Innovative Approaches to Pavement Condition Data Collection

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ABSTRACT

This paper highlights a series of novel and developing methods of pavement condition assessment using advancing technologies. The data collected by these methods can be used to improve pavement performance management, infrastructure investment decisions, and broad transportation asset management and planning efforts. This information is intended for transportation and planning agencies who wish to explore novel technology-enabled methods to improve pavement performance management within a comprehensive performance-based transportation asset management system.

Five categories of pavement data collection are discussed herein:

- Smartphone Accelerometry Indices
- Crowdsourced Pavement Condition Data
- Automated Vehicle Systems Data
- In Situ Structural Health Monitoring
- Automated Distress Classification
INTRODUCTION

Transportation agencies are frequently challenged by budget constraints to maintain pavement and other infrastructure in good condition. To meet these challenges, agencies across the country are developing data-driven performance-based transportation asset management (TAM) programs to optimize infrastructure investments across a long-term timescale. For most, if not all, transportation agencies, roadway pavements are the central feature of a TAM program. Effective pavement performance management requires accurate and pertinent data regarding pavement condition. Many agencies are strongly interested in exploring new methods of data collection and utilization.

Many transportation planning efforts, including pavement condition measurement, are largely responsive to federal reporting and planning requirements such as the National Highway Performance Program (NHPP). These federal programs require specific data regarding pavement condition, including International Roughness Index (IRI), percent cracking, rutting, and faulting. These pavement performance measures must conform to specifications given in the guiding regulations, which typically reference AASHTO standards.

However, the NHPP reporting requirements are considered the minimum data necessary to effectively manage pavement assets within a modern performance-based TAM program. This paper highlights a series of novel and non-typical methods of pavement condition assessment that can further improve investment decisions and support broader transportation planning efforts. Most of the methods described herein would not apply to federal reporting requirements through the NHPP. This information is intended for transportation and planning organizations who wish to explore novel technology-enabled methods of pavement condition measurement to further optimize pavement performance management.

Five categories of pavement data collection are discussed:

- Smartphone Accelerometry Indices
- Crowdsourced Pavement Condition Data
- Automated Vehicle Systems Data
- In Situ Structural Health Monitoring
- Automated Distress Classification

SMARTPHONE ACCELEROMETRY INDICES

There have been several research and pilot projects aimed at using the accelerometers and GPS receivers in smartphones to measures of pavement roughness. Three significant examples of projects exploring this method are introduced, below.

MDOT/UMTRI Data Probe

The Michigan Department of Transportation (MDOT), with the University of Michigan Transportation Research Institute (UMTRI), has investigated the possibility of using MDOT maintenance vehicles to obtain pavement condition data. The Data Probe project attempted to correlate smartphone accelerometry data with existing pavement metrics (i.e., IRI and PASER). The Data Probe team determined during preliminary work that attempting to use accelerometry to recreate PASER ratings (a subjective “windshield survey” assessment) was unlikely to be successful. Researchers did find some correlation between smartphone accelerometry and IRI, but the resulting data was not precise enough to be of much use in TAM or pavement condition reporting (1).

One barrier to the Data Probe approach is that data capture was envisioned as limited to
deployed MDOT fleet vehicles, which could make only a limited number of passes over a section of road within a given time period. In fact, MDOT had hoped to capture useable data after only a single pass. Such an approach requires carefully controlling various factors in the data-capture process that are not feasible in typical conditions (2). A more promising approach to using smartphone data to assess pavement condition is to aggregate data from numerous passes, such as the NDSU method discussed below.

**NDSU Road Impact Factor**

The Upper Great Plains Transportation Institute at North Dakota State University (NDSU) has developed a method of using smartphone accelerometry to derive a novel index of pavement roughness called the road impact factor (RIF). The RIF index has shown to correlate to IRI and can be derived from any vehicle at any speed (3). Precision similar to that achieved by a standardized IRI profilometer can be achieved in a limited number of passes (as few as seven) when a single vehicle is used at a relatively consistent speed and the smartphone is precisely mounted within the vehicle. An extension of this method, called time-wavelength-intensity-transform (TWIT) can obtain pavement roughness data with less control over variables, but requires substantially more passes (4).

**Roadroid**

One instance of a pavement data smartphone app that has been commercially deployed is Roadroid. Developed in Sweden, Roadroid uses a combination of vehicle calibration and repeated measurements to obtain usable data. Roadroid data can be collected with a standard Android smartphone and typical passenger vehicle. Frequent data collection allows agencies to monitor roughness changes over time. This can give early warnings of changes and damage, enable new ways to work in the operational road maintenance management, and can serve as a guide for more accurate surveys for strategic asset management and pavement planning.

