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Project Title:
Statistical Analysis and Sampling Standards for Maintenance Management Quality Assurance (MMQA)

University:
University of Utah

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Research Needs:
Maintenance management is very critical to the efficient allocation of resources and greater efficiencies in work processes. State DOTs need to continuously plan maintenance activities to monitor and maintain their highways, bridges, and other transportation infrastructures. Considering the limited budget and resources, maintenance activities need to be carefully planned and deployed such that the field inspections for measured conditions are conducted appropriately and statistically representative. It is thus necessary to develop a standardized statistical method to determine the samples (frequency and amount) to be collected to streamline productivity and ensure maintenance quality. This project will also develop a methodological framework for compiling, processing and statistically analyzing the data from sampled field inspections. Resampling statistical method might be used here in case the collected data are not significantly representing the "true" measurement. The framework will be able to determine the overall conditions of the system based on the collected sample data.

It is critical to streamline the process of sampling field inspection sites through developing a statistical framework. An effective sampling method ensures that the items chosen to be measured from the entire "population" is statistically represented. Instead of inspecting all the sites available, the sampling method can identify a limited number of sites for inspection yet accurately represent the conditions of the overall system. The proposed statistical method would be effective to achieve the satisfying accuracy with significantly less resource and funding.

Upon the collection of measured items, it is of great importance to report the finding in a manner that all maintenance levels are fully aware of the quality of maintenance of the areas that are pertinent to them. The proposed methodological framework will achieve this by generating a

transferable analytical procedure to determine the overall conditions of the system, which provides references for senior leaders to prioritize the maintenance activities.

Research Objectives:

The primary objective of this research project is to develop sampling standards for MMQA to effectively measure roadway conditions and return a Level of Maintenance (LOM) grade that is statistically valid at the statewide level, the region level, and the station level. Secondary objectives of this research project are to develop methodological framework to analyze the measured samples in order to obtain the overall system conditions. Resampling method might be developed as well in case that the sampled measurement is insufficient to represent the overall population.

Research Methods:

In 1997, UDOT implemented the MMQA (now MMQA+) program for the purpose of evaluating and reporting the effectiveness of its maintenance program. The program divides the entire maintenance efforts into seven different groups (16 measures in total), including snow and ice, non-hard surface maintenance, roadside maintenance, vegetation control, drainage and slop repair, traffic services, and rest area maintenance. With a couple of exceptions, all measures are now semiannual (UDOT, 2012). To improve on the existing guideline as well as to provide a more efficient management of the maintenance activity, it is desirable to design a measuring plan that accustomed to the nature of various activities, just to enable users to monitor trends more easily, making the MMQA program more useful for managing the workload.

The research will start by examining the historical inventory of the measures identified, in an effort to understand the overall distribution of the measured features, including the frequency, measured segments, condition, etc. Statistical analysis will then performed to determine the proper distribution of degradation for different measures. In response to the primary goal of this research of choosing the proper sampling frequency and sampling segment for measuring the roadway conditions, it is important to understand the underlying distribution based off of the historical data. And when the historical data is insufficient to infer the actual distribution, resampling method will be applied in this study to construct confident interval in order to determine the "true overall level of maintenance". A computer simulation technique called "bootstrap" is applied to find the confidence interval. Bootstrap is a model-free based resampling approach (Ruppert, 2011). It is one way that modern computing has revolutionized statistics.

Assume that ***B*** number of resamples were drawn from the original sample. Let $\bar{Y}_{boot,b}$ and $s_{boot,b}$ be the sample mean and standard deviation of the *b*th resample, *b*=1,….***B***, and let $\bar{Y}$ be the mean of the original sample. We can define:

$$t_{boot,b} = \frac{\bar{Y} - \bar{Y}_{boot,b}}{s_{boot,b}/\sqrt{n}} \tag{1}$$

For Equation (1), note that for the resample, the population mean is $\bar{Y}$. That is to say, a resample is taken using the original sample as population. Because the resamples are independent of each other, the collection of $t_{boot,1}, t_{boot,2} \ldots$ can be treated as a random sample from the distribution of t-statistics. After ***B*** values of $t_{boot,b}$ have been calculated, the $\alpha/2$-lower and –upper quantiles of these $t_{boot,b}$ values can be determined, namely t_L and t_U. The bootstrap confidence interval for μ can be expressed as:

$$(\bar{S}(n)+t_L*\sqrt{S^2(n)/n},\ \bar{S}(n)-t_U*\sqrt{S^2(n)/n}) \quad (2)$$

In Equation (2), $\bar{S}(n)$ and $S^2(n)$ are the mean and variance of the original sample, and only t_L *and* t_U are calculated from the ***B*** bootstrap resamples.

This research will provide a systematic approach for the Maintenance Division, at the statewide level and at the region level, to effectively plan their maintenance activities. The methodological framework developed can serve as guidance for the application of the MMQA program. It will be of great interest to maintenance engineers and managers to help streamline the work process and improve efficiency.

