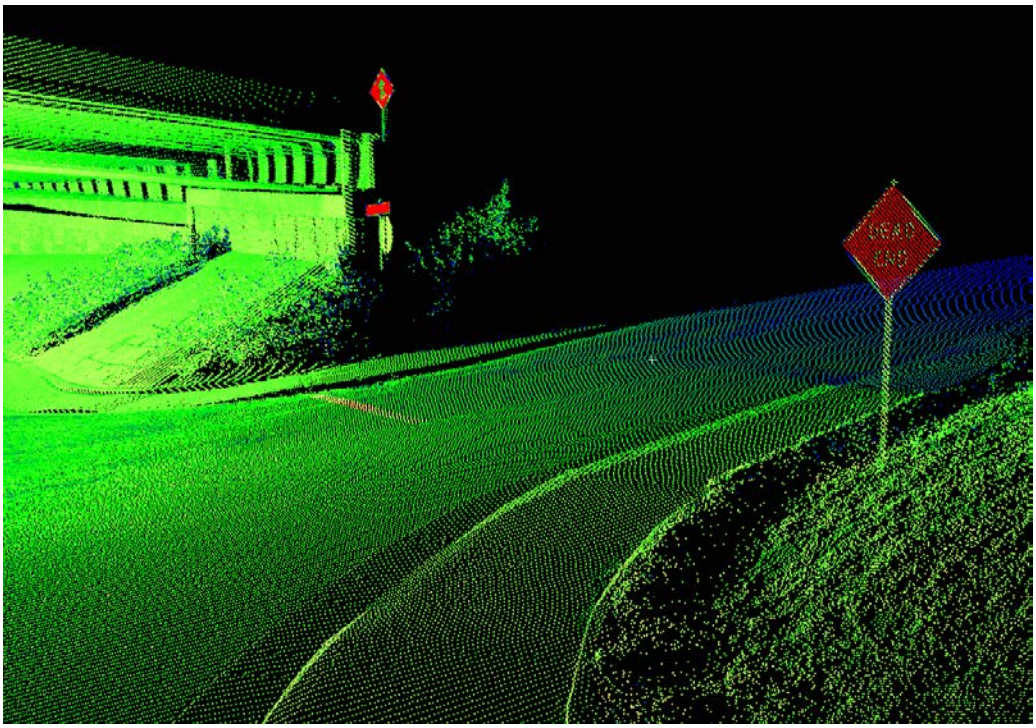

Figure 2- Street signs in a mobile lidar point cloud colored by intensity (red = strong) on the ODOT mobile lidar test course. However, note that these scans were acquired with a different system than ODOT's current system. The geometric orientation of the scanner to the signs can have a significant impact on the data captured on the sign face.

3.0 Objectives of the Study

In light of these research needs, this study seeks to:

- Develop a model for retro-reflectivity and radiometric calibration for ODOT's mobile lidar system.
- Generate a set of quality control metrics for pavement marking and sign retro-reflectivity based on information derived from mobile lidar data
- Establish procedures for creating GIS data layers from the output of the above steps to support decision making by supervisors and integrate analysis results into ODOT's overall workflows.

3.1 Benefits

This project has the potential to provide the following direct benefits to ODOT:

1. Enable safer data acquisition through reduction of roadside data collection
2. Ensure a high level of service of retro-reflective markings and signs for the public
3. Increase efficiency of data collection by leveraging existing ODOT mobile lidar acquisition
4. Improve QA/QC for lines and signs by enabling measurements continuously
5. Enhance asset management by improving user interaction with the data as well as improving the success of automated feature extraction algorithms
6. Provide quantitative data for warranty disputes

7. Provide geospatial data layers that support informed decision making by supervisors
8. Improve MAP-21 compliance

This research further enables Oregon DOT to obtain even more value with the current mobile lidar scan acquisitions, where data are routinely being acquired for a variety of purposes across the state. The mobile lidar data acquisition has already shown solid performance, ROI, and many other benefits in ODOT. This helps reduce duplicative travel and field work, including in remote areas.

4.0 Implementation

The project team will work closely with Oregon DOT Geometronics on performing the radiometric calibration and field testing so that this work can be completed in conjunction with their existing data collection efforts. The radiometric calibration software will be developed such that it fits readily into their existing processing workflows.

We will also work with the lane marking maintenance personnel to obtain datasets on lane marking performance and to help guide the development of the GIS decision software tool and associated user manual.