Collected measurement data are wirelessly transferred via a web service to an internet mapping server with spatial filtering functions (10).

Roadroid can provide estimated IRI by correlating android smartphone accelerometry data to known vehicle types through experimentally determined formulas, or can allow the user to calibrate IRI measurement to the specific vehicle if an appropriate reference road is available. Roadroid estimated IRI was found to be “moderately correlated” with true IRI ($R^2=0.515$). Roadroid developers acknowledge that this is not an appropriate replacement for formal IRI measurement, but intend the program as a monitoring system and superior alternative to subjective rating systems (11). The system has been deployed as a contract service using dedicated probe vehicles, though developers acknowledge that it would have even higher value as a passive crowdsourcing application (12).

**CROWDSOURCING PAVEMENT CONDITION DATA**

Crowdsourcing involves leveraging the combined intelligence, knowledge, or experience of a group of people to answer a question, solve a problem, or manage a process. Opportunities for crowdsourcing have greatly increased with the broad adoption of internet-connected devices, especially smartphones (5).

This paper considers crowdsourcing as divided into two types: active and passive. Active crowdsourcing refers to volunteers actively and purposefully providing data. Passive crowdsourcing refers to data that is collected from people without them taking a specific action to submit the data. For example, if a person used a smartphone app to submit a photo and
location of a pothole, this would be active crowdsourced data. On the other hand, if the person downloaded and ran a smartphone application that uses accelerometry data to automatically detect and report a pothole, this would be passive crowdsourced data.

**Active Crowdsourced Reporting**

Many transportation agencies already crowdsource data on potholes and other issues by allowing system users to report problems via mobile or web applications (5). But such methods cannot easily provide a timely and accurate system-wide perspective. Traditional web reporting tools require the user to manually input relatively detailed location information; many users likely perceive this process as a barrier. Additionally, many users are not familiar with the distribution of jurisdiction for public roads between state, county, and local entities; applications that don’t allow for reporting across the entire network may confuse and frustrate would-be volunteers.

Crowdsourcing pavement data is likely more effective with applications that are able to accept reports across jurisdictions and agencies. Many services offer convenient features such as complaint classification and support in routing citizen reports to appropriate agencies. One such app, SeeClickFix, has become a popular service and has been adopted by many public agencies as an official citizen engagement platform (6). In the UK, the national government has deployed a pothole reporting app with nationwide scope. UK’s app was specifically designed to allow bicyclists to report road conditions that pose a safety hazard to bikes, but the app is available for all road users (7).

These citizen-reporting crowdsourcing methods are important public-relations tools for transportation agencies. In the absence of sanctioned citizen reporting methods, citizens might opt to self-deploy reporting platforms. Such grassroots platforms could be beneficial, but agencies risk losing control of the process. Such citizen-deployed platforms are often created to publically shame agencies into action (8).

Most existing pothole-reporting mechanisms are focused on reactive operations and maintenance activities. The data is not often stored and incorporated into asset management programs. One challenge in using such methods for TAM is generating enough public participation to obtain useful system-wide data. Another challenge is assuring that the data does not lead to uneven distribution of resources and entrenchment of existing socioeconomic inequalities due to demographic biases in users of such an app (9). Despite the challenges, if structured and managed properly, the data generated by these citizen reporting systems could provide value in determining recurring problems, patterns, and impact on public satisfaction.

**Passive Crowdsourced Reporting**

Many research organizations and transportation agencies are pursuing low-cost pavement data using connected vehicles or devices. Consumer-grade sensors—such as those installed on smartphones—have been shown capable of detecting potholes, rough pavement, and low friction areas (2, 4). But pavement data collected via smartphone is inherently imprecise due to real-world limitations in the controllability of measurement methods and conditions. Obtaining the required number of data points to monitor an entire road network likely requires *crowdsourcing* data collection to public volunteers. Many of the same principles used in developing smartphone accelerometry indices (as described above) can be extended to crowdsourced methods to achieve relatively precise results across much of the road network.

While many projects have investigated recreating standard pavement condition measurements (such as IRI or PASER). These efforts typically achieve reasonable correlation,
but not sufficient enough to be useful (4). Further, even if perfected, such methods could not be used for federal reporting requirements unless they were included in the regulatory specifications and/or referenced industry standards.

Using crowdsourcing to obtain pavement condition would more likely be successful with development and implementation of novel metrics developed specifically to make use of smartphone-based crowdsourced data (4). Roadroid, described above, is an example of a mobile pavement data collection app that uses a purposefully-created metric. The most challenging component of such a project would likely be obtaining sufficient public participation.

