Research Project Work Plan

for

IMPACT OF TRUCK PLATOONING ON LOADING OF BRIDGES IN OREGON

SPR-848

Submitted by

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and

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for

Oregon Department of Transportation
Research Unit
555 13th St. NE, Ste 2
Salem, OR 97301-6867

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Revised: July 2020
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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

(If federal funds are used)
Federal Highway Administration (FHWA)
Washington, D.C.  20590

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

Michael Scott, Professor
School of Civil and Construction Engineering
Oregon State University
101 Kearney Hall
Corvallis, OR 97331    Phone: (541) 737-6996

1.1 Associate Investigator(s)

Thomas Schumacher, Associate Professor
Department of Civil and Environmental Engineering
Portland State University
Engineering Building 301B, 1930 SW 4th Ave
Portland, OR 97201    Phone: (503) 725-4199

Avinash Unnikrishnan, Associate Professor
Department of Civil and Environmental Engineering
Portland State University
Engineering Building 301D, 1930 SW 4th Ave
Portland, OR 97201    Phone: (503) 725-2872

1.2 Technical Advisory Committee (TAC) Members

Matthew Mabey, ODOT Structures Research Coordinator
Rebecca Barrow, ODOT Bridge Engineer
Kelly Freeman, ODOT Bridge Engineer
Holly Winston, ODOT Bridge Engineer
Charles Hutto, CCD, OD Permits
2.0 Problem Statement

Truck platooning, an autonomous vehicle technology where multiple heavy trucks operate at close spacing (headspacing), has been authorized for use in Oregon under HB 4059 Section 40 without requiring permitting or notification to the agency. This allows groups of trucks to travel very close to each other, increasing the loading on bridges, with the potential to exceed stress levels allowed by the current bridge formula. This potential overloading could reduce the lifespan of Oregon bridges. In order to preserve the life of existing bridges and ensure structural safety of bridges on highways where truck platooning is expected, it is important to gain an understanding of the potential impact of truck platooning on Oregon’s current bridge inventory.

Current research on truck platooning from other states focuses more on how to design new bridges rather than estimate impacts on extant bridges. Given the aging of Oregon’s bridges, there is a concern from bridge engineers in ODOT that the agency will be reacting to wear and tear of new truck configurations and the load ratings predicted by new platooning software. In order to preserve and maintain Oregon’s vast investment in bridges, it is prudent to take a proactive approach to truck platooning by understanding the potential issues. This proposed research on loading issues can help craft policies and plans for conversations with fleet owners, regulators, and others to avoid damaging bridges and increasing the costs associated with maintaining Oregon’s transportation infrastructure.

3.0 Objectives of the Study

The objective of this research is to determine what combination of truck configurations (axle weights and spacings) and platooning headspace may exceed acceptable stress levels for bridges carrying heavy loads. To answer this question, bridge superstructure load ratings will be performed on representative bridges with select truck platoon configurations and compared with truck loads currently used in Oregon. Results from the modeling will be used to create a set of policy and regulatory recommendations that could be used to update load ratings on Oregon’s bridges.

3.1 Objectives and Benefits of the study include:
● Quantification of truck platoon load effects on bridges that will provide a basis to anticipate, mitigate, or eliminate increased maintenance and/or reduced service life pro-actively instead of waiting until damage has occurred.
● Facilitation of freight mobility by determining if truck platooning across bridges may be done without restrictions, or with minimal restrictions.
● Providing a basis for collaboration with platooning system developers, fleet owners, and regulators in designing and implementing truck platooning systems.
● The specifics of truck platooning parameters such as axle loads, axle spacing, and headspacing will be determined that allow for operation at acceptable load levels.
● Providing a basis for determination of the range and scope of load rating conditions, such as bridge type and configuration, under which truck platooning may need to be included as a rated vehicle class.
● Creation of a set of policy and regulatory recommendations for freight mobility regulation and for load rating of existing bridges.

**Key Deliverables:** Recommendations to modify policies and regulations for load rating various bridge superstructures for the distribution of configurations, weights, and number of platooning trucks that will best preserve the condition of the OR bridge inventory. Modeling results and recommendations for potential bridge strengthening locations and load rating implications.

4.0 Implementation

Implementation of these results within ODOT may include:
● Policy recommendations for the implementation of truck platoons
● New design load requirements for bridge strengthening projects
● Revised inspection schedules for critical bridges
● Recommendations for live load factors for future load ratings

Additionally, the results of this research may be of use to the developers of truck platooning software in creating an adaptable system that avoids bridge restrictions.