5.0 Research Tasks

5.1 Expected tasks:

Task 1: TAC Meeting #1

Project kick off meeting.
Time Frame: July - August 2016
Responsible Party: PI, ODOT Research Coordinator, TAC
Cost: $1,000
Deliverable: TAC meeting attendance, TAC meeting presentation, TAC Meeting Minutes
TAC Action: Review and understand project research problem statement, research question, the limits of the research, and the project schedule. Advise ODOT Research Coordinator regarding any critical issues with the project's scope or schedule. Advise PI's regarding related professional practices, standards, methods and context for the project.
ODOT Action or Decision: Review TAC advice, discuss with PI, and if necessary direct PI to make changes to project documents.

Task 2: Draft Literature Review

The literature review will focus on a number of issues relevant to the research problem statement and research question. A variety of topics will be researched such as:

- Radiometric calibration procedures for mobile lidar
- Research procedures utilizing mobile lidar intensity information for pavement markings and sign-retroreflectivity extraction and evaluation.

- Current business practices of line and sign retro-reflectivity evaluation, performance modeling, and warranty evaluation procedures. Compare national approaches to ODOTs so that a practical approach can be applied considering ODOT's current practices.
- Perform a review of technologies utilized and current calibration procedures for retro-reflectivity measurements of transportation assets such as striping and signs
- Document current mobile lidar acquisition processes and status at Oregon DOT.

Time Frame: June - November 2016
Responsible Party: PI
Cost: $12,000
Deliverable: Draft Literature Review
TAC Action: Read Draft Literature Review and advise ODOT Research Coordinator regarding any gaps in the literature.
ODOT Action or Decision: Review TAC advice, discuss with PI, and if necessary direct PI to make changes to project documents.

Task 3: Draft Research Methodology.

This task includes identification and description of required data, variables, and specification of analysis technique. The Draft Research Methodology will document the proposed data collection including data availability, data quality, optional data, excluded data, costs and risks to the project related to failure of the data collection. The Draft Research Methodology will discuss sampling methods and identify the expected sample size. The Draft Research Methodology will determine what kinds of statistical techniques will be used to analyze the collected data.

Time Frame: January 2016
Responsible Party: PI
Cost: $12,000
Deliverable: Draft Research Methodology Report Section.
TAC Action: Read Draft Research Methodology in preparation for TAC Meeting # 2.
ODOT Action or Decision: Schedule TAC Meeting #2

Task 4: TAC Meeting #2

This TAC meeting is intended to set the course for the completion of the project
Time Frame: February 2016
Responsible Party: PI, ODOT Research Coordinator, TAC
Cost: $2,000
Deliverable: TAC meeting attendance, TAC meeting presentation, TAC Meeting Minutes, meeting agenda
TAC Action: TAC review of Draft Research Methodology and Draft Literature Review. Advise ODOT Research Coordinator regarding any critical issues with the project's research design. If possible reach consensus regarding the content and methods contained in the draft research design. Advise ODOT Research Coordinator regarding project next steps.

ODOT Action or Decision: Review TAC advice. Assess project potential for successful completion. If necessary direct PI to make changes to project documents. Provide formal acceptance of Draft Research Methodology. Authorize PI to proceed with subsequent steps, notify by memo or email.

Task 5: Data Collection. (Test Sites).

Collect data for analysis. Records will be kept of data collection tools or methods and tool/method calibration. The design of any specialized data collection tools or algorithms will be documented and delivered to the Agency. Data will be recorded in a standardized and secure form. Data will be collected, stored and delivered to ODOT in compliance with Federal requirements. The procedures will be documented in the Draft Research Methodology.

Test 1: Conduct controlled tests with the mobile lidar and static scanning systems in the ODOT pavement striping field evaluation site in collaboration with ODOT to:
I. Compare lidar retro-reflective readings with ground truth measurements and field spectrometer and retro-reflectometer. What error rate would we encounter (e.g., how many false-positives) in comparing lidar scans to retro-reflectivity values? What precision of length of faulty line does the maintenance crew need from a lidar scan?
II. Evaluate ability of the lidar data for tracking width, thickness, and consistency of striping.

For these tests it is envisioned that 5-10 passes would be completed 3 times during the day (dawn, mid-morning, mid-afternoon) to investigate the effects of solar illumination on the results. Test 1 will be scheduled in August or September 2016. Signs of various conditions with retro-reflective readings will also be placed alongside the road to be scanned simultaneously.

Additional tests will be completed using a static scanner with similar properties to the scanner included on ODOT's mobile lidar system. These tests will be conducted on the OSU campus to evaluate the degradation of intensity with environmental conditions.

Test 2: The scanner will be set up at the same location near several retro-reflective signs and pavement markings at various times of day (e.g., dawn, morning, noon, afternoon, night) to evaluate the influence of sun position and illumination on retro-reflective readings with the scanner.

Test 3: Scans will be collected before and after a rainstorm from the same location at a site with several retro-reflective signs and pavement markings to evaluate the degradation of laser intensity from rain.

