Infrastructure Pavement Assessment and Management Applications Enabled by the Connected Vehicles Environment Research Program - Phase I: Proof-of-Concept

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Introduction

A fundamental role of transportation agencies is to effectively manage the enormous public investment in pavement. This ranges from developing strategies and systems to periodically assess pavement condition and develop maintenance plans to maximize pavement life within limited budgets, to making tactical decisions regarding treatment during adverse weather conditions to keep roadways functional. A fundamental requirement in this management activity is to collect data to assess the condition of the pavement. The current state-of-the-practice in pavement condition data collection is to use specialized sensors and equipment to support this activity. This represents a significant cost burden on agencies, and also this technical approach to data collection scales poorly. In other words, given the need for specialized equipment and sensors, it is very difficult to collect data at more locations in a timely, cost effective manner.

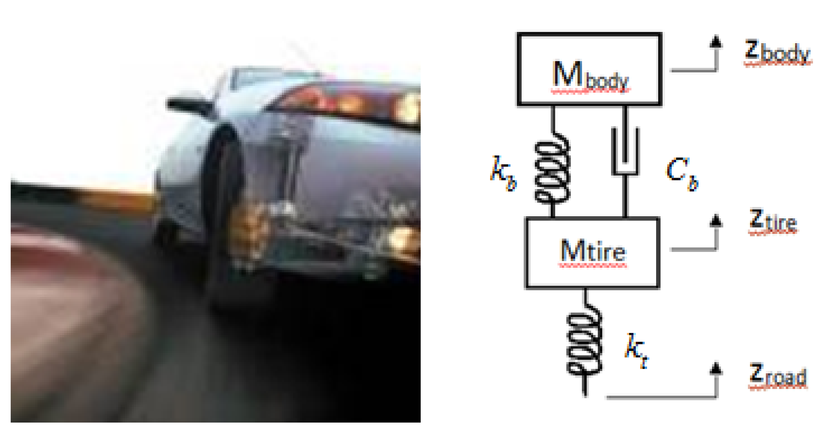
A potential advantage offered by connected vehicles is that this program promises to closely tie the infrastructure to the vast vehicle fleet using the infrastructure. Given the large set of sophisticated sensors integrated in modern vehicles, it is possible that these vehicular sensors may be used as a means to assess pavement conditions. In other words, the entire vehicle fleet can be transformed into probes measuring pavement conditions at all locations in frequent time intervals. The purpose of this collaborative research program between Virginia Tech and the University of Virginia is to conduct the applied research necessary to investigate the feasibility of this concept through component and system prototyping and testing on the Virginia Connected Vehicle UTC testbed. To provide a specific focus to the research program, the work will address two specific pavement applications: roughness measurement and friction assessment during snow and rain.

Research Objectives

The objective of this collaborative research program is to develop prototypes and conduct a field test of system level applications of a connected vehicle pavement condition measurement system. This will allow the research team to investigate (1) different approaches to a connected vehicle pavement measurement system; and (2) determine the optimum procedures for collecting, processing, aggregating, and storing the data to support engineering and management decisions. The UTC Virginia test bed will be used to support this work, and it will build upon previous work funded by the Cooperative Transportation Systems Pooled Fund Study (CTS PFS) and the Mid-Atlantic University Transportation Center (MAUTC).

Specific objectives of this program can be summarized as follows:

1. To gain experience in a system-level pavement condition measurement applications to determine feasibility.
2. To compare a DSRC versus a smart phone based approach to this application.
3. To investigate the utility of the data produced for supporting pavement/asset management decisions (connected vehicle experts at UVA CTS will work collaboratively with pavement experts at VTTI).



$$M_{body}\ddot{z}_{body} = C_b\left(\dot{z}_{tire} - \dot{z}_{body}\right) + k_b\left(z_{tire} - z\right.$$

$$M_{tire}\ddot{z}_{tire} = -C_b\left(\dot{z}_{tire} - \dot{z}_{body}\right) - k_b\left(z_{tire} - z_b\right. + k_t\left(z_{road} - z_{tire}\right)$$

Figure 1. Quarter Car Model

Methodology

The research program has been developed as a two-phase effort. This proposal covers Phase I, which will include the refinement and deployment at the Smart Road of the roughness approach, and a proof-of-concept validation of the friction measurement application. The second phase (not included in this proposal) is planned to include the deployment of the ride quality applications at the more complex NOVA CV Testbed, the validation of the friction measurement application and a comprehensive evaluation of the novel pavement assessment approach.

