Washington State Department of Transportation

RESEARCH REPORT GUIDELINES

Prepared by WSDOT Research and Library Services

Washington State Department of Transportation
Julie Meredith, Secretary

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GUIDELINES FOR WSDOT RESEARCH REPORTS

The guidelines presented here are primarily directed to researchers for projects funded by federal State Planning and Research (SPR) dollars, per Title 23 CFR 420.209 (a)(6), in accordance with federal regulations for documenting research activities. This guidance is also recommended for agency reports documenting research projects funded by other sources, especially if those projects were administered by the WSDOT Research Office.

Final research reports are required for all SPR-funded projects. Additionally, in WSDOT contracts for phased studies or studies that span several years, interim reports may also be specified to document progress, conclusions, or recommendations at a given point in the study.

The revised and updated guidance provided in this document includes report requirements along with general recommendations for final reports. Consult your Research Coordinator for how these guidelines may apply to interim reports.

ACCESSIBILITY REQUIREMENTS: Final Research Reports submitted to WSDOT must be accessible per ADA and Section 508 requirements

This requirement is in accordance with Section 508 of the Rehabilitation Act of 1973, as amended, and Title II of the Americans with Disabilities Act (ADA).

As a means to accomplish transportation research technology transfer, final reports documenting SPR-funded projects are required to be distributed to various federal online repositories to facilitate availability of research results for the wider transportation community. In order to be accepted into these repositories (USDOT/National Transportation Library's ROSA P, Transportation Research Board's TRID, etc.), reports need to be formatted to be accessible and available to everyone, including individuals with disabilities.

It is important to be mindful of and to meet accessibility standards from the very beginning of writing reports. Going back to try to fix issues in a completed report can be difficult to impossible and very time-consuming.

It is the research team's responsibility to produce reports that are accessible and compliant with ADA/Section 508. If report writers are unfamiliar with creating such reports, it is strongly recommended that they seek appropriate guidance, assistance and/or expertise *before* they begin writing a report. WSDOT is not in a position to provide this kind of support

Information on creating compliant documents is readily available on the web, and most universities have "how-to" resources and webpages devoted to the process. Additionally, many word processing/document production platforms, including MS Word, have built-in features to facilitate the creation of compliant documents.

TPF-5(442), the Transportation Research and Connectivity Pooled Fund, has developed a wealth of resources to build skills and assist report writers in creating accessible and Section 508 compliant reports.

TRAC (Washington Transportation Center)-affiliated researchers at UW and WSU should consult this report production webpage on TRAC's website for helpful information, including a Word document template that is 508 compliant and a Section 508 Compliance Guide.

As of this writing, content on WSDOT web pages is required to meet the standards of Web Content Accessibility Guidelines (WCAG) Version 2.1, Level AA; this is currently the widely recommended standard.

Please note that we require final reports to be submitted in Word format. For information on how to create Word document that are accessible, you may find Microsoft's step-by-step instructions and videos helpful.

TIPS: Problematic issues with compliance that are fairly common include the following:

- Complex and/or improperly formatted tables with merged or empty cells, poorly formatted or missing headings.
- Lack of "alt text" for images, or if auto-generated, the alt text has not been checked for accuracy. NOTE: an accessibility checker may "pass" alt text if any text has been auto-generated. **Alt-text must always be checked**, especially if it has been auto-generated, as it may be inaccurate or even nonsensical.
- Incorrect reading order – reading order is usually tagged automatically and must be checked and corrected as needed, so that someone who uses a screen reader will perceive the content in its logical order. This requires looking at every page of the report.

Please pay special attention to these format elements.

After completing your report, please run the accessibility checker in Word and/or convert your document to a PDF and run the Adobe accessibility checker. Fix all issues before submitting the report.

WSDOT will run an accessibility check when receiving reports. Non-compliant reports will be returned to the research team for remediation.

GENERAL REPORT GUIDANCE

Objective: To create a 35- to 50-page digital research report in Word format, comprised of elements described below, that documents the research project.

NEW: As noted in the *Research Contract Scope of Work Preparation Guide & Template*, you will also need to prepare a 2-page project summary (which should also be ADA/Section 508 compliant). We will supply a template, with content to include the following:

- Project title
- Problem
- What we did
- Results
- Next steps

Format, structure: See detailed recommendations, below

Example Report: Appendix A

Distribution: Research reports documenting SPR-funded research will be distributed to required recipients/federal repositories as stipulated by FHWA, and to subscribers of WSDOT's Transportation Research topical alerts.

Upon request, reports of WSDOT research funded by other sources may also be distributed to the federal repositories. Per state statute, all WSDOT research reports, as agency publications, will also be sent by the WSDOT Library to the Washington State Library for inclusion into the State Digital Archives, accessible through WSL's online catalog.

This format is intended to provide concise, abbreviated documentation of a project. The report should provide readers with a brief history of the problem and the ways in which others have addressed it, an overview of the research approach and procedures used, and a thorough understanding of the findings and their implications

If a project requires more exposition and/or technical documentation that would cause the report to greatly exceed the recommended page limit, please discuss how to proceed with the WSDOT Research Coordinator assigned to your project.

Upon completion, reports should be submitted electronically to your Research Coordinator, in Word format. Please include at least one photo in .jpg format for WSDOT to use on the report cover.

Researchers at the University of Washington and Washington State University should follow the procedures set up by their respective Washington State Transportation Center (TRAC) offices to submit reports to WSDOT.

LENGTH AND FONT

Research reports should be no longer than 35 to 50 double-spaced pages, including figures and tables.

Margins should be 1 inch on top and bottom and 1.25 inches on the left and right.

To aid in readability and accessibility for readers with low vision or those who use screen readers, sans serif type faces are recommended, with an 11- or 12-point font size. Examples of preferred fonts include, but are not limited to, Aptos, Arial, Calibri, Helvetica, Tahoma and Verdana.

STYLE

To achieve uniformity and consistency, use the latest edition of *Webster's Third International Dictionary* for spelling, definitions and compounding. Published standards of learned societies are accepted in questions of usage of technical terms. Other matters of style and usage should be based on widely accepted style manuals such as the *Chicago Manual of Style* or *The Gregg Reference Manual*.

PARTS OF THE RESEARCH REPORT

- Title page
- Technical Report Documentation Page (with Abstract), DOT Form F1700.7
- Disclaimer
- Acknowledgments
- Table of Contents
- Lists of Figures and Tables
- Body of Report
  - Executive Summary
  - Introduction or Background
  - Review of Previous Work

  - Research Approach/Procedures
  - Findings/Discussion
  - Conclusions
  - Recommendations/Application/Implementation
- References
- Appendices

Title Page

Using the format shown in Appendix A, the title page should include the:

- type of report (e.g., Draft Report, Final Research Report, Interim Report)
- title of project and agreement number
- report title
- name(s) of principal investigator(s), other authors, and their research agency(ies)
- name and title of project's subject matter expert/technical contact at WSDOT
- name of sponsoring agency
- month and year report completed (this will be considered date of publication).

It is also customary to indicate the name of the current Secretary of Transportation if WSDOT is the sponsoring agency, as shown in the sample report in Appendix A.

Form DOT F1700.7 (8-72), Technical Report Documentation Page

Link to the Technical Report Documentation Page (TRDP) form above, or obtain it from the WSDOT Research Office. It is also incorporated into many report templates. The form requires an abstract, which should be self-contained and not require reference to the report to be understood. The abstract should be comprehensible by a non-technical audience and should not contain jargon, acronyms, abbreviations, symbols, or equations. Within about 200-250 words, it should briefly outline the primary objectives and scope of the study; describe the techniques or approaches used in the project (only to the extent necessary for comprehension); and concisely present the findings and conclusions. "Key words" should reflect language used in the report. Additional key word terms that are topically relevant can be found in the Transportation Research Board's (TRB) *Transportation Research Thesaurus* at https://trt.trb.org.

Disclaimer

The disclaimer is to read as follows:

> *The contents of this report reflect the views of the author(s), who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation, Federal Highway Administration, or U.S. Department of Transportation [and/or another agency]. This report does not constitute a standard, specification or regulation.*

Acknowledgments [optional]

If desired, include a brief statement recognizing individuals and/or organizations for their specific contributions or support during the project.