Time Frame: September – December 2016
Responsible Party: PI
Cost: $15,000
Deliverable: A Memo documenting data collection, and any specialized data collection tools or algorithms. Provide documentation that the raw data is securely stored and

protected from data corruption. (Federal projects may require delivery of raw data to the Agency)
TAC Action: None
ODOT Action or Decision: Review

Task 6: Data Analysis

Analyze data collected in Task 5, primarily using methods anticipated in Task 3. Revise as Draft Research Methodology to document deviations, and update the Draft Literature Review to support any methods of analysis not previously included in the literature review.

Develop correction equations and write supporting open-source software to perform the radiometric calibration directly as part of Oregon DOT's data processing workflows.

Develop a semi-automated GIS workflow to extract lane markings and signs from mobile lidar data, evaluate their retro-reflective condition, and correlate with additional geospatial information such as ODOT's crash database to prioritize sections for lane marking or sign maintenance. This decision tool could display data in both tabular and visual formats. The visual output would be geospatial databases viewable in GIS, Google Earth, or Microstation software. The information would be presented as layers similar to ODOT's pavement condition GIS database.

Time Frame: September – June 2017
Responsible Party: PI
Cost: $40,656
Deliverable: Draft Analysis Report Section
TAC Action: Review and comment
ODOT Action or Decision: Review

Task 7: Data Collection. (In Situ).

Collect data for analysis for a section of highway as identified in the Draft Research Methodology. Records will be kept of data collection tools or methods and tool/method calibration. The design of any specialized data collection tools or algorithms will be documented and delivered to the Agency. Data will be recorded in a standardized and secure form. Data will be collected, stored and delivered to ODOT in compliance with Institutional Review Board approvals and Federal requirements. The PI will be responsible for documentation of any departures from the Draft Research Methodology.

Conduct tests of a 2-mile stretch of actual roadway identified in collaboration with ODOT to:

I. Compare lidar retro-reflective readings with ground truth measurements with field spectrometer and retro-reflectometer. What error rate would we encounter (e.g., how many false-positives) in comparing lidar scans to retro-reflectivity values? What precision of length of faulty line does the maintenance crew need from a lidar scan?

II. Evaluate ability of the lidar data for tracking width, thickness, and consistency of striping.

Time Frame: July-August 2017
Responsible Party: PI
Cost: $10,000
Deliverable: A Memo documenting data collection, and any specialized data collection tools or algorithms. Provide documentation that the raw data is securely stored and protected from data corruption. (Federal projects may require delivery of raw data to the Agency.)
TAC Action: None
ODOT Action or Decision: Review

Task 8: Data Analysis

Analyze data collected in Tasks 5 and 7, primarily using methods anticipated in Task 3. Revise as Draft Research Methodology to document deviations, and update the Draft Literature Review to support any methods of analysis not previously included in the literature review.

Test, tune and refine correction equations and accompanying open-source software to perform the radiometric calibration directly as part of Oregon DOT's data processing workflows. These corrections will be developed and calibrated using the field tests in Task 5 and then validated using the field data collected in Task 7.

Develop an automated GIS workflow to extract lane markings and signs from mobile lidar data, evaluate their retro-reflective condition, and correlate with additional geospatial information such as ODOT's crash database to prioritize sections for lane marking or sign maintenance. This decision tool could display data in both tabular and visual formats. The visual output would be geospatial databases viewable in GIS, Google Earth, or Microstation software. The information would be presented as layers similar to ODOT's pavement condition GIS database.

Time Frame: August-December 2017
Responsible Party: PI
Cost: $40,344
Deliverable: Draft Analysis Report Section
TAC Action: Review and comment
ODOT Action or Decision: Review

Task 9: Draft Final Report

Publication ready Draft Final Report in the prescribed ODOT report format. (Formatting includes correct fonts, spacing, citations and graphics). Contents include: an updated abstract, acknowledgement, disclaimer, introduction, Updated Lit Review (Task 2), Final Research Methodology (Task 3), Draft Analysis Report Section (Task 6),

discussion of results, conclusions, and potential for future research, application, or technology transfer, and other sections as appropriate.

The final report will also provide user manuals for the software, recommendations for mobile scanning acquisition, and metadata needs to ensure data will be of sufficient quality for retro reflectivity measurements on striping and signage.

Time Frame: December 2017-March 2018
Responsible Party: PI
Cost: $20,000
Deliverable: Draft Final Report using ODOT's report template
TAC Action: TAC review and feedback to the ODOT Research Coordinator
ODOT Action or Decision: Review and counsel prior to TAC meeting

Task 10: Draft ODOT Research Note

Write 1000 to 1500 word summary of the research project. The summary will concisely document the research findings, value of the research to the agency, science and society, and any limitations on the use of the findings.