5.0 Research Tasks

5.1 Expected tasks:

**Task 1: TAC Meeting #1**

Project kick off meeting.

*Time Frame:* November 2020

*Responsible Party:* PI, ODOT Research Coordinator, TAC, Work split between OSU and PSU will be 59% and 41%.

*Cost:* $1000
Deliverable: TAC meeting attendance, TAC meeting presentation, TAC meeting minutes

TAC Action: Review and understand project research problem statement, research objectives, and the project schedule. Advise ODOT Research Coordinator regarding any critical issues with the project’s scope or schedule. Advise PIs regarding related professional practices, standards, methods and context for the project. The investigators will give a presentation of their proposed research approach and methodology to solicit input from ODOT/TAC. The approach will include bridge types, the specific load rating procedure (e.g. MBE-LRFR, ODOT LRM), as well as the scope of the modeling/analysis, in particular the methods of 2D analysis and extent of 3D bridge modeling to be considered in this research.

ODOT Action or Decision: Review TAC advice, discuss with investigators, and if necessary direct PI to make changes to project documents.

Task 2: Draft Literature and Real World Practice Review

The literature and real world practice review of issues relevant to the research problem statement and research question such as:

- The theoretical context for the research on structural analysis of bridges for vehicle loading.
- Past truck platooning studies performed in the US as well as abroad will be reviewed with the goal to develop a basic understanding of the technology and which truck platoon configurations might be applicable for Oregon’s bridges.
- Research that has quantified the impact of truck platoons on existing bridges.
- Current State legislation, policies or plans to allow or implement truck platooning.
- Current and/or planned truck platoon configurations (axle spacings and weights, as well as headspaces) developed by truck platoon manufacturers.
- Outreach to truck platoon manufacturers to determine how load rating software could possibly be incorporated into “on board” truck platoon control software.
- Known and/or planned truck platoon behaviors (including changes to configuration) in relationship with other traffic, and/or in response to other highway conditions such as the presence of other trucks or truck platoons, profile grades, congestion, emergency vehicles, lane changes, weather conditions such as rain, snow or icing, and TP restrictions, etc.
- A list of bridges on critical routes to be considered for analysis representing common types in Oregon. These will be determined by ODOT feedback, published ODOT research, as well as NBI data.

Time Frame: October 2020 - February 2021

Responsible Party: PSU will be responsible for this task. Work split will be OSU 40% and PSU 60%.

Cost: $22,400

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 investigators, and if necessary direct PI to make changes to project documents.

**Task 3: Draft Research Methodology Report.**
The Draft Research Methodology Report will document:
- The proposed analysis and techniques for 2D and 3D modeling of bridges.
- Truck platoon load configurations and how they are integrated and analyzed in conjunction with currently used truck/traffic loading models.
- Configuration details for critical Oregon bridges.
- What kinds of statistical techniques will be used to analyze the collected variations of truck platoon loadings and estimated probabilities of simultaneous loading of a truck platoon, multiple truck platoons, and independent single trucks on a bridge.
- The load rating approach used to evaluate the potential impacts of truck platooning on the selected bridges.
- Potential impacts to bridge maintenance and preservation raised by the TAC in Task 1.

**Time Frame:** March 2021 - June 2021  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 80% and PSU 20%  
**Cost:** $17,920  
**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. On high risk and exploratory projects, this is the point where ODOT will consider authorizing future work.

**Time Frame:** June 2021  
**Responsible Party:** PI, ODOT Research Coordinator, TAC. Work split between OSU and PSU will be 53% and 47%  
**Cost:** $4480  
**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: Analysis Parameter Development**

This task includes defining expected loadings and configurations for truck platoons/convoys based on literature review and input from ODOT. This might include variables such as axle spacing and weights, head spacing, as well as platoon length. Determine what permutations of truck platoon configurations will be tested. Establish how truck platoons will be considered in conjunction with live loads currently used for load rating, i.e., OR legal trucks, specialized hauling vehicles, emergency vehicles, and continuous trip permit (CTP) trucks) used in load rating. Choose which bridge types in Oregon will be modeled to evaluate those configurations. Finally, the response entities (or output) of these models to be used for evaluation will be determined.