Table of Contents

It is preferable to include a List of Figures and a List of Tables after main contents listing.

List of Abbreviations [optional]

If it would be helpful to readers, include an alphabetical list of abbreviations and acronyms.

Body of Report

As noted above, the body of the report should be organized as follows:

Executive Summary. Write the executive summary with the busy transportation professional in mind. Summarize the report by capturing the highlights in no more than 10 pages, which should be comprehensible apart from the larger document. It should contain a readable yet condensed description, explained within the context of the project scope and objectives, of the research findings, conclusions, and recommendations that evolved from the project. Beyond these elements, it should contain only information that is essential to an understanding of the findings and how they relate to the solution of the operational problem.

Introduction or Background. Discuss the problem that led to the study, current knowledge that can help in its solution, and the objectives and scope of the research being documented.

Review of Previous Work. Summarize or highlight the project's literature review, state-of-the-art survey, or the work that others have performed in relation to the problem at hand.

Research Approach/Procedures. Discuss the approach that was used in attempting to solve the problem. Include additional information in the appendices, such as forms and/or survey questions that may have been used in soliciting information, or technical details regarding test procedures or analyses.

Findings/Discussion. Present the specific research findings that evolved from the project. Include in the appendices summary data, principal mathematical formulas that were developed, or other technical details.

Conclusions. Conclusions are concerned with more general principles suggested in the findings. They are extensions of the findings beyond conditions specific to the project.

Recommendations/Applications/Implementation. Recommendations should address specific actions that WSDOT should consider. Discuss the implications of the findings in relation to standards, specifications, policies, and procedures; what they add to an understanding of the problem; and what effects they have on economy, safety, and/or other aspects of the problem. Assess their limitations. Items recommended for implementation should be identified and necessary implementation steps listed.

References

1. Arrange the reference list alphabetically by author (or publication information if no author); list only the references cited in the text.

2. Denote a reference at the appropriate place in the text with the author’s last name and the publication date in parentheses (preferably after, rather than interrupting, a sentence). Example: (Reed 1993).

   To include a page number, follow the author and date with a comma and the page number. Example: (Reed 1993, 62)

3. Do not reference any material that would not be available to readers in printed form, such as unpublished material, personal communications, phone

conversations, etc. Instead, state these references in parentheses in the text with the term “unpublished data”.

4. Do not use ibid., op. cit., or loc. cit. If a reference is cited more than one time in the text, repeat the author/date citation.

5. Be sure that references are complete. If a reference has no date, include the information "undated."

6. Do not include sources not cited in the text. To include additional sources, create a separate bibliography.

<u>Appendices</u>

Appendices should contain (1) materials that are needed to support, explain, or substantiate the main body of the report or (2) discussions of a technical nature that would be inappropriate for or disruptive to the main body of the report. Each appendix should be designated by letter and title, and references to appendices should be made at appropriate places in the text. Pages in appendices should be labeled with the letter of the appendix followed by page number (e.g., A.1, A.2, B.1 . . . etc.).

Appendices may contain the following:

- survey(s), the responses to which informed the report
- state-of-the-art or -practice survey
- manuals and guidelines
- documentation and further elaboration of research findings
- forms, laboratory test records, etc.
- mathematical analyses
- project statement and project work plan (including any approved revisions).

Appendices are not necessarily indicated for every report.

METRICATION

Current WSDOT rules do *not* require that authors use International System (SI) units. SI units in parentheses are encouraged, following U.S Customary units, however. WSDOT recommends the current version of the *American National Standard for Metric Practice,* at this writing, *IEEE/ASTM SI_10-2016 (2017),* and AASHTO's *Guide to Metric Conversion (1993)* for guidance in converting units from U.S. Customary to SI.

EQUATIONS

Special considerations are required to make equations accessible/Section 508 compliant. Usually this means an equation needs to be inserted as an image or figure, with alt text. The equation editor in Word is usually not sufficient. Please seek guidance in some of the resources mentioned earlier and/or current accessibility standards online for proper treatment of equations.

Distinguish carefully among the following:

- all capital and lowercase letters
- capital O, lowercase o and 0 (zero)
- lowercase l and number 1 (one)
- letter X, Greek letter χ and the multiplication sign x
- prime ', apostrophe' and superscript ^{1}
- English and Greek letters such as B and β, n and η, u and μ, p and ρ, and w and ω

Number all displayed equations with Arabic numerals in parentheses aligned flush right, e.g.:

$$(x+a)^n = \sum_{k=0}^{n f(x)=a_0+\sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L}+b_n \sin\frac{n\pi x}{L}\right)} \binom{n}{k} x^k a^{n-k}$$

Equation 1

FOOTNOTES

Avoid using footnotes to the text. Incorporate such notes within the text.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviations, acronyms, and symbols must be fully spelled out or defined the first time they are used in the report; the definition or spelled-out form should be given first, followed by the abbreviated term in parentheses. Subsequent mention in the report can then be the abbreviated form. This guidance also applies to the abstract on the Technical Report Documentation Form.

A list of abbreviations and acronyms may also be included as an aid to readers, following the Table of Contents or Lists of Figures and/or Tables.

TABLES

In addition to presenting a good deal of information in compact form, properly formatted tables are important to achieve accessibility and section 508 compliance. Tables can be problematic, so it is important to be aware of how to construct an accessible table.

In brief, tables should have a simple structure. **Merged and blank cells are not permissible**. They must have a title/caption, and a description of the content (alt text) if the data/information is not easily conveyed by the headers.

Solely using colors to convey meaning should be avoided, as screen readers and individuals who are color-blind may not be able to distinguish different colors. Shades of gray may be acceptable if enough contrast exists between background shading and text.

MSWord and other document platforms have built-in features that help with creating accessible documents, including automatically generating alt text for tables, but results should always be checked for accuracy and logic.

1. If tables are not presented on separate pages, leave at least 1 inch of white space between a table and surrounding text. If possible, avoid running tables over multiple pages, but if not possible, make sure to format so that headers are carried over for accessibility.

2. Number the tables consecutively with Arabic numerals and give each table a title/caption. If using the ‘Styles’ function in Word, headings used for table titles should be consistent throughout the document (e.g., use Caption for all table titles). In longer reports or those with many tables, you may number the tables by chapter (e.g., Table 1.1, Table 1.2, Table 2.1). The title should briefly identify the table. Furnish background information, describe the results given in the table, or include information provided by column heads in the text, not in the table title.

3. Refer to each table at the appropriate place in the text to provide continuity and context, particularly to individuals using screen readers.

4. Give each column in the table a heading and leave plenty of space around headings. It is also advisable to set off the title of the table a bit so that auto-tagging of the document will be more accurate.

5. Denote footnotes in tables by superscript letters.

6. Indicate the meaning of a dash (—) when it is used in a table, i.e., whether it is used to indicate missing data, incomplete research, data not applicable or unavailable, or a problem investigated but no results.

7. Check the accuracy of all totals.

8. The size of the type in tables should be no smaller than 10 point.

9. Each table **must** have a title. Table titles belong on top of the table.

FIGURES

1. Use professionally drawn graphics and charts that are clean, sharp, and either black on white or contrasting colors. Solely using colors to convey meaning should be avoided, as screen readers and individuals who are color-blind may not be able to distinguish different colors. Shades of gray may be acceptable if enough contrast exists to make the figure accessible. Images of photocopies, pencil drawings, blueprints or ozalid prints, and negatives are **not** acceptable.

2. Insert jpgs of black and white or color photographs that are sharp, with good contrast, to show detail. Slides and negatives are **not** acceptable.

3. If figures are not presented on separate pages, leave at least 1 inch of white space between a figure and the text.

4. Number figures consecutively with Arabic numerals. If using the 'Styles' function in Word, headings used for table titles should be consistent throughout the document (e.g., use Caption for all table titles). Figure titles belong underneath the figure. In longer reports or those with many figures, you may number the figures by chapter (e.g., Figure 1.1, 1.2, 2.1, etc.).

