City-Wide Application of a Vehicle-Mounted Multi-Sensor Pavement Monitoring System

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Extended Abstract

The StreetScan Pavement Management System (PMS) is introduced. It empowers cities to make more cost effective road repair decisions. At the heart of the system is a van outfitted with a patented, multimodal sensor array that rapidly collects data for every street in the city. Custom data processing and fusion algorithms are applied to convert the sensor data into more actionable condition indices. A unique combination of decision trees and mathematical models are then applied to determine when, where, and how to repair each street in the most cost effective manner. Users are able to visualize and interact with these repair suggestions, as well as the sensor data and condition indices, through an innovative web-based GIS application. The StreetScan PMS is considerably more affordable than conventional PMSs and has a faster turnaround time. This paper validates its effectiveness in the real world by taking a look at two recent applications: 1) a city-wide application in Beverly, MA and 2) an application to several streets in Boston, MA.

For years cities have misused their limited resources on the wrong road repair decisions. These mistakes have accumulated into overwhelming backlogs and are a main reason America’s roads are crumbling with over 1.3 million miles in poor or mediocre condition [1]. At the root of the problem is that cities aren’t properly equipped to handle road repair decisions, which are incredibly complex.

Public perception of road repair decisions is oversimplified. The tendency is to believe that everything revolves around potholes, which are easy to locate because of their large size, easy to prioritize because they are hazardous and must be fixed immediately, and easy to repair with rapid methods that are highly standardized and affordable. In reality, the majority of repair budgets are spent on decisions that take place after the potholes are filled, when cities must decide which roads need more extensive repairs or full reconstruction. These decisions are much more complicated than potholes because factors like the method of repair and prioritization are no longer trivial. Furthermore, preventive maintenance must be considered. The complexity of these factors is explained in the bullets below.

- **Repair Method:** There are many repair methods to choose from such as slurry, chip seal, microsurfacing, cold planing and overlay, shim and overlay, hot in-place recycling, full reconstruction, and more. It must be decided which method, or several methods, is needed. Furthermore, it must be decided whether to apply repairs for just a portion of the road, for the full road, or for several roads. All of these decisions are influenced by road condition, which means cities also need to consider the presence, quantity, and severity of various distresses such as rutting, cracks, bumps, depressions, raveling, shoving, and patches.

- **Prioritization:** Due to limited resources, cities cannot improve all defective roads every year. Deciding which ones is a complex problem that requires consideration of the required repair methods and associated costs for every street in the city. It is also necessary to consider the city’s
current and projected repair budget, road ages, functional class (e.g. arterial, collector, local), number of lanes, traffic loads, and maintenance and rehabilitation history.

- **Preventive Maintenance:** This is the practice of making minor repairs in the early stages of a road’s life, when it’s still in good condition. This is when repairs are cheapest, fastest, and have the greatest long term benefit. A recent case study in Michigan shows that preventive maintenance can save cities roughly $310,000 per lane mile in repair costs, and can extend the service life by 16 years [2]. Implementing preventive maintenance requires consideration of repair method and prioritization as described above. However, the types of repairs are different. They include crack sealing, joint sealing, and localized repairs for potholes, depressions, poorly constructed utility patches, and minor leveling. There is an additional level of complexity because preventive maintenance techniques are only beneficial for a short period of time, which means cities need to have a much more current understanding of city-wide road conditions.

Making the right repair decisions requires thorough investigation and comparison of the above factors. Cities are overwhelmed by this complexity. In order to handle it, experts agree that they must use a PMS [3]. These are data driven, strategic approaches to gathering and utilizing information about a city’s roads to make the most cost effective repair decisions. Modern PMSs have three key components: 1) collect condition data; 2) data driven repair decisions; and 3) visualize. Details are provided in Table 1.