**Time Frame:** July 2021 - October 2021  
**Responsible Party:** PSU will be responsible for this task. Work split will be OSU 47% and PSU 53%  
**Cost:** $27,947  
**Deliverable:** Memo documenting data collection, and any specialized data collection tools or algorithms.  
**TAC Action:** Review memo regarding data collection and note any discrepancies or potential issues.  
**ODOT Action or Decision:** Review

**Task 6: Modeling and Analysis**

Using truck platoon configurations and scenarios with OR legal trucks, CTP trucks, and other scenarios developed in Task 5, bridges selected in coordination with the TAC will be analyzed. All analyses will be carried out in Python using the OpenSees finite element framework and will be documented in Jupyter notebooks, an interactive environment that combines analysis code, documentation, and visualization in one location.

In 2D, the analyses will consist of sweeping truck platoon axle loads along girder lines and applying distribution factors to determine histories of bending moment and shear. Load rating factors will be computed considering moment, shear, and combined moment and shear, which was found to be critical in previous ODOT-sponsored research on load rating conventional reinforced concrete bridges.

To circumvent distribution factors, which can be overly conservative, and to load rate cross beams, 3D analyses will be carried out, also by sweeping axle loads across a bridge deck using a simplified 3D modeling approach endorsed by the TAC. Histories of bending moment and shear in the bridge girders and cross beams will be computed in OpenSees, then rating factors will be calculated considering flexure, shear, and flexural shear interaction. Guidance on the most effective and appropriate modeling approach will be sought from the *Manual for Refined Analysis in Bridge*.
Design and Evaluation (FHWA Report #HIF18046) and other sources identified in the literature review.

All load rating calculations will be visualized in Jupyter notebooks for rapid interpretation by ODOT. The bridge models and loading scenarios will be parametrized in the notebooks so that ODOT bridge engineers can examine bridges not considered in this project, but that have similar features to the examined bridges. For example, bridges with different span lengths and number of spans and truck platoons with different head spacing and/or axle weights and configurations.

All Jupyter notebooks with OpenSees analyses and load rating calculations and visualizations will be made available to ODOT in an archived and secure manner, either through password protected cloud-based services or on servers maintained by ODOT.

The notebooks will be made available to ODOT bridge engineers for the assessment of other bridges not considered in this project.

**Time Frame:** October 2021 - June 2022  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 68% and PSU 32%  
**Cost:** $62,880  
**Deliverable:** Draft Analysis Report Section  
**TAC Action:** Review and comment  
**ODOT Action or Decision:** Review

**Task 7: 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 Literature 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.

**Time Frame:** June 2022 - August 2022  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 50% and PSU 50%  
**Cost:** $17,887  
**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 8: 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 practical limitations on the use of the findings.
**Time Frame:** June 2022 - August 2022  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 50% and PSU 50%  
**Cost:** $17,887  
**Deliverable:** Draft ODOT Research Note using ODOT’s report template  
**TAC Action:** Review and comment on Research Note  
**ODOT Action or Decision:** Review and advise

**Task 9: 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:** September 2022  
**Responsible Party:** PI, assisted by the ODOT Research Coordinator, TAC. Work split between OSU and PSU will be 60 and 40%  
**Cost:** $5400  
**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 10: Final Report**  
Edit Draft Final Report to incorporate edits identified by the ODOT research Coordinator after the last TAC meeting.

**Time Frame:** October 2022 - December 2022  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 77% and PSU 23%  
**Cost:** $16,200  
**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 11: Final Research Note**  
Edit Draft Research Note to incorporate edits identified by the ODOT research Coordinator after the last TAC meeting.

**Time Frame:** October 2022 - December 2022  
**Responsible Party:** OSU will be responsible for this task. Work split will be OSU 80% and PSU 20%
Cost: $16,200
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 and software (Jupyter notebooks) produced during the project. The Project Investigator shall ensure the data is labeled and organized to facilitate future access.

5.3 Safety and Related Training

Safety training should be not required for this project as the work encompasses computer-based analysis and modeling rather than fieldwork. The investigators are up to date on their required conflict of interest training at their respective universities.

6.0 Time Schedule

This section specifies the 27-month timeline 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. (A sample matrix is shown below.)

<table>
<thead>
<tr>
<th>Task</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
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<tbody>
<tr>
<td></td>
<td>FY21</td>
<td>FY22</td>
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<td></td>
<td>Oct-Dec</td>
<td>Jan-Mar</td>
<td>Apr-Jun</td>
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<tr>
<td>1: TAC Meeting #1</td>
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<td>2: Draft Lit. Review</td>
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<td>3: Draft Methodology</td>
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<td>5: Data Collection</td>
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<td>6: Modeling &amp; Analysis</td>
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<td>7: Draft Final Report</td>
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<td>8: Draft Research Note</td>
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<td>11: Final Research Note</td>
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*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.

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