Expected Outcomes:
This project will develop a sampling method that will assist with MMQA to determine the frequency, length of segments, and number of sites for measuring conditions. It will also develop a methodological framework for analyzing the collected samples and determine the overall system conditions for examination by all levels of maintenance.

Relevance to Strategic Goals:
This project is most relevant to the USDOT strategic goals of "State of Good Repair" and "Economic Competitiveness".

State of Good Repair
With USDOT's emphasis on improving the conditions of the aging infrastructure, this project establishes a data-driven framework to better monitor and manage the transportation asset through maintenance activities. The project will develop appropriate sampling standards for various maintenance activities conducted using historical maintenance inventory records. And the methodological framework proposed will streamline the analysis process of the measured samples to obtain the overall system conditions, inform senior leaders in UDOT to make comprehensive assessment of roadway system, and help inform investment decisions and optimize management strategies.

Economic Competitiveness
A high quality and fully functioning transportation infrastructure is vital to the economy development, it is also the prerequisite for future growth. As a critical component of keeping the State's economy competitive, maintenance activities require a significant number of personnel, equipment, and materials to ensure the infrastructure conditions are well documented and properly responded. It is thus imperative to plan and schedule the maintenance work efficiently to fully utilize the available resources. This project will achieve that goal by developing methodology for efficient sampling of the roadway conditions of various maintenance activities, taking into account the economic utilization and prioritization of available resources.

Educational Benefits:
One graduate student will be heavily involved in this research. He/she will lead the preparation of journal publications resulting from the work, and in most cases, deliver conference presentations. The project will serve as a basis for his/her dissertation work. The University of Utah will open an undergraduate/graduate level course on "Traffic System Analysis" in 2016. The procedure for

estimating sampling frequency and distribution from historical data, resampling techniques, and determining the overall level of maintenance will lead to new material included in the course to teach the students practical skills on transportation asset management.

Work Plan:

The above objectives will be accomplished through a phased approach. The following major tasks are anticipated for each of the phases:

Phase I: Preliminary Synthesis

1. Review literature and practice regarding maintenance management and quality assurance.

2. Meet with the project TAC to present findings in the literature review, determine measurable activities (and inventory), and present preliminary understanding of sampling methods.

Phase II: Methodological Framework Development

3. TAC meeting to discuss Phase II plan and receive approval for Phase II work.

4. Develop a detailed framework for developing statistical analysis and sampling method for MMQA.

5. Develop sampling method for the selected measures.

6. Determine sample size (number of samples and length of sample segment), and conduct field inspection for the identified measures.

7. Statistically analyze the sampled measures and refine the methodological framework to determine the overall LOM.

8. Present at various venues (TAC meetings, District Engineer's meeting, and Annual UDOT conference) about the final result of the project.

9. Prepare a draft final report describing all previous tasks of the research. Circulate the draft report for peer review.

10. Submit a final report that addresses comments received during the peer review.

A schedule of activities is provided on the following page.

Technology Transfer Plan

The potential audiences for this research are individuals involved in the traffic operations and transportation asset management, including traffic engineers, planners, and senior leaders at

FHWA and at individual state DOTs. The following agencies, offices, and committees are those most likely to take a leadership role in implementing the research results:

- Utah Department of Transportation
- FHWA Office of Operations
- TRB Maintenance and Operations Management
- TRB Highway Capacity and Quality of Service Committee
- TRB Freeway Operations Committee

The proposed principal investigator routinely interacts with UDOT, UTA, FHWA, SHRP 2 Reliability Program, and the listed TRB Committees. The 2015 Midyear Meetings of TRB Highway Capacity and Quality of Service Committee, TRB Maintenance and Operations Management, and TRB Freeway Operations Committee will be an opportunity to share early results and future directions of the research project. The proposed principal investigator will work with the committee chairs to possibly get a presentation on the project added to the agenda. The proposed principal investigator and her graduate students routinely attend TRB's annual meeting as well. At least one TRB paper on this work will be submitted for presentation and publication.

No.	Major Task	Q 4 2014			Q 1 2015			Q 2 2015			Q 3 2015			Q 4 2015		
	Phase I:															
1	Literature synthesis on maintenance management and quality assurance															
2	TAC meeting to present preliminary understanding on the sampling method															
	Phase II:															
3	TAC meeting for Phase II approval															
4	Framework development for MMQA															
5	Develop sampling methods															
6	Determine sample size and conduct field inspection															
7	Analyze the sampled measures and determine the LOM															
8	Present final results															
9	Prepare draft final report															
10	Submit a final report															

Project Cost:
Total Project Costs: $50,000
MPC Funds Requested: $20,000
Matching Funds: $30,000 Source of Matching Funds: Utah Department of Transportation

TRB Keywords: Level of Maintenance, Statistics, Sampling, Quality Assurance.

References:

Ruppert, D. Statistics and Data Analysis for Financial Engineering. 1st Edition. Springer. 2011.

Utah Department of Transportation. Maintenance Management Quality Assurance Plus (MMQA+) Inspection Manual. July 2012.