MPC-528
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Project Title:
Hotspot and sampling analysis for effective maintenance management and performance monitoring

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University of Utah

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Research Needs:
Field inspection is critical to the effective performance monitoring and asset maintenance. Given the constraints on budget and time, the inspection activities thus require significant attention for planning and monitoring. Particularly, sampling technique is needed for each asset item to determine the portion of population to be inspected, frequency at which the inspection should be conducted, and method to be used to collect the information. The new Maintenance Management Quality Assurance (MMQA) Mobile, a mobile application developed for the Utah Department of Transportation (UDOT) maintenance crew to automate the field inspection process, provides an innovative solution for accurately recording and tracking the asset conditions through geotagging the information during inspection. It also provides great data sources and new dimensionality for uncovering the maintenance condition with great level-of-details that was previously impossible to achieve. For example, the signage inventory was collected from September 2014 to March 2015 through MMQA Mobile. There is a total of 67,259 sign assemblies statewide. More than 8,500 defect observations were recorded in the database. Figure 1 illustrates the maintenance network with segments color-coded to represent Level-of-Maintenance during this data collection effort. A snapshot which is a sample zoom-in inspection on the signs in desire/deficient conditions is also shown.

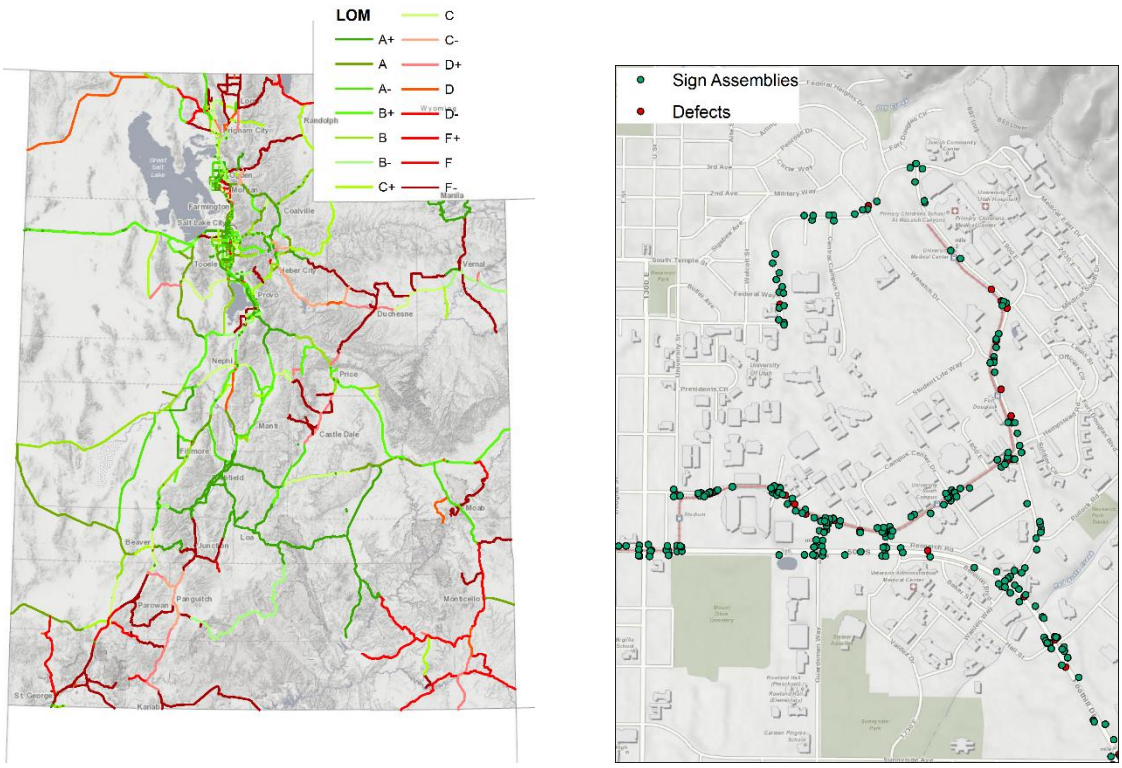


FIGURE 1 Location of defects and color-coded roadway segment LOM.