An example of an application that captures pavement data without trying to approximate pre-existing metrics is StreetBump, deployed by the City of Boston. StreetBump is a smartphone-based application to identify potholes. It was originally deployed as a tool for city employees (13). However, the city opened the application for public use and has collected valuable data from this crowdsourcing effort (15). StreetBump’s creators believe that if the app were to demand less interaction from users (e.g., manually starting the app and sending data) the potential for useful data collection via crowdsourcing would increase (13).

**AUTOMATED VEHICLE SYSTEMS DATA**

Automated Vehicle Systems refer to any vehicle-based systems that collect data for the purpose of automated vehicle control systems functions. For example, anti-lock brakes (ABS) is a system that uses sensors to detect wheel-spin rates to automatically rapidly cycle the brakes and help the driver maintain control of the vehicle. The data used to activate the ABS braking system could potentially be shared with transportation agencies to identify slippery pavement conditions.

In most cases, any data generated by automated vehicle systems is solely for internal use of the system (16). However, this is only a result of typical architectural design. There are no hard barriers to off-loading vehicle data if system designers allow for it. Developers of automated vehicle systems have already begun exploring system and network architectures that would allow for data sharing with transportation authorities for purposes of pavement condition assessment.

**Jaguar Land Rover Research**

Jaguar Land Rover is developing a method to detect, predict, and share data on potholes. The pothole system is designed primarily to improve automated vehicle performance (by avoiding potholes). Jaguar Land Rover’s research team is already working with Coventry City Council (UK) to understand how road profile information gathered by this technology could be shared with road authorities, and exactly what data would be most useful for their roads maintenance teams to identify and prioritize repairs (17).

**Google**

Google, now famously developing self-driving cars in California and elsewhere, has filed a patent for “systems and methods for monitoring and reporting road quality” (18). Google’s patent envisions using embedded vehicle sensors and localization data to continuously monitor road conditions. A computer in the vehicle would convert sensor readings into road-quality metrics and transmit pertinent data through a mobile network to a central server for distribution in road quality reports and to improve driving directions and mapping software (18).

Google’s patent appears directed at detecting malfunctions in vehicle sensors. However, this system, if widely implemented, would create a network-wide map of pavement roughness.
Between Google’s self-driving car program and Android Auto (operating system for vehicle head units), Google is well positioned to implement this program at some future date. Transportation agencies should remain aware of Google’s activities in this area and consider engaging with the company for access to any pavement condition data that is generated.

Other Potential Partners

Various companies are developing tools that could be leveraged to collect pavement data. Mercedes has implemented a cloud-based vehicle-to-vehicle communication system in the E Class sedan to distribute information on travel conditions (19). Several automakers, including GM, have put substantial effort into reading pavement markings for automated driving. In addition to traditional automotive industry, companies thought to be developing highly-capable automated vehicle systems or enabling mapping software include HERE, Uber, TomTom, and Apple. The data needed to achieve highly automated driving would likely be highly valuable if used in transportation asset management programs.

IN SITU STRUCTURAL HEALTH MONITORING

Many projects have experimented with embedding sensors in bridge and pavement infrastructure to measure strain and record load history. MDOT has installed such a system as part of a structural health monitoring system on the remote Cut River Bridge in Michigan’s upper peninsula (20). In a separate project, Road Weather Information Systems (RWIS), MDOT has installed temperature and moisture sensors on pavement surfaces and subsurfaces to feed into environmental sensor stations. The data from such sensors is aimed for maintenance crews, but could also be useful for pavement performance management. Such data could be used to precisely measure pavement deterioration rates and develop mechanistic models for pavement deterioration (21).

Infrastructure-embedded sensors are relatively rare, due partially to cost of installation and maintenance. Traditional sensors must be powered and wired, requiring fragile data and power support systems. One potential solution to these issues is the advancement of self-powered sensors. Such sensors operate independent of an external power source by minimizing power requirements and incorporating a permanent long-life battery or capability to harvest kinetic energy (from structural vibration or mechanical strain). Future development of self-powered in-pavement sensors could provide valuable data to pavement performance management programs. Transportation agencies should remain aware of advancements in remote sensor technologies and related services when considering future improvements to transportation asset management programs.