5. Refer to each figure by number at the appropriate place in the text to provide continuity and context.

6. Do not use lettering on figures smaller than 10 point.

7. Figure sizes, line weights, and letter sizes should be uniform throughout the report, to the extent possible.

8. Each figure must have a title/caption, which belongs below the figure.

9. Each figure must have descriptive alt text.

ADA/TITLE VI NOTICE

By law, all WSDOT public documents must include Americans with Disability Act and Title VI of the Civil Rights Act of 1964 notifications. WSDOT usually includes these notices as part of the report cover that we add to finalized reports, though you may include them if desired.

For your information, as of this writing, these are the current notices:

Title VI Notice to Public

It is the Washington State Department of Transportation's (WSDOT) policy to assure that no person shall, on the grounds of race, color, or national origin, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its programs and activities. Any person who believes his/her Title VI protection has been violated, may file a complaint with WSDOT's Office of Equity and Civil Rights (OECR). For additional information regarding Title VI complaint procedures and/or information regarding our non-discrimination obligations, please contact OECR's Title VI Coordinator at (360) 705-7090

Americans with Disabilities Act (ADA) Information

This material can be made available in an alternate format by emailing the Office of Equity and Civil Rights at wsdotada@wsdot.wa.gov or by calling toll free, 855-362-4ADA(4232). Persons who are deaf or hard of hearing may make a request by calling the Washington State Relay at 711.

COMPLETED REPORTS

When you have finished your report, you may find it helpful to consult the *Final Research Report Checklist* on the next page. We've created it as an aid to checking for certain problematic issues we have seen with submitted reports over the years; using it may save you from having your report returned for further work.

Submit your completed report, as a Word document, to your assigned Research Coordinator. You may also submit a PDF version, if you wish, but a Word version is required to facilitate minor edits or adjustments WSDOT may need to make, such as when we add the report cover. **Please include at least one project photo, in .jpg**

format, or another image or graphic related to the project for the report cover. Also, please remember to include the two-page project summary.

We appreciate your assistance in producing final research reports that accurately document research projects and findings. When shared, these reports will be valuable contributions to the transportation sector's body of knowledge.

Thank you!

QUESTIONS?

If you have any questions or concerns about producing your report, please feel free to contact your Research Coordinator, and/or the TRAC Technical Editor, as appropriate.

FINAL RESEARCH REPORT CHECKLIST

This checklist is designed as a helpful guide for researchers to ensure that as final reports are being submitted for web publication and distribution, they have undergone thorough review and are accurate, complete and ready for dissemination. Thank you for checking!

FORMATTING

□ Report is in Word format and in final form (i.e., no “DRAFT” notations/watermarks).

□ Report has been checked and is fully accessible/ADA and Section 508 compliant.

□ Technical Report Documentation Page (TRDP, Form DOT F1700.7 (8-72)) is included following Title Page and filled in as completely and accurately as possible.

□ WA-RD report number, as applicable, has been assigned and is noted in Box 1 of TRDP *Contact your Research Coordinator if you need a WA-RD report number.*

□ Titles and dates match on title page of report and TRDP, and are accurate.

□ Disclaimer page is included following TRDP.

□ Table of Contents (TOC) page numbers as listed match actual paging.

□ As applicable, References and Appendix/Appendices are listed in TOC.

□ Tables and Figures are included in separate lists following the TOC (preferred) or, if few in number, incorporated into TOC.

□ 2-page Project Summary prepared and is ADA/Section 508 compliant.

□ Complete report (all pages including any appendices), and Summary is being submitted.

CONTENT

□ Formulas and calculations have been double-checked.

- □ Imbedded links have been double-checked and any broken ones corrected or deleted.
- □ Content has been checked and approved by project team Subject Matter Expert(s)/Technical Advisory Group.

REPORT PUBLICATION AND DISTRIBUTION

- □ Photo(s) for cover, in .jpg format, are also to be submitted with report for publication.
- □ Report is ready for public distribution to local and national online repositories, as required, and to appropriate WSDOT Research Topical listserv subscribers.

REFERENCES AND ADDITIONAL INFORMATION

The websites and additional sources of information listed below were referenced in the guidelines and/or are included to provide supplementary guidance for report production.

ASTM International. *SI Quick Reference Guide: International System of Units (SI): The* Modernized Metric System--ASTM R0017. 2017.

The Chicago Manual of Style, 18th ed., 2024. Chicago: University of Chicago Press.

IEEE/ASTM. *American National Standard for Metric Practice -- IEEE/ASTM SI 10-2016.* 2017.

Sabin, William A. *The Gregg Reference Manual: a manual of style, grammar, usage, and formatting*, 11thed., 2011. NewYork: McGraw-Hill.

TPF-5(442) Transportation Research and Connectivity Pooled Fund Study: *508/Accessibility web page*: https://transportation.libguides.com/c.php?g=1028270&p=7596790/

TRAC (Washington State Transportation Center). *Report Production* web page: https://depts.washington.edu/trac/trac-uw/report-production/

Transportation Research Board. *Transportation Research Thesaurus*: https://trt.trb.org/

USDOT. Technical Report Documentation Page, DOT Form F 1700.7 (8-72), 1972. Link to fillable form.

Webster's Third New International Dictionary, 3rd ed., revised, 2002. Philip Babcock Gove, ed. Springfield, MA: Merriam-Webster.

WSDOT. *Research Contract Scope of Work Preparation Guide & Template* [2026].

APPENDIX A

EXAMPLE RESEARCH REPORT

NOTE: Some chapters in this sample report have been abridged to reduce the length of this appendix but retain the structure to illustrate the guidance outlined in this document.

Final Research Report WA-RD 932.1
Maintenance Performance Measurement
Agreement 1462, Task 34

WSDOT MAINTENANCE PERFORMANCE MEASURE ALGORITHMS

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Washington State Department of Transportation Technical Monitors
Kelly Shields/ Bruce Castillo Performance Measurement Team HQ Maintenance Office

Prepared for

The State of Washington
Department of Transportation
Roger Millar, Secretary

August 2023

TECHNICAL REPORT DOCUMENTATION PAGE

REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO.
WA-RD 932.1		

4. TITLE AND SUBTITLE

WSDOT MAINTENANCE PERFORMANCE MEASURE ALGORITHMS

5. REPORT DATE

August 2023

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

Kishor Shrestha

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Washington State Transportation Center (TRAC)
Washington State University, Box 641060
Pullman, Washington 99164

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

Agreement T1462, Task 34

12. SPONSORING AGENCY NAME AND ADDRESS

Research Office
Washington State Department of Transportation
Transportation Building, MS 47372
Olympia, Washington 98504-7372
Project Manager: Doug Brodin, 360-705-7972

13. TYPE OR REPORT AND PERIOD COVERED

Final Report

14. SPONSORING AGENCY CODE

WSDOT

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This research project focuses on deteriorating roadway asset conditions, emphasizing the challenges encountered by the roadway maintenance division of the Washington State Department of Transportation (WSDOT). The project goal is to develop algorithms for prediction models that will forecast the levels of service (LOS) performance conditions of six important highway assets: culvert maintenance, barrier maintenance, traffic signal systems, ditches, slope repairs, and shoulder maintenance. These algorithms are based on a data-driven approach. The algorithms provide a step-by-step process to develop prediction models. The models can be used to forecast LOS performance conditions and trends under various funding levels, allowing them to set performance targets that align with available funds and asset maintenance priorities, potentially preventing expensive reactive maintenance. Data collection included direct collection from WSDOT and two-phase questionnaire surveys to document factors impacting LOS performance conditions. Statistical analyses such as the Relative Importance Index (RII), Kolmogorov-Smirnov and Shapiro-Wilk normality tests, and Mann-Whitney U tests were employed to determine critical factors for each of the six assets. The project identifies the top five highly ranked factors for each asset, which are utilized during model development.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Culvert Maintenance, Barrier Maintenance, Traffic Signal Systems, Ditches, Slope Repairs, Washington State.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
None	None	82	

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation, Federal Highway Administration, or U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

I would like to acknowledge the Washington State Department of Transportation (WSDOT) for providing funding for this research project. In particular, I would like to acknowledge Kelly Shields, Performance Measurement Manager, HQ Maintenance Office, Doug Brodin, Research Manager, Greg Selstead, Assistance Maintenance Engineer (retired), Andrea Fortune, Assistant State Maintenance Engineer, Bruce Castillo, Performance Measure Manager for their support to this project. I also appreciate all the state DOT professionals who provided their insights in this study

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EXECUTIVE SUMMARY

This executive summary provides an overview of this WSDOT research project to address the issue of roadway asset conditions. The primary objective of the project was to develop algorithms that predict the performance conditions of six important highway assets: culvert maintenance, barrier/guardrail maintenance, traffic signal systems, ditches, slope repairs, and shoulder maintenance. The algorithms use a data-driven approach and predict levels of service (LOS) performance conditions and trends under various funding levels. The algorithms developed in this project are the first step to developing prediction models.