Using the MMQA mobile data, this research will identify the defect hotspots within the network. On the basis of another ongoing research for developing the sampling standard for MMQA, this research aims at using this dataset with finer resolution to determine the location and frequency for asset sampling. The previous roadway maintenance segmentation is of different length even for the same station, it poses great challenges for providing a sampling solution that is applicable to all stations and all routes. The Markov Decision Process is developed as a technique in the ongoing research to model the sampling location and frequency. However, the previous segmentation and data resolution issue make it difficult to construct deterioration transition matrix. With the new MMQA mobile data, it allows the sampling method to be accurately developed by fine-tuning the segment/sample unit. Coupled with optimization technique that takes into account budget and time limitation, the final sampling method will provide a comprehensive guidance in both spatial and temporal dimensions to optimize the inspection work flow.

Research Objectives:

The primary objective of this research is to analyze the MMQA mobile data and identify the defect hotspots on the GIS platform to guide the road segmentation. With the shorter road segment that contains accurate maintenance inspection information, sampling method utilizing machine learning techniques will be developed to suggest the location and frequency of sampling. The sampling procedure will also take in account the inspection routing optimization.

Research Methods:

The MMQA program was established by the UDOT in 1997 for evaluating and reporting the effectiveness of its maintenance activities. The program has evolved ever since then to provide

systematic guidance for feature condition thresholds, funding projection and allocation, and LOM measurements. MMQA provides guidance on a total of 17 measurement activities such as snow and ice, litter pickup, vegetation control, etc. It further offers detailed specifications on the criteria of desired/deficient conditions of each activity. Inspectors are required to be familiar with the procedure and methodologies described for each maintenance activity before going into the field. The graphical description serves to help them confidently describe the condition of any particular feature. The maintenance performance is measured and reported in the form of LOM, expressed as 15 different letter grades (A+ to F-). The entire statewide highway system is divided by 76 maintenance stations. Each station further divides each of its routes into one or more segments (2,048 segments in total). The personnel would conduct inspections for each route segment, and record both the total number of features to be maintained on that segment and the total number of deficient features. The LOM is further computed via record post-processing.

Using Signage Repair and Replace database as an example, Table 1 shows its corresponding grading scale for LOM estimation.

TABLE 1 LOM Grading Scale for Signage in MMQA

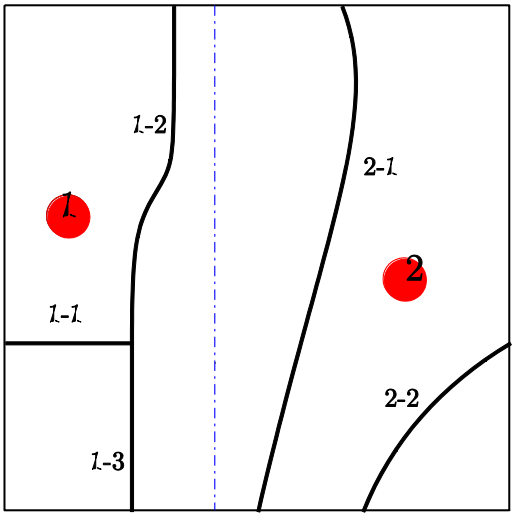
Percent Deficient	Grade	Percent Deficient	Grade
0.00-1.71	**A+**	13.41-14.99	**C-**
1.72-3.41	**A**	15.00-16.69	**D+**
3.42-5.00	**A-**	16.70-18.39	**D**
5.01-6.70	**B+**	18.40-19.99	**D-**
6.71-8.40	**B**	20.00-21.69	**F+**
8.41-10.00	**B-**	21.70-23.39	**F**
10.01-11.70	**C+**	23.40-100.00	**F-**
11.71-13.40	**C**		

In another ongoing UDOT project, titled "Statistical Analysis and Sampling Standards for Maintenance Management Quality Assurance (MMQA)", the research team developed a sampling scheme that integrates Fisher information with spatial sampling technique - Generalized Random-Tessellation Stratified Design (GRTS) that can be customized based on agencies sampling requirements, e.g. station-balanced, spatially-balanced, etc.