### Table 1. Components of a modern PMS

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<th>#</th>
<th>Component</th>
<th>Description</th>
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<td>1</td>
<td>Collect Condition Data</td>
<td>A survey is performed to measure the condition of every street in the city. This requires measuring the road’s profile and surface distress information as well. The end result is a massive dataset that is difficult to interpret. Accordingly, algorithms are applied to convert the data into condition indices that are more actionable, such as indices for specific distresses and ASTM standards like Pavement Condition Index (PCI), International Roughness Index (IRI), and Mean Texture Depth (MTD).</td>
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<tr>
<td>2</td>
<td>Data Driven Repair Decisions</td>
<td>Algorithms are applied to the condition data to determine when, where, and how to repair each street in the most cost effective manner. Typically, these algorithms also take into account the city’s long term goals, current and projected repair budget, preferences for specific repair methods, and local costs for repair materials and contractors. Furthermore, the algorithms are often influenced by design data such as road ages, functional class, number of lanes, traffic loads, maintenance history, and location of road assets such as manholes, drainage, and utility covers.</td>
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<td>3</td>
<td>Visualize</td>
<td>Software is used to provide users with a clear and concise way to visualize and interact with the results of the first two components. Options are provided to view repair decisions and condition data as statistics, plots, tables, reports, or overlaid on a map of the city.</td>
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The most critical, and complex, aspect of a PMS is the condition data. This data gets the highest weight when making repair decisions. If it’s unreliable, the repair decisions become non-optimal and cities end up misusing their limited resources. Furthermore, condition data is important because of several benefits it provides beyond its use in PMSs, such as for quality control, obtaining additional funds for repair budgets, and opposing non-expert repair demands from politicians and the public.
Considering its leading role in PMSs, it’s essential that condition data are accurate, objective, and up-to-date. Cities use automated methods to achieve this. Automated methods are vehicles outfitted with sensors. These systems are rapid, covering cities at the posted speed limits without slowing other drivers. They use a combination of expensive cameras and line lasers to create high resolution 3D maps of the road’s surface contours. Condition data is then extracted by analyzing these contours, and image data from the cameras, with algorithms or human inspectors.

The major limitation of automated methods is cost. A typical system (i.e. van outfitted with sensors) costs ≥ $1 million [4]. Often the cost is even higher than this because many of these systems require significant manual post processing (e.g. expert must review collected images to identify damage), which can be very expensive. These costs make it difficult for cities to afford automated methods. Though they’ve been around for many years, a recent study in Illinois shows that only 30% of the agencies surveyed are using them [5]. Unable to afford automated methods, cities have two other options. The first option is to use manual methods developed over 30 years ago that are subjective, labor intensive, hazardous to inspectors, prone to human error, cause traffic congestion, and too slow for preventive maintenance (turnaround time can be greater than 6 months). The second option is do-nothing. Both options are unacceptable and lead to non-optimal repair decisions.

This paper introduces the StreetScan PMS to overcome the data collection limitations of traditional PMSs, while also providing an innovative approach to repair decisions and visualization. For the data collection component, a van outfitted with a low cost, patented multimodal array of sensors (e.g. microphones, cameras, radar, tire pressure sensing) is utilized to survey street conditions. Data from the sensors is fed to a variety of custom algorithms, some of which use multisensor data fusion, to output several condition indices for each street, including PCI, IRI, and MTD.

A key distinction from automated methods, is that the condition data is obtained without using manual post processing. Instead, all algorithms are automated, which reduces cost and speeds up the turnaround time to just a few days. A further distinction is that the StreetScan PMS does not generate high resolution 3D maps of the road’s surface contours. This allows much more affordable sensors to be used, reducing the cost of the van system by roughly 80-85%. The tradeoff is that the StreetScan PMS van can’t identify the location and size of distresses with mm accuracy. In reality, this is not a substantial tradeoff as many cities aren’t interested in this level of detail. And they certainly aren’t interested in the extra costs associated with storing the massive datasets. Cities care more about having a system that is objective, rapid, and doesn’t cause traffic congestion, which are all features that the StreetScan PMS provides.

For the second component in Table 1, the StreetScan PMS inputs condition data to a unique combination of decision trees and deterioration models. A priority assessment model is used as well that factors in a cost-benefit analysis. The output from these models tells users when, where, and how to repair each street in the most cost effective manner.

For the third component in Table 1, StreetScan PMS utilizes a custom web-based GIS application that is intuitive and flexible, providing cities with many options to visualize repair decisions and condition data. Since the software is web-based, zero installation is required and it can be accessed from any computer, tablet, or phone connected to the internet. A summary of the StreetScan PMS is provided in Fig. 1.
This paper validates the effectiveness of StreetScan PMS in the real world by taking a look at two recent applications. First, an application in Beverly, MA, is considered. The SPMS was applied city-wide. Data collection results and management software were handed over to city officials for use in real-world decision making. They provided feedback about cost, turnaround time, usefulness of the data, and user friendliness of the visualization software. Second, an application in Boston, MA, is considered. The StreetScan PMS was applied to the same streets as a conventional PMS from a respected engineering company. A comparison analysis was done that shows SPMS results are consistent with the conventional method.

References