For data collection, two major strategies were used to achieve the project objectives. The first step was acquiring direct WSDOT data on asset LOS condition and expenditure. Second, two-phase questionnaire surveys were conducted with WSDOT professionals to collect their insights regarding the factors influencing the LOS conditions of the six assets. The Relative Importance Index (RII) analysis approach was used to assess the survey results, the Kolmogorov-Smirnov and Shapiro-Wilk normality tests were utilized to assess if the dataset was distributed normally, and the Mann-Whitney U test was used to identify differences between the group of variables.

The factors affecting the LOS condition of an asset were ranked, and then highly ranked factors were identified for each of the six roadway assets. For example, the five highly ranked factors for culvert maintenance are hydrological/weather conditions, previous maintenance dates, current LOS, scoured around culvert/pipe, and material type.

Similarly, the highly ranked factors for the other five assets have also been determined. The data analysis results indicated that each asset has more than ten highly ranked factors.

Once the data was analyzed, the project developed prediction model algorithms for each of the six assets. The key steps involved in developing the algorithm for predicting the LOS condition of assets were identified and explained. The key steps of culvert maintenance algorithm are

- Step 1: Identify, collect and understand the significant factors of culvert maintenance and clean the data
- Step 2: Visualize the data
- Step 3: Split the data into training and test datasets Step 4: Develop a regression model
- Step 5: Validate the model Step 6: Test the model
- Step 7: Make predictions using the model

Once the model is validated and tested, it can be used to predict culvert LOS condition. To advance the project in developing prediction models, the author recommends applying Machine Learning (ML) techniques for a future study. High-dimensional datasets and non-linear variables can be processed by ML models, producing more accurate results. The accuracy of prediction models will be improved by training the models with historical and real-time data. The ML technique especially helps in developing more dependable prediction models, while saving time in developing the models and training, validating and testing the models.

Findings and results from this project have great promise for enhancing the overall condition of roadway assets, assuring greater mobility, and fostering economic growth for millions of Americans. WSDOT and other states may use the algorithms in developing the prediction models. The prediction models assist in predicting asset conditions, calculating base funds required for individual assets, and efficiently allocating resources. The project outcomes provide WSDOT with a robust platform to improve asset management decision-making, eventually resulting in safer and more environmentally friendly roads for the general public.

1. INTRODUCTION

Highways are the lifeline of mobility for millions of Americans, and they are essential for economic growth. Vehicle mile travel (VMT) is increasing in the U.S. per Federal Reserve Economic Data (FRED 2022); however, the performance of highway assets is not satisfactory. According to the American Society of Civil Engineers (ASCE) report card, over 40% of public roadways were in poor or mediocre condition in 2021, and that number was consistent for several years (ASCE 2021). With the poor conditions of highway assets, challenges for state departments of transportation (DOTs) are increasing.

The challenges facing the Washington State DOT (WSDOT) Highway Maintenance Program are continually increasing, which weakens its ability to provide a State of Good Repair for highway assets. For example, in 2020, WSDOT met 68% of its highway maintenance asset condition targets, which was down from 77% in 2019 (Shields and Andrea 2021). WSDOT Maintenance has been evaluating the effectiveness of its Maintenance Program through outcome-based performance measures, referred to as level of service (LOS) since 1996 (WSDOT 2018). As it has become known, the Maintenance Accountability Process (MAP) is a comprehensive planning, measuring, and managing process that provides a means for communicating the impacts of policy and budget decisions on program service delivery to key customers, including WSDOT Executive Leadership, the Legislature, and the public.

The challenges come in many forms, including aging equipment, personnel shortages, aging assets, and system additions, as well as underfunding in both preservation and maintenance. Figure 1-1 illustrates the growing needs of WSDOT's Maintenance Division budget to maintain highway assets in acceptable condition. Studies have shown that for several highway assets, 'due,' 'past due,' and 'far past due' for maintaining assets increased to 46% in 2020 from 37% in 2019 (Weston 2021). The current budget limitations have led to an inability to maintain and preserve all highway infrastructure assets as needed at acceptable levels, or keep annualized investments within a reasonable range of lowest life-cycle cost. In most cases, a lack of available funding delayed maintenance activities; additionally, the consequences of delayed maintenance are usually underestimated or not fully considered (NCHRP 2017). Often, WSDOT personnel are faced with making data-driven, trade-off decisions

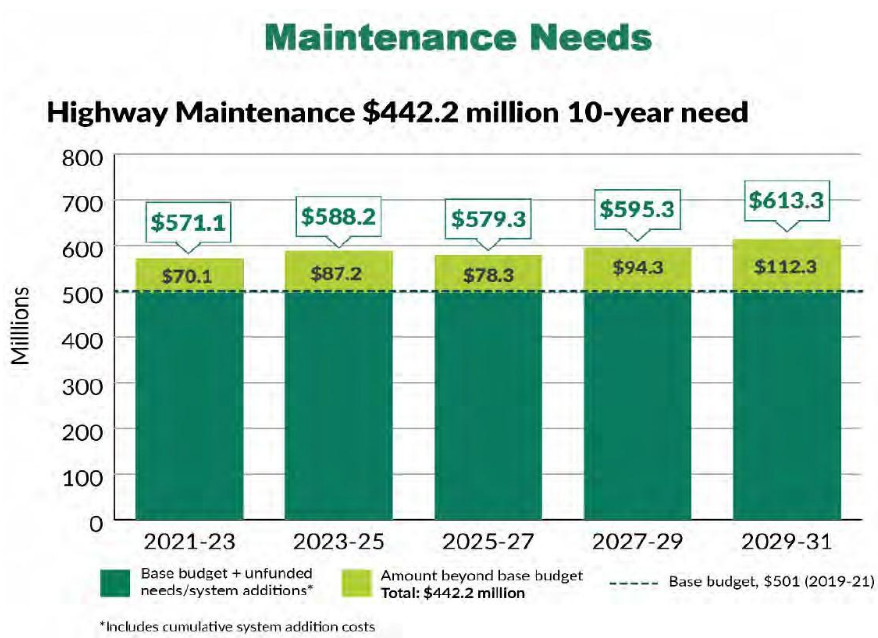

Figure 1-1. WSDOT Maintenance Budget Needs

When assets are not maintained at the right time, it may result in the need for reactive maintenance activities, which cost significantly more. For example, the chip seal cost could be $50,000 to $60,000 per lane mile (Weston 2021). If chip sealing is not done on time and paving is past due, because of backlog and poor condition, major rehabilitation may be required; major rehabilitation is $400,000 to $500,000 per lane mile (Weston 2021), which is considerably more expensive than chip seal.

Thus, predicting future conditions of highway assets using advanced technologies has become necessary today. Machine learning (ML), Artificial Intelligence (AI), and other similar advanced technologies have been utilized in various sectors to address such challenges. Tsai and Wang (2015) developed an algorithm to detect pavement raveling. In that 2015 study, the authors used a data-driven texture analysis techniques approach to classify whether pavement is raveled. In another study, vehicle travel time on a highway was predicted using an algorithm development (Saleh et al. 2023). To predict the travel time, the algorithm evaluated the traffic flow for congestion, slow movement, or free-flow using an eight-step algorithm. In other studies conducted by various authors, predicted friction on roadway pavements and predicted road accidents using ML technologies (Karimzadeh and Shoghli 2020; RAI 2022).