Roughness Measurement

Currently, pavement assessment data is collected by VDOT once per year for the interstate highway system and primary roadways, and once every five years for secondary roadways. The data is collected by a VDOT contractor using a specialized vehicle platform and a suite of sensors. This condition data is analyzed to produce indices which serve as the basis for pavement maintenance decision making, and thus allocation and disbursement of the portion of the annual budget dedicated to pavement maintenance. If a connected vehicle approach were utilized, VDOT could experience significant cost savings in terms of data collection, and have access to data on a much more frequent basis. The core hypothesis of this component of the program is that V2I technology can be used to collect and integrate information from connected vehicles to (1) provide uniform, continuous, and immediate and cost-effective data about transportation infrastructure health and level of service, which can be used to support pavement management decisions; and (2) define performance measures and health indices that better relate with users' safety, perception, and expectations.

Pavement Friction

Highway maintenance operations are also important for maintaining road safety during inclement weather. Such operations integrate snow- and ice-control strategies, travel information, traffic operations, weather effects, environmental impacts, incident management, and customer satisfaction. For example, under winter conditions, the main objective of a snow- and ice-control strategy is to bring the road surface to a safe state for the driving public within a reasonable period of time. An important factor during such operations is the ability to determine the optimum treatment and timing for the treatment, and the amount of chemicals/ abrasives that must be applied to achieve a safe surface condition. Surface friction measurements provide useful information for improved winter maintenance operations and mobility. Recent studies suggest surface friction levels could be obtained from the traction control system (TCS) and antilock breaking system (ABS) already installed on production vehicles.

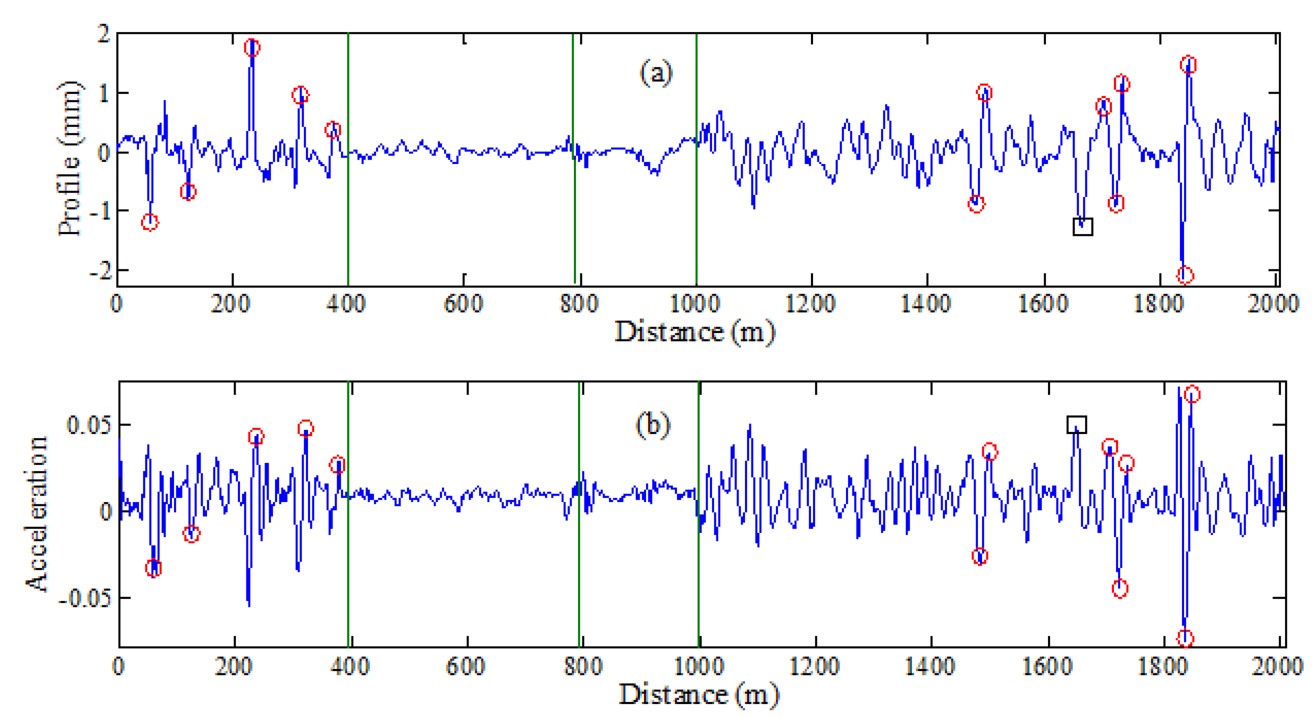


Figure 2. Measurements Taken at the Smart Road: (a) Smoothness Profile and (b) Acceleration Profile.
(Note the qualitative similarities in the sections defined by the vertical [green] lines. Also, locations of clearly similar peaks are highlighted in [red] circles. The [black] squares identify two peaks at the same location that are at a 180° phase [reversed peak].)