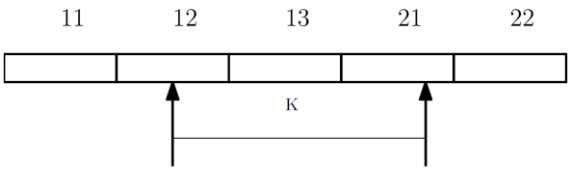
The basic idea of GRTS method is to create a quadrant-recursive function that maps two-dimensional space into one-dimensional, thereby defining an ordered spatial address for the population. In the maintenance application, the target population is the roadway segments partitioned by stations. To illustrate the GRTS sampling scheme, Figure 2 shows an example region where five roadway segments are under the maintenance jurisdictions of two stations (circled). The segments are randomly labeled according to the station ID. When mapping the 2-dimensional space into an ordered 1-dimensional linear structure, the features in Figure 2(a) would be transformed into Figure 2(b). Note that in Figure 2(b), each segment is assigned equal probability, yet unequal probability can be tempered by the allowance of unequal length for each unit as shown in Figure 2(c). The sampling scheme can be expressed as:

$$d + (i-1) \times k \qquad for\ i = 1,2,\ldots.,n \tag{1}$$

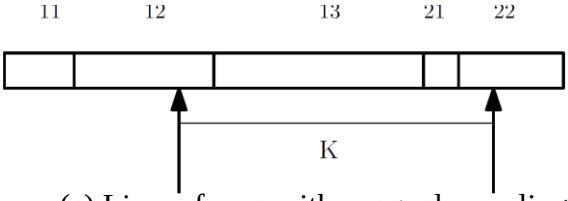
where d is a random start within the 1-dimensional space along $[0,k)$, L is the total length of line, n is the sample size, and $k=L/n$.



(a) Example region for maintenance activities



(b) Linear frame with equal sampling probability



(c) Linear frame with unequal sampling probability weighted by the number of signs within each roadway segment

FIGURE 2 Example of GRTS algorithm for maintenance activity sampling.

Building upon this preliminary result, the research team will design a sampling scheme capturing conditions of multiple assets for maintenance activity optimization. In other word, it is a sampling method that is not only confined to signage, but also extended to an optimized sampling of multiple assets simultaneously (e.g. guardrail, vegetation control, culvert, etc.) The proposed method will address where the agencies would need to collect one sample set with the maximum information of multiple assets for LOM estimation. The method will integrate Locality-Sensitive Hashing (LSH) algorithm with clustering sampling that can be customized on the basis of local agencies' requirements.

Expected Outcomes:

This research will provide a systematical approach for identifying the asset defects on the existing roadway network and determining the sample size and frequency for an effective maintenance management. The result of this research will be implemented in the future updates of the MMQA Plus program to guide the sampling process and provide reference for the overall system level of maintenance. Specifically, the research will provide GIS products with defect hotspots identified utilizing the MMQA mobile data. It will also present a refined sampling framework for the MMQA and an automated procedure for maintenance inspection routing optimization.

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 a graduate level course on "Transportation System Modeling" in Fall 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. Analyze the MMQA mobile data to identify the defect hotspot and guide the roadway segment unit determination.

2. Meet with the project TAC to present preliminary findings and seek feedback on the roadway segmentation.

Phase II: Methodological Framework Development

3. Identify the asset inventory that will be considered for sampling.

4. Apply the LSH sampling method to the roadway network based on the new segmentation.

5. Determine the location and frequency of sampling for each asset item given the constraint on time and budget.

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

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

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

A schedule of activities is provided as follows:

No.	Major Task	Q 2 2016			Q 3 2016			Q 4 2016			Q 1 2017			Q 2 2017		
	Phase I:															
1	Analyze the MMQA mobile data for hotspot analysis															
2	TAC meeting to present preliminary findings															
	Phase II:															
3	Identify the asset inventory for sampling															
4	Apply the LSH sampling method to the new roadway segmentation															
5	Determine the location and frequency of sampling for each asset															
6	Present final results															
7	Prepare draft final report															
8	Submit a final report															

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

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 and TRB Maintenance and Operations Management 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.

Project Cost:
Total Project Costs: $100,000
MPC Funds Requested: $ 50,000
Matching Funds: $ 50,000

TRB Keywords:
Level of Maintenance, Hotspot Analysis, Sampling, Quality Assurance.