The ability to predict asset performance would help the WSDOT Maintenance Division to set performance targets that balance available funds, acceptable performance expectations, and maintenance division priorities (Adams et al. 2014), which could potentially prevent the need for expensive reactive maintenance actions.

The principal objective of this project is to develop algorithms that will be used as a basis to develop prediction models later. The prediction models can be used to forecast the performance condition of highway assets. This project focused on six highway assets to develop algorithms, which use a data-driven approach, utilizing historical data. Developing the algorithms gives WSDOT Maintenance Division the ability to predict LOS performance data in order to predict trends under differing funding conditions. The six highway assets are listed below.

1. MAP Activity 2A2- Culvert Maintenance
2. MAP Activity 6A7- Barrier /Guardrail Maintenance
3. MAP Activity 6B1- Traffic Signal Systems
4. MAP Activity 2A1- Ditches
5. MAP Activity 2A5- Slope Repair
6. MAP Activity 1A3- Shoulder Maintenance

2. REVIEW OF PREVIOUS WORK

The literature related to highway asset management was collected and reviewed. The main sources of the existing literature were ResearchGate, ASCE Libraries, and WSU Libraries. The review of existing studies is presented in three sub-sections as below. They are i) roadway condition, vehicle mile travel, and consequences of delayed maintenance, ii) performance measurement of roadway assets, and iii) studies on specific assets.

2.1 ROADWAY CONDITION, VMT, AND CONSEQUENCES OF DELAYED MAINTENANCE

In the United States, there are over four million miles of public roadways (ASCE 2021). As the backlog of road maintenance and rehabilitation grows annually, in 2021, 43% of roadways were in poor or mediocre condition. While most interstate highways are in good condition, most non-interstate highways and collector roads are in poor condition. One of the principal reasons for the poor road conditions in Washington State is a result of funding specific to preservation.

The consequences of continued deterioration of road conditions are increased costs to highway maintenance and safety issues resulting from lowered Level of Service (LOS), as well as additional expenses on fuel and repair and increased congestion and delays on travel. It is necessary to prioritize strategic investment in roadway preservation and improvement (NCHRP 2017). The scorecard also provided recommendations, including increasing maintenance budgets to address the roadway system's LOS; developing an asset management plan and incorporate life-cycle cost analysis, building resilient infrastructure, and integrating resilience planning into asset management plans.

Vehicle Mile Travel (VMT) is a direct indicator of most roadway asset conditions, and it is increasing across the United States including Washington state (PSRC 2018; FRED 2022). According to the Federal Highway Administration (FHWA), VMT in 2019 was over 18% more than in 2000 (USDOT 2022; ASCE 2021).

The National Cooperative Highway Research Program (NCHRP 2017) studied the consequences of delayed highway asset maintenance. In many states, agencies have employed various maintenance treatments to slow down deterioration and restore asset conditions; however, in many cases, the treatments employed were delayed due to budget limitations. Study results show that delayed maintenance leads to lower LOS and early deterioration, as well as the need for expensive maintenance actions. Results also show that tools are available to quantify the effects of employing maintenance activities for highway pavements and bridge assets; however, assessing the dollar savings and asset performance enhancement of employing the maintenance activities on time is simply not possible. Therefore, this NCHRP study developed a framework with a procedure to quantify the evaluation of delayed maintenance for seven highway assets: pavements, bridges, culverts, guardrails, lighting, pavement marking, and signs. Many pavement management systems incorporate deterministic models or probabilistic models, and the bridge management system incorporates probabilistic models. This study recommends the following maintenance scenarios to assess the consequences of delayed maintenance: address all needs, do nothing, and delayed maintenance, as well as budget-driven with limited maintenance funds.

2.2 PERFORMANCE MEASUREMENT OF ROADWAY ASSETS

In Washington state, highway assets have been evaluated using outcome-based performance measures since 1996 (WSDOT 2018). The maintenance program measures the performance of highway maintenance assets that can be categorized into three types, which are i) condition assessment, ii) operational assessment, iii) task completion. Condition assessment is done through the Maintenance Accountability Process (MAP). The MAP is a mechanism for monitoring and communicating the results of maintenance activities, such as conducting field surveys. WSDOT's MAP determines the number of deficient culverts out of all culverts that fall within the 0.10-mile sample site. Currently, WSDOT samples 756 different locations across the state that contain a wide variety of inventory. Operational assessment features inventory against the number of repairs against the number of systems. Finally, task completion is measured based on the number of tasks that can be completed against the planned task amount, or the total number of tasks that should have been completed against a known inventory.

The WSDOT Maintenance Division reports statewide highway asset LOS conditions. In 2020, WSDOT met 68% of its highway maintenance asset condition targets and missed 32% of asset condition targets. The eight missed target highway assets were: i) sweeping and cleaning, ii) catch basin and inlet maintenance, iii) stormwater facility maintenance, iv) slope repair, v) roadside cleanup, vi) noxious weed control, vii) bridge cleaning, and viii) pavement striping maintenance. Out of these eight maintenance assets, four missed the target with LOS rating of 'F', which means the assets are in poor or failing conditions, and system failures are likely.

A study was conducted to evaluate the performance of pavements, forecast its condition, and determine the effects of maintenance and rehabilitation strategies (Baladi et al. 2017). The authors established new pavement performance measures and rating systems, which were applied using pavement condition data. The inventory and pavement condition data, as well as distress data were obtained from long-term pavement performance (LTPP) data from three state agencies: Washington State Department of Transportation, Colorado Department of Transportation, and Louisiana Department of Transportation.

The new systems developed were utilized to compute the benefits of maintenance treatment used, identify the impact of weather, and evaluate the design variables on pavement durability. The study made several conclusions, including that thin overlay treatment was not the viable solution to improve pavement performance of cracks (alligator, longitudinal, and transverse cracking) in all regions. After the overlay, the cracks were hidden, but resurfaced again through the overlay after a few years. Slurry seal and crack sealing may improve the International Roughness Index (IRI) and/or rutting but does not improve the pavement performance in terms of cracks. However, aggregate seal coats improve the IRI, rutting, and cracking in all climatic regions.

2.3 STUDIES ON SPECIFIC ASSETS

2.3.1 Culvert Maintenance

Culvert maintenance is an important task of the roadway system as it directly impacts the roadway and local hydrology (Pajouh et al. 2020). Culverts reduce the risk of hydroplaning, vehicle tires being affected by hydrodynamic drag, and a reduction of weather-related crash potential, and the culverts may in many storm events potentially prevent flooding on the roadways during rainfall. A study conducted by Pajouh et al. (2020) shows that the type of culvert material impacts the frequency of culvert maintenance; the size of the culvert and type of inlet/ outlet also impact the culvert maintenance (Jensen et al. 2001; Albuquerque et al 2011). Lack of maintenance for culverts (Figure 2=1) can result in damage not only to the roads on an urban, suburban, and rural level but can also be a detriment to ecosystem (Gharaibeh and Lindholm 2013). Table 2-1 presents factors affecting the LOS condition of culverts.

Figure 2-1. A Culvert at US 195 Washington State

Table 2-1. Factors Affecting the LOS Condition of Culverts

S.N.	Factors Affecting the LOS Condition of Culverts	Sources
1.	Previous date of maintenance	Based on PI's experience
2.	Material type: concrete vs. galvanized steel vs. PVC vs. HDPE	Pajouh et al. (2020)
3.	Length of culvert or serving for Interstate, US, or SR roadways	Albuquerque et al. (2011), Okafor et al. (2023)
4.	Height or diameter of the culvert	Albuquerque et al. (2011)
5.	Orientation of the culvert (cross or approach)	Pajouh et al. (2020)
6.	Inlet / outlet end type	Jensen et al. (2001)v
7.	Current LOS	Based on PI's experience
8.	Funding allocated for the current year	Albuquerque et al. (2011)
9.	Hydrological/weather condition in the area - Precipitation	Pajouh et al. (2020)
10.	Location: urban, suburban, rural area, alluvial fan, upstream land use	Gharaibeh and Lindholm (2013)
11.	Age of culvert	Gassman et al. (2016)
12.	Culvert that pass fish life (Yes/No)	Jensen et al. (2001)
13.	Water/soil related - PH, saltwater exposure, bed loading	Pajouh et al. (2020)
14.	Record of repair - repaired and functional (Yes/No)	Gassman et al. (2016)
15.	Depth of fill or depth buried	Okafor et al. (2023)
16.	Scoured around culvert pipe and headwalls	Gassman et al. (2016)

2.3.2 Barrier Maintenance

According to a study conducted by Karim et al., barrier maintenance is directly influenced by the local factors including weather, average annual daily traffic (AADT) of the road, and what specific type of highway the road is (divided, two-lane, or multi-lane) (Karim et al. 2011). These factors affect the performance of barriers and thus imply the ways that they must be maintained. Supporting this idea, Karim et al.'s study also implies that the age of the barriers has an impact on their need to be maintained. This especially is true as Washington state has such a wide variety of annual weather types which leads to a greater attention towards barrier age as they are impacted by the local weather factors. Figure 2-2 presents concrete barrier and Table 2-2 presents the factors affecting the LOS condition of barrier maintenance with their sources.