Table 1. Data Analysis and Reduction Tool (DART) Components

Sensors	Vehicle Network	Incident Box	Video Cameras	Onboard Components	Data Products
Global Positioning System (GPS) Lane Tracker 3D Acceleration Front Radar RF Sensor Seat Acceleration Sound Level Meter	Speed Distance Ignition Signal Brake Activation (including ABS and TCS) Turn Signals	Light Level Incident Pushbutton Microphone	Face Forward Rear-Left Rear-Right	Data Reliability Check Software	Truck performance data file Digital video file Digital audio file

Major Tasks Accomplished Under Project

Task 1 Refine measurement concepts (VTTI)
In this task the team will investigate the best approaches to derive roughness and friction measures from vehicular sensors. This will involve looking at previous work and modifying/enhancing the algorithms as necessary for fundamental measurement approach.

Task 2. Test measurement components on the Smart Road UTC CV Testbed (VTTI)
In this task, the research team will test the concept at the Smart Road CV Testbed to validate it based on experimental data. The Smart Road facility will be evaluated repeatedly using one of the instrumented vehicles (i.e., a research vehicle instrumented with the most recent generation data acquisition system [DAS]). The data gathered will then be compared with the information obtained from the extensive pavement surface condition collected through the Virginia Surface Properties Consortium at the Smart Road. The data accumulated by the vehicle and the type of information that can be obtained from that data are summarized in Table 1. This controlled experiment study will allow us to match the pavement condition and kinematic signatures exactly. Preliminary results suggest that under these controlled conditions, an ideal level of agreement between the pavement profile and probe vehicle dynamics can be obtained.

Task 3. Refine system level design concepts (UVA)
In this task, the team will consider these approaches within the framework of the Connected Vehicles UTC. The team will use existing naturalistic driving data to use a data-driven analysis technique to determine if alternatives to the concepts are required. Finally, the team will also extend the concepts to support real-time collection of pavement friction data for use in weather operations. The time critical nature of this application will necessarily require a different approach – and may impact communications technology used. At the completion of this task, concepts will be defined to support both real-time and non real-time applications.

Task 4. Prototype system applications (UVA)
Based on the resulting concepts of Task 3, it is likely that the team will be able to explore the effectiveness of the concepts using data collected through the VTTI instrumentation package. In other words, it will not be absolutely necessary to prototype all of the concepts in order to conduct the feasibility assessment of this project. In this task, based on a careful analysis of data collected through instrumentation and requirements of the applications, the team will chose a single concept to prototype in the UTC testbed in order to demonstrate and test the pavement applications.

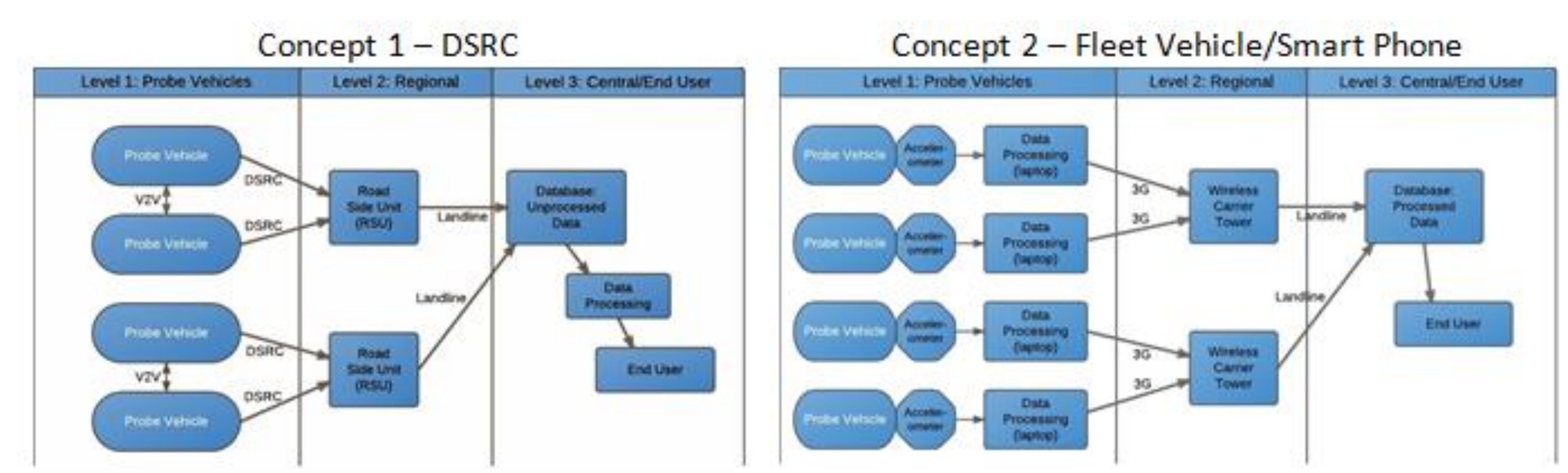


Figure 4. Alternative system level design concepts for pavement assessment data collection to support pavement management

CVI