AUTOMATED DISTRESS CLASSIFICATION

Detailed description of pavement distresses (e.g., cracks) are necessary in modeling and forecasting pavement deterioration. Federal regulations require reporting only the percentage of pavement surface that is cracking, but not any data regarding the type of cracking. Cracking occurs on pavement surfaces for a variety of reasons, such as excessive loading, climate factors, construction deficiencies, or some combination of these (22). The pattern of cracking might indicate the mechanism by which it occurred, allowing for improved accuracy in pavement condition forecasting and TAM planning (23). It is now possible for software to automatically characterize cracking types, a task previously requiring manual inspection by engineers (24). It is likely that the capability of this technology will continue to improve given the recent advancement in automated image recognition and classification.
Vehicle-mounted inertial profilers already collect rutting and IRI data at traffic speed
(23). Some researchers are working on methods to collect similar distress data with low-cost
camera vision systems attached to ordinary vehicles. Improved cameras and laser-based
techniques allow for detection of cracks that are not apparent to human vision. This could be
critical in identifying emerging pavement issues, and in refining mechanistic-empirical models,
as pavement cracks usually begin at the bottom of a pavement layer and propagate upward (25).
While still relatively costly, contract services are available to assess pavement using
various imaging technologies such as infrared, radar, lidar, and 3D imaging. Data acquisition
equipment could be fitted to vehicle-based data acquisition systems, or even unmanned aerial
vehicles (UAVs). Expanded use of these technologies, as costs allow, would provide improved
assessment of pavement structural health and data regarding failure mechanisms and rates.
Similar technology could be used to obtain data on a variety of highway assets beyond pavement.
Many transportation agencies already utilize accepted methods of automated distress
classification through contracted services. Agencies should remain aware of the expanding array
of products and services available in this rapidly advancing field.

SUMMARY AND CONCLUSIONS

This paper highlights a series of novel and developing methods of pavement condition
assessment using advancing technologies. The data collected by these methods can be used to
improve pavement performance management, infrastructure investment decisions, and broad
transportation asset management and planning efforts. Most of the methods described herein
would not apply to federal reporting requirements such as the National Highway Performance
Program (NHPP). This information is intended for transportation and planning agencies who
wish to explore novel technology-enabled methods to improve pavement performance
management within a comprehensive performance-based transportation asset management
system that exceeds minimum requirements.

Five categories of pavement data collection approaches are introduced:

Smartphone Accelerometry Indices

There have been numerous attempts to use smartphone-embedded sensors (especially
accelerometry) to measure pavement roughness. These projects typically find that reasonable
correlation to actual pavement condition is possible, but difficult to achieve in real-world
conditions. Achieving acceptably precise data requires controlled data-collection methods and
multiple measurements. These projects are most successful when utilizing novel indices (rather
than re-creating existing indices such as IRI or PASER). At least one of these projects, called
Roadroid, has been commercialized and is available in limited regions in Europe.

Crowdsourcing Pavement Condition Data

Crowdsourcing pavement condition measurement involves leveraging the combined
intelligence, knowledge, or experience of a group of people to collect data on road conditions.
Active crowdsourcing refers to volunteers actively and purposefully providing data, and is often
used by agencies, for example, by providing a method for road users to report potholes and other
problems. Passive crowdsourcing refers to data that is collected from people without them
actively submitting the data. At least one passive crowdsourcing pavement condition
measurement app has been deployed: StreetBump has provided the City of Boston with valuable
data on the condition of city streets via a smartphone app, downloaded by volunteers, that
automatically detects potholes while the user drives. The most potentially useful application of
such a metric is likely using it to replace subjective rating systems (e.g., PASER).

Automated Vehicle Systems Data

Automated Vehicle Systems refer to any vehicle-based systems that collect data for the purpose of automated vehicle control systems functions. In most cases, any data generated by automated vehicle systems is solely for internal use of the system. However, developers have already begun exploring system and network architectures that would allow for data-sharing with transportation authorities.

In Situ Structural Health Monitoring

Embedded sensor systems are an established method of monitoring conditions of transportation assets. Due to the costs associated with installing and maintaining such systems, embedded sensors are relatively rare and used primarily on large bridges. However, recent advancements in sensors and wireless networking imply that low-power wireless sensors are becoming a viable option for assessing infrastructure condition including pavement deterioration. Though this method could not be widely utilized across an entire road network, it could be especially valuable in monitoring high-value or high-risk assets, and developing long-term pavement performance models.

Automated Distress Classification

Many transportation agencies already use vehicle-mounted data acquisition equipment to collect pavement distress data. Images can be interpreted manually, or, increasingly, by pattern-recognition algorithms. Typically, agencies use this method only to collect the basic metrics needed for federal reporting, such as percent cracking.

Recent advancements and cost reductions in sensing technology, as well as advancements in algorithmic event detection, are allowing for increasingly accurate and detailed information regarding pavement distresses. When incorporated into a pavement performance management program, such data could enable very accurate pavement condition forecasting and refinement of pavement life-cycle models.

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