Figure 2-2. Roadway Concrete Barrier at US 12 Washington

Table 2-2. Factors Affecting the LOS Condition of Barriers

S.N.	Factors Affecting the LOS Condition of Barrier Maintenance	Sources
1.	Average Daily Traffic	Karim et al. (2011)
2.	Type of Barrier - Beam; Jersey; Cable	Karim et al. (2011)
3.	Location - Ramp; Corner, illuminated intersection/corridor	Liu (2013)
4.	Type of Highways - divided, two lane, multi-lane	Karim et al. (2011)
5.	Pavement Type - Portland Cement Concrete Pavement, Hot Mix Asphalt, Bituminous Surface Treatment	Based on PI’s experience
6.	Shoulder Build-up	Based on PI’s experience

S.N.	Factors Affecting the LOS Condition of Barrier Maintenance	Sources
7.	Weather	Karim et al. (2011)
8.	Last year's Outcome Threshold	Based on PI's experience
9.	Previous date of repair or replace (after repaving or third-party damage)	Hawzheen (2008)
10.	Funding allocated current year for potential repairs	Hawzheen (2008)
11.	Record of repair - Repaired and functional (Yes/No)	Hawzheen (2008)
12.	Age of the Barrier elements (guardrail posts)	Karim et al. (2011)

2.3.3 Traffic Signal Systems

Traffic signal systems (TSS) is a vital component of roadway safety. Figure 2-3 presents a TSS system. Traffic congestion is a significant cause of vehicle accidents, incremental delays, fuel consumption, and operational costs. Thus, paying attention to TSS has a direct impact on the economy and the safety of public. With this in mind, the LOS condition of TSS correlates accordingly with the location of the TSS and their presence in high accident areas (Atewi, 2022). On the topic of safety, storms may affect the performance of TSS. It is important that TSS bear minimal impact from storms, wind gusts, and other varying factors as the impacts of these can result in unsafe traffic conditions both during and after the storm (Irwin et al, 2016).

Westbrook attributes the age of the bulbs in a TSS to the LOS as well (Westbrook and Rasdorf 2023). As modern technology has advanced, it is important to consider that newer light emitting diode (LED) bulbs have become significantly more effective than where they were 20 years ago. Thus, the age and type of bulb impacts the overall LOS condition (Westbrook and Rasdorf 2023). From experience in the field, it is also important to consider not only the age of the bulbs in a TSS, but also the age of the wiring system including connections, the pole itself, and the control system. Table 2-3 presents the factors affecting the LOS condition of TSS.

Table 2-3. Factors Affecting the LOS Condition of TSS

S.N.	Factors Affecting the LOS Condition of TSS	Sources
1.	Types of signal system	Based on PI's experience
2.	Location: Corrosion vs non-corrosion areas	Based on PI's experience
3.	High accident area	Nuri et al. (2022)
4.	High storm/hurricane location	Irwin et al. (2016)
5.	Last year's LOS	Based on PI's experience
6.	Previous date of repair (wiring and connections)	Westbrook and Rasdorf (2023)
7.	Funding allocated current year for potential repairs	Chen et al. (2009)
8.	Record of repair - Repaired and functional	Westbrook and Rasdorf (2023)
9.	Age of the bulbs	Westbrook and Rasdorf (2023)
10.	Age of wiring system including connections	Based on PI's experience
11.	Age of the pole	Based on PI's experience
12	Age of the control system	Based on PI's experience
13.	Method of operating the system	Based on PI's experience

[…THIS CHAPTER ABBREVIATED TO SHORTEN THE EXAMPLE]

3. RESEARCH APPROACH

Figure 3-1 demonstrates the overall research methodology of this project. The scope and objectives were defined, and related literature on the topic of highway asset management in general and on the topic of six assets were administered to gather data of factors affecting the LOS condition of assets. Questionnaire surveys were conducted with WSDOT professionals to collect data and then analyzed. Finally, this project developed six algorithms to predict LOS condition of assets.

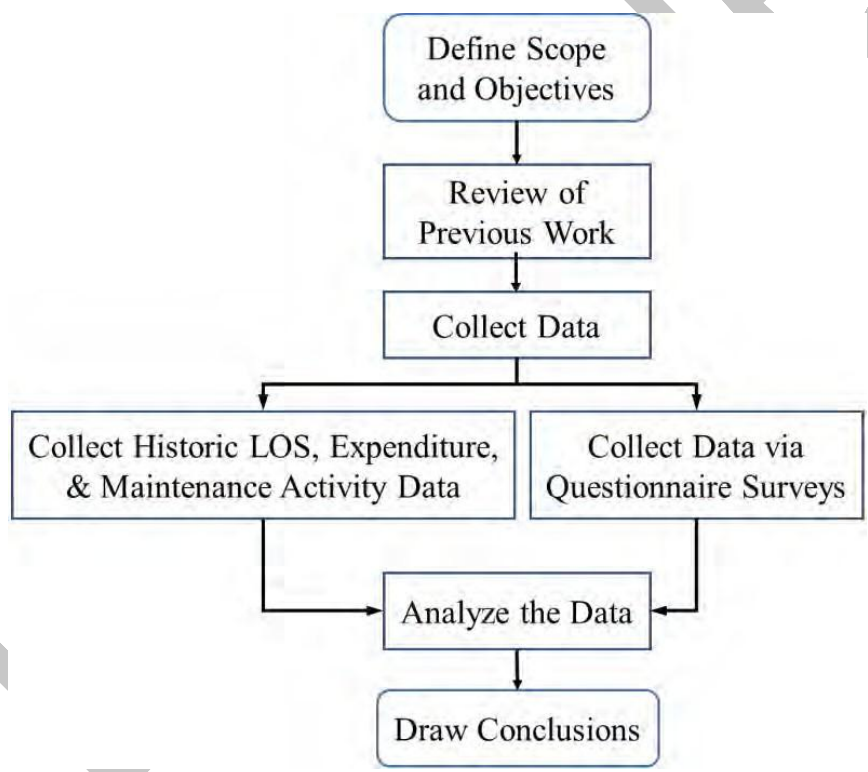

Figure 3-1. Overall Research Approach

3.1 DATA COLLECTION

This research project gathered data in two ways: through direct data collection from WSDOT and via surveys. The direct data collection involves collecting historic LOS data, expenditure records, and maintenance activities records completed for the six assets. The provided data detailed the work in the Maintenance Management System (MMS) for each asset. These data were collected in the Excel files. Moreover, this research project collected ranking data via questionnaire surveys administered to with WSDOT professionals. These surveys were regarding the factors affecting the LOS condition of six assets. The following sub-sections explain the data collection process via the questionnaire surveys.

