# MPC-533
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Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure

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**Research Needs**

The poor current condition and continued deterioration of transportation assets, including bridges and other structures, is a well-documented concern in the United States (ASCE 2017). State Departments of Transportation (DOTs) are challenged with the need to improve (or at least maintain) the condition of large networks of assets with inadequate budgets. Inspection is an important part of the asset management process that provides the information upon which maintenance and repair decisions are made. This proposal focuses on the specific issues associated with bridges, but the framework is anticipated to have applications to other types of infrastructure.

For the past several decades, U.S. bridge inspection practices have been based on a model that requires most bridges be inspected on a fixed two-year cycle, and where the vast majority of inspections are conducted visually. There is a growing recognition that bridge inspection practices are in need of enhancement in order to provide for public safety and the most effective use of maintenance and repair budgets (ASCE/SEI-AASHTO Ad Hoc Group, 2009). For example, recent research has studied the development of risk based inspection practices that seek to extend inspection periods for low risk bridges and focus inspection efforts on the most critical elements (Washer et. al., 2014). A significant body of research has also investigated the application of a variety of nondestructive evaluation (NDE) techniques to bridge inspection (particularly bridge decks) (Gucunski, et.al. 2013).

The potential of NDE methods beyond visual inspection to enhance our understanding of bridge condition has been demonstrated; but challenges remain in the effective utilization of NDE by DOTs. One significant limitation is the difficulty in interpretation of collected data that limits the accuracy of NDE techniques. For example, recent analysis of commercially conducted NDE bridge deck scans on four Colorado bridges showed that the scanned results often did a poor job of identifying areas on bridge decks in need of repair and in estimating the level of repair needed (Vemuri and Atadero, 2016).

Another issue limiting the application of NDE (beyond visual inspection) by state transportation agencies is the cost. States currently have well established practices by which they conduct and pay for routine visual inspections. Introducing other NDE methods as routine is challenging because they are not yet in a position to replace visual inspection, and thus are viewed as an additional cost that must be paid. Paying for NDE might reduce the funding available to conduct preventive maintenance or repair structures. On the other hand, NDE might be a cost savings measure if its findings are accurate enough to prevent mobilizing a large construction crew for only a limited amount of repair work, or if it ensures that repairs are conducted in a timely fashion while repair costs are still lower (i.e., the structure has not deteriorated to a poorer condition stage where the cost of repair is significantly higher). In order for transportation agencies to adjust their inspection practices to best use the capabilities of various NDE techniques beyond visual inspection, they must have confidence in the methods to inspect the bridge and an understanding of the lifecycle cost implications of NDE use. This study will focus specifically on the lifecycle cost implications of using NDE methods besides visual inspection to inspect bridges.

**Research Objectives**

1. Identify all relevant cost items to be included in the Life Cycle Cost Analysis (LCCA) model for bridge inspection using visual and other NDE methods.
2. Gather data from sources such as DOT records and NDE contactors to define well established costs for bridge inspections.
3. Develop models to determine costs for parameters that are not well established, for example the cost of a missed maintenance opportunity.
4. Use the LCCA model to analyze different scenarios and study the impact of different inspection schemes on the lifecycle costs for an individual bridge.
5. Conduct a preliminary investigation into how lifecycle costs for an individual bridge would impact lifecycle costs for inspection of a small bridge network
6. Produce guidance for decision-makers on how best to incorporate NDE techniques into existing inspection practices based on the results of the previous objectives

The goal of this study is to develop a Life Cycle Cost Analysis model that incorporates costs associated with different types of inspections in order to provide bridge management decision makers the information they need to most effectively integrate advanced inspection strategies such as NDE methods beyond visual inspection into their inspection practices. The objectives listed above are designed to meet this goal.

**Research Methods**
Reinforced concrete (RC) bridge decks are one of the most significant maintenance issues facing DOTs; and there is a variety of information available on the application of different NDE techniques to inspecting RC bridge decks. Thus the research team will consider RC bridge decks and their associated types of deterioration, inspection and repair as the example case for development of the LCCA model. Literature review and consultation with DOT engineers will be used to develop the LCCA model for this specific scenario. Cooperation with DOT engineers and commercial firms specializing in NDE will be used to establish known costs. Existing deterioration models for RC bridge decks will be used to model costs associated with conducting preventive maintenance in time, or too late. These models will be probabilistic models based on Markov chains and a new mechanistic model developed in a recently completed research study by one of the PIs (Nickless and Atadero 2017). The completed LCCA model will be used to analyze a variety of different inspection schemes (timing and technique) for an individual bridge to identify trends in how the use of NDE impacts lifecycle costs associated with inspection. The research team will then conduct a preliminary investigation into how these trends would impact inspection decisions for a slightly larger network.