Time Frame: February – March 2018
Responsible Party: PI
Cost: $4,000
Deliverable: Draft ODOT Research Note using ODOT's report template
TAC Action: None
ODOT Action or Decision: Review and advise

Task 11: TAC Meeting #3.

This TAC meeting will include a review of the Draft Final Report, and Draft Research Note prior to the TAC meeting. The TAC will offer advice on the content and clarity of these work products. The TAC will also advise on post research implementation.

Time Frame: April- May 2018
Responsible Party: PI, assisted by the ODOT Research Coordinator, TAC
Cost: $2,000
Deliverable: TAC meeting attendance, TAC meeting presentation, TAC Meeting Minutes
TAC Action: TAC review of Draft Final Report, and Draft Research Note. Advise ODOT Research Coordinator regarding any critical issues with the project's research design. Advise ODOT Research Coordinator regarding any required final edits to the Draft Final Report, and Draft Research Note.
ODOT Action or Decision: Review TAC advice. If necessary direct PI to make changes to project documents.

Task 12: Final Report

Edit Draft Final Report to incorporate edits identified by the ODOT research Coordinator after the last TAC meeting

Time Frame: May – June 2018
Responsible Party: PI
Cost: $5,000
Deliverable: Final Report
TAC Action: None
ODOT Action or Decision: Review. Provide formal acceptance of Final Report. Publish Final Report on ODOT's research website

Task 13: Final Research Note

Edit Draft Research Note to incorporate edits identified by the ODOT research Coordinator after the last TAC meeting
Time Frame: June 2018
Responsible Party: PI
Cost: $1,000
Deliverable: Final Research Note
TAC Action: None
ODOT Action or Decision: Review. Provide formal acceptance of Research Note. . Publish Final Report on ODOT's research website

5.2 Reporting

All reports shall 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 shall be responsible for submitting deliverables as 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, shall deliver to ODOT in electronic format the data produced during the project. The Project Investigator shall ensure the data is labeled and organized to facilitate future access. ODOT shall warehouse the data.

5.3 Safety and Related Training

Prior to accessing ODOT right-of-way (ROW), all personnel who will work on ODOT ROW shall complete safety training appropriate to the work to be performed within the ROW. The Project Investigator shall 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 time line for the project, listing the task headings and showing monthly and/or quarterly time blocks in which each task will be accomplished. Also shown are interim and final deliverables.

Task	2016						2017												2018					
	FY17												FY18											
	Jul - Sep			Oct - Dec			Jan - Mar			Apr - Jun			Jul - Sep			Oct - Dec			Jan - Mar			Apr - Jun		
1 Tac Meeting 1		*																						
2 Draft Lit Review					*																			
3 Draft Research Methodology							*																	
4 Tac Meeting 2								*																
5 Data Collection (Test Site)			*																					
6 Data Analysis I												*												
7 Data Collection (Field)														*										
8 Data Analysis II																		*						
9 Draft Final Report																					R			
10 Draft ODOT Research Note																					R			
11 TAC Meeting 3																							*	
12 Final Report																								F
13 Final Research Note																								F

*Deliverables
R - Draft report submitted for ODOT review.
F - Revised report submitted to ODOT for publication. End of contract.

7.0 Budget Estimate

An itemized budget for the project is included here showing expenditures for each task by fiscal year and in total.

Task	FY17	FY18	Total
1. Tac Meeting 1	**$1,000**	**$0**	**$1,000**
2. Draft Lit Review	**$12,000**	**$0**	**$12,000**
3. Draft Research Methodology	**$12,000**	**$0**	**$12,000**
4. Tac Meeting 2	**$2,000**	**$0**	**$2,000**
5. Data Collection (Test Site)	**$15,000**	**$0**	**$15,000**
6. Data Analysis I	**$40,656**	**$0**	**$40,656**
7. Data Collection (Field)	**$0**	**$10,000**	**$10,000**
8. Data Analysis II	**$0**	**$40,344**	**$40,344**

9. Draft Final Report	**$0**	**$20,000**	**$20,000**
10. Draft ODOT Research Note	**$0**	**$4,000**	**$4,000**
11. TAC Meeting 3	**$0**	**$2,000**	**$2,000**
12. Final Report	**$0**	**$5,000**	**$5,000**
13. Final Research Note	**$0**	**$1,000**	**$1,000**
Total for tasks (Contract amount)	**$82,656**	**$82,344**	**$165,000**
Support/management (ODOT completes)	$8,000	$7,000	$15,000
Total for ODOT (ODOT completes)	**$90,656**	**$89,344**	**$180,000**