3.1.1 Phase 1 Survey Development:

The research project team developed the Phase 1 survey to identify and document factors affecting LOS condition of six assets. Factors were collected through the existing literature and the experiences of the project team, and a list of factors for each of the six assets were prepared. The surveys also included a description that stated how asset conditions are assessed (A through F), which was taken from WSDOT Maintenance Manual. The contents of the Phase 1 survey of six assets are presented in Appendix A. That survey was distributed to related senior asset managers for their review, and they were also asked to add additional factors that they suspect might affect the LOS condition of assets. The WSDOT managers provided their feedback either in the survey or through email. The additional factors provided by the WSDOT managers/ professionals were included in the Phase 2 survey. These additional factors were presented in the results and discussion section in Table 4-6 (TSS), Table 4-8 (Ditches), Table 4-10 (Shoulders), and Table 4-12 (Slopes).

3.1.2 Phase 2 Survey Development:

The Phase 2 survey was developed based on the Phase 1 survey and feedback received from WSDOT asset managers. For the six assets, six phase 2 survey questionnaires were developed. For the Phase 2 surveys, participants were given 10 days to complete the survey. If a significant number of professionals had not completed the survey, a follow up email was sent to increase the response rate. In the Phase 2 survey, the list of factors that affects the LOS condition of assets were distributed to the relevant WSDOT professionals, and the respondents were asked to rank the provided factors on the Likert scale from 1-to-X, where 1 refers to the most important factor and X refers to the least important factor. (X is the variable, and is different for different assets, for example, there are 16 factors in culvert maintenance, so the respondents were asked to rank the factors from 1-to-16.)

Specific surveys were distributed only to those professionals working with that specific asset for an extensive period. The surveys were conducted on word files and respondents provided numbers ranking the provided factors. These surveys were collected through email conversation, and their responses were stored digitally on a Spreadsheet separately for each asset for data analysis.

3.2 DATA ANALYSIS

3.2.1 Relative Importance Index (RII) Method

After data was collected from survey respondents, data analysis was performed. First, data regarding crucial factors that affect the LOS condition of each asset were analyzed using a descriptive analysis. Then, for each asset, the Relative Importance

Index (RII) method was used to rank the factors. The equation (1) given below was used to find out the RII values. This method is similar to the one adopted by Shrestha (2016).

$$\text{RII} = \frac{\sum_{i=1}^{N} W_i}{A \, x \, N} \qquad \text{Eq.1}$$

where, Wi = Rank assigned by i^{th} responder; A = Highest rank; N = Total number of respondents.

3.2.2 Kolmogorov-Smirnov and Shapiro-Wilk Test

Following descriptive analysis, the gathered responses were analyzed to determine if the collected dataset were normally distributed. The Kolmogorov-Smirnov and Shapiro-Wilk normality tests in Statistical Package for Social Sciences (SPSS) were utilized. If the dataset were normally distributed, parametric tests are conducted. Conversely, if the dataset were not normally distributed, non-parametric tests are conducted.

3.2.3 Mann Whitney U tests

As explained in the result section, the datasets in this project were not normally distributed; therefore, the project team conducted a non-parametric test, the Mann Whitney U tests, to compare two groups. If the p-value of the test statistics were less than 0.05, the test result is significant. Using these test results, the project team determined critical factors affecting the LOS condition of the each of the six assets.

4. RESULTS AND DISCUSSION

In the Round 2 surveys, WSDOT professionals were asked to rank the listed factors based on how important they are comparatively. The number of factors listed in the surveys were different for different assets. The summary of the responses received is presented in Table 4-1 below. The following sub-sections present details about the data analysis of the six assets.

Table 4-1. Phase 2 Survey Responses

Roadway Assets	No. of Factors in Phase 2 Survey	No. of Responses Received
1. Culvert Maintenance	16	29
2. Barrier Maintenance	12	31
3. Traffic Signal System	14	23
4. Ditch Maintenance	18	30
5. Slope Repair	22	8
6. Shoulder Maintenance	29	8

4.1 RANKING OF FACTORS AFFECTING THE LOS OF CULVERT MAINTENANCE

In the Phase 2 survey of Culvert Maintenance, the respondents were asked to rank the factors that affect the LOS of culverts. Participants were asked to rank sixteen factors. The top five highly ranked factors based on RII analysis were as follows: “Hydrological/ weather condition in the area – Precipitation,” “Previous date of maintenance,” “Current LOS,” “Scoured around culvert/pipe and headwalls,” and “Material Type: Concrete vs. Galvanized Steel vs. PVC vs.

HDPE.” Table 4-2 presents the summary of the results. The “Hydrological/ weather condition in the area – Precipitation,” factor received the highest rating from responders.

Table 4-2. Ranking of Factors Affecting the LOS of Culverts

Factors	Sample Size (N)	RII Values	Ranking
Hydrological/ weather condition in the area – Precipitation	29	0.63	1*
Previous date of maintenance	29	0.58	2*
Current LOS	29	0.57	3*
Scoured around culvert/pipe and headwalls	29	0.55	4*
Material Type: Concrete vs. Galvanized Steel vs. PVC vs. HDPE	29	0.51	5*
Age of Culverts	29	0.50	6*
Location: Urban, Suburban, Rural area, Alluvial fan, Upstream land use	29	0.49	7*
Record of repair – Repaired and functional (Yes/No)	29	0.48	8*
Height or Diameter of the Culvert	29	0.46	9*
Culverts that pass fish life (Yes/No)	29	0.46	10*
Water/soil related – PH, saltwater exposure, bed loading	29	0.45	11*
Length of Culvert or serving for Inter State, US, or SR roadways	29	0.44	12*
Depth of fill or depth of buried	29	0.38	13*
Inlet / Outlet End Type	29	0.38	14*
Orientation of the Culvert (Cross or Approach)	29	0.34	15*
Funding allocated for the current year	29	0.28	16

Note: Significant at α level 0.05
* Significant at α level 0.05

After the factors were ranked from 1-16 based on the RII analysis, statistical analysis was conducted to determine the critical factors affecting the Culvert Maintenance. When Mann-Whitney U tests were administered to determine the group differences, the test results show that the group of top fifteen factors are statistically significantly higher rated than 16^{th} factor (Table 4-3).

Table 4-3. Results of Mann-Whitney U Tests of the Factors Affecting the LOS of Culverts

Geotechnical-related Change Orders on Cost Overrun	N	Mean Rank	Sig.
Factors ranked 1 through 15	435	226.80	0.01*
Factors ranked 16	29	318.00	

Note: Significant at α level 0.05
* Significant at α level 0.05

4.2 RANKING OF FACTORS AFFECTING THE LOS OF BARRIER MAINTENANCE

Responders ranked the factors affecting the LOS condition of barriers to the Barrier Maintenance Phase 2 survey. They were asked to rank each of the twelve stated factors. The five highly ranked factors based on RII study are "Type of Highways - divided, two lane, multi-lane," "Location - Ramp; Corner, Illuminated Intersection/Corridor," "Average Annual Daily Traffic," "Types of Barrier - Beam; Jersey; Cable," and "Previous Date of Repair or Replacement." The results are summarized in Table 4-4. The factor "Type of Highways - divided, two lane, multi-lane," obtained the highest rating from respondents.

Table 4-4. Ranking of Factors Affecting the LOS of Barriers

Factors	N	RII Values	Ranking
Type of highways – divided, two lane, multi-lane	31	0.69	1*
Location – ramp; corner, illuminated intersection/corridor	31	0.66	2*
Average annual daily traffic (AADT)	31	0.65	3*
Types of barrier – beam; jersey; cable	31	0.64	4*
Previous date of repair/ replacement	31	0.45	5*
Record of repair – repaired and functional (Yes/No)	31	0.42	6*
Age of the barrier elements	31	0.40	7*
Weather	31	0.40	8*
Shoulder build-up	31	0.38	9*
Funding allocated towards current year for potential repairs	31	0.30	10*
Pavement type – Portland cement concrete pavement, hot mix Asphalt, bituminous surface treatment	31	0.28	11*
Last year's outcome threshold	31	0.23	12

Note: Significant at α level 0.05
* Significant at α level 0.05

The critical factors impacting the barrier condition were identified after the factors were ranked from 1 to 12 based on the RII analysis. The group of the top 11 factors is statistically substantially higher rated than factor 12 when Mann-Whitney U tests were used to evaluate the group differences. The summary of the Mann-Whitney U tests is presented in Table 4-5.