**Expected Outcomes**
This project has two primary expected outcomes. 1) This study will produce a model for predicting the lifecycle costs associated with different inspection strategies including timing of inspection and inspection technique. The prediction tool will be programed in Microsoft Excel so as to be accessible to bridge managers. 2) This research project will use the LCCA tool to study the impact of different inspection schemes and provide general recommendations for bridge managers on how to begin incorporating NDE into their management practices.

**Relevance to Strategic Goals**

- State of Good Repair

This project primarily addresses the USDOT strategic goal: State of Good Repair. This project will study the most cost effective ways to incorporate advanced inspection strategies into DOT bridge management activities. The results of this project are expected to help DOTs more effectively allocate inspection dollars, enhancing the available information for management decision making and preserving funds for use in repair and maintenance of bridges both of which should help reach a state of good repair.

**Educational Benefits**
A Ph.D. student will be hired to assist the PIs in conducting this research project; and it is anticipated that this research will form a foundation for their dissertation. Furthermore, Dr. Atadero has recently developed a graduate level course titled: Inspection, Management and Repair of Structures; and the findings of this research project may be introduced in that course.

**Technology Transfer**
The research team will collect data from DOT engineers to ensure that the LCCA model developed by the research team considers the factors deemed important by practicing bridge managers. As the study progresses we will keep our CDOT contacts apprised of our findings; and at the end of the study we will ask to present this research to them. We will also collect data

from commercial firms that conduct NDE on bridges; and this collaboration will provide the opportunity to also inform commercial NDE practitioners of the findings of our LCCA. It is anticipated that the practitioners might use findings of this study to more effectively market their products and services to agencies managing bridges.

In addition to the technology transfer that will happen through these working relationships, the research team will also disseminate project findings to other researchers through technical publications (journals, conferences, reports) and presentations.

**Work Plan**

1. Literature Review
2. Establish costs for LCCA model
3. Establish Framework for LCCA model for inspection costs
4. Collect data for readily available costs
5. Develop models to compute other relevant costs (such as the cost of a missed maintenance opportunity).
6. Code LCCA model in Excel
7. Analyze costs associated with different inspection models
8. Summarize findings to provide guidance to decision makers
9. Prepare final report and other methods of project dissemination.

Task 1: A detailed literature review will be performed on the topics of LCCA as well as bridge inspections. We anticipate this task to conclude by the end of the 2nd month of the project.

Task 2: We will consult with DOT engineers to determine the costs to include in the LCCA model We anticipate this task to conclude by the end of the 3rd month of the project.

Task 3: Based on the information gathered in Task 1 and Task 2, a framework will be established for the inspection LCCA model. We anticipate this task to conclude by the end of the 4th month of the project.

Task 4: Data will be collected for the costs identified to be included in the LCCA model. We anticipate collecting costs for different types of inspection on a per bridge and per unit area basis, costs for different types of repairs ranging from preventive to extensive, and indications of how costs vary for different types of construction, age of structure, and level of accessibility. We anticipate this task to conclude by the end of the 6th month of the project.

Task 5: Additional models will be developed to determine other costs (such as cost of a missed maintenance opportunity). We anticipate this task to conclude by the end of the 10th month of the project.

Task 6: The final LCCA model incorporating all cost elements will be coded in MS Excel resulting in a user-friendly interface. We anticipate this task to conclude by the end of the 13th month of the project.

Task 7: Different inspection scenarios (i.e., based on inspection timing and methodology) will be developed and analyzed using the finalized LCCA model. We anticipate this task to conclude by the end of the 16th month of the project.

Task 8: The findings will be summarized into general suggestions for cost effective implementation of NDE methods for bridge inspection. We anticipate this task to conclude by the end of the 18th month of the project.

Task 9: A final report will be prepared and efforts will be undertaken to disseminate findings and provide technology transfer to the transportation agencies. We anticipate this task to conclude by the end of the 22nd month of the project.

**Project Cost**

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| Total Project Costs: | $108,000 |
| MPC Funds Requested: | $54,000 |
| Matching Funds: | $54,000 |
| Source of Matching Funds: | Faculty Time and effort |

**References**


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