Table 4-5. Results of Mann-Whitney U Tests of the Factors Affecting the LOS of Barriers

Geotechnical-related Change Orders on Cost Overrun	N	Mean Rank	Sig.
Factors ranked 1 through 11	341	179.08	
Factors ranked 12	31	268.11	0.01*

Note: Significant at α level 0.05
* Significant at α level 0.05

4.3 RANKING OF FACTORS AFFECTING THE LOS OF TRAFFIC SIGNAL SYSTEMS (TSS)

The factors affecting the LOS of TSS were ranked by respondents to the Phase 2 TSS Survey. Participants were asked to rank fifteen factors. The five highly ranked factors based on RII analysis are "Age of wiring system including connections," "Age of the control system," "Inability to complete preventive maintenance due to lack of FTEs," "Age of the bulbs," and "Previous date of repair (wiring and connections"). Table 4-6 presents the summary of test. The factor that respondents rated highest was "Age of wiring system including connections."

[…**THIS CHAPTER ABBREVIATED TO SHORTEN THE EXAMPLE]**

5. CONCLUSIONS AND RECOMMENDATIONS

This research project primarily focuses on the challenges that the Maintenance Division of the Washington State Department of Transportation (WSDOT) is facing in dealing with the deteriorating state of roadway assets. It is impossible to overstate the significance of well-maintained roadways for economic development and mobility. Minimally, transportation assets need to meet expectations. The primary goal of this project is the development of algorithms that will help create prediction models to forecast the performance condition of six important highway assets: traffic signal systems (TSS), barrier maintenance/guardrail, ditches, and slope repairs.

The algorithms will give WSDOT the ability to predict levels of service (LOS), performance, conditions, and trends under various funding allocations, using a data-driven approach.

Essentially, this predictive capacity will help define performance objectives that align with the available funds, the performance expectations, and the priorities of the maintenance division, potentially avoiding the need for expensive reactive maintenance actions.

The results of this study will enable WSDOT to prioritize funding allocations based on asset condition or LOS, resulting in more effective and efficient highway infrastructure maintenance programs. The project findings, therefore, show great potential for enhancing the general state of roadway infrastructure, providing greater mobility and future economic growth for millions of Americans.

Two major data collection methods were used to accomplish the goal of this project: (1) direct data collection from WSDOT regarding asset condition and expense and (2) a two-phase survey to collect factors impacting the LOS of the six assets. Asset managers reviewed the first phase survey and provided input that went into the second phase survey. Six asset-specific surveys were distributed to each asset professionals, and they ranked the provided factors on a Likert scale. A descriptive analysis of the key elements influencing the LOS of each asset was conducted before beginning the statistical data analysis. Following that, the factors for each asset were ranked using the Relative Importance Index (RII) technique. Statistics were examined using the Statistical Package for Social Sciences (SPSS). If the dataset was not normally distributed, the Shapiro-Wilk test was performed to determine this, and the Mann-Whitney U test was used in its place.

This study aimed to rank and determine the crucial elements influencing the LOS conditions of six roadway assets. A thorough list of variables was provided for each asset in the Phase 2 surveys done with WSDOT professionals, and they were asked to rank them in order of significance. The top five culvert maintenance variables, according to the RII approach, are a) hydrological/weather condition in the area – precipitation, b) previous date of cleaning, c) current LOS, d) scoured around culvert/pipe and headwalls, and e) material type: concrete vs. galvanized steel vs. PVC vs. HDPE.

Similarly, the top five factors for Barrier Maintenance, TSS, Ditches, Shoulder, and Slope Repair assets are a) type of highways - divided, two-lane, multi-lane, b) location - ramp; corner, illuminated intersection/corridor, c) average annual daily traffic,

d) types of barrier – beam, jersey, cable, and e) previous date of repair or replacement; a) age of wiring system including connections, b) age of the control system, c) inability to complete preventive maintenance due to lack of FTEs, d) age of the bulbs, and e) previous date of repair (wiring and connections); a) slope (steepness) of ditch, b) width and depth of ditch, c) local weather patterns, rainfall, snowfall, d) unstable slopes / slide area, and e) proximity to falling rocks nearby; a) edge drop off adjacent to paved shoulder, b) cracks, type, and width of cracks present, c) erosion of gravel shoulder, d) current state of shoulder, and e) type of shoulder: paved, unpaved, or composite (combined); a) current state of slope, b) existing signs of erosion, c) slope steepness, d) slope material type (earth, gravel, other), and e) slope height, respectively.

Since the datasets were not normally distributed, Mann-Whitney U tests were employed in SPSS to identify critical factors testing significant group differences. The existing studies showed that the insignificant variables can be eliminated during the prediction model development if some variables are insignificant based on p-value (>0.05). The findings of this study give WSDOT a strong foundation on which to build predictive models that will aid in better resource allocation and asset management decision-making, ultimately leading to better maintenance plans, improved road conditions, and greater overall efficiency in managing the assets of the highway system. The results of the study have the potential to improve highway asset management methods not just within the WSDOT but also in other states, resulting in safer and more sustainable highways for the benefit of the public.

[…**THIS CHAPTER ABBREVIATED TO SHORTEN THE EXAMPLE]**

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APPENDIX

Phase 1 Survey Questionnaires A1.1

Culvert Maintenance

A Survey on Factors Affecting the LOS of Culverts

1. From the literature review and the research team's experience, the factors affect the LOS of a Culvert next year include the following 11 items. Please add other factors that you think may affect the LOS of a Culvert.
    a. Previous date of maintenance
    b. Material Type: Concrete vs. Galvanized Steel vs. PVC vs. HDPE
    c. Length of Culvert or serving for Inter State, US, or SR roadways
    d. Height or Diameter of the Culvert
    e. Orientation of the Culvert (Cross or Approach)
    f. Inlet / Outlet and End Type
    g. Current LOS
    h. Funding allocated for the current year
    i. Hydrological/ weather condition in the area – Precipitation
    j. Location: Urban, Suburban, Rural area, Alluvial fan, Upstream land use
    k. Age of Culvert
    l. Culvert pass fish life (Yes/No)
    m. Water/soil related – PH, saltwater exposure, bed loading
    n. Record of repair – Repaired and functional (Yes/No)
    o. Depth of fill or depth of buried
    p. Scoured around culvert/pipe and headwalls

A1.2 Barrier Maintenance

A Survey on Factors Affecting the LOS of Barrier Maintenance

1. From the literature review and the research team's experience, the factors that may affect the Level of Service (LOS) of Barriers include the following items below. The outcome of the system is measured as "the percent of barrier that is damaged or missing." More information is presented in the Table below. Please add other factors that you think may affect the LOS of the Barriers.

   a. Average Daily Traffic
   b. Types of Barrier – Beam; Jersey; Cable
   c. Location – Ramp; Corner, illuminated intersection/corridor
   d. Type of Highways – divided, two lane, multi-lane
   e. Pavement Type – Portland Cement Concrete Pavement, Hot Mix Asphalt, Bituminous Surface Treatment
   f. Shoulder Build-up
   g. Weather
   h. Last year's Outcome Threshold
   i. Previous date of repair or replace (after repaving or third-party damage)
   j. Funding allocated current year for potential repairs
   k. Record of repair – Repaired and functional (Yes/No)
   l. Age of the Barrier elements (guardrail posts,)

Maintenance Accountability Process
Perfomance Measures

Group -

Activity Number:	6A7		**Priority Rank**		13
Activity Name:	Barrier Maintenance				
Survey Period:	Summer		**Detail Level:**		Statewide
Indicator:	Damaged or defective barrier.				
Outcome Measure:	Percent of barrier that is damaged or missing.				
Outcome Unit:	% Def.				
Outcome Thresholds	**Service Level**				
	A	**B**	**C**	**D**	**F**
	0 - 1%	1.1% - 3%	3.1% - 5%	5.1% - 10%	> 10%
Comments:	Surveys indicate type of barrier, i.e. beam or jersey barrier.All barrier types including cable barrier will be collected under field surveys separately.				
Data Source	Field Surveys				

This is an image of the Survey on Factors Affecting the LOS of Culverts that the authors used. It asks respondents to confirm 11 items that may affect the LOS of a culvert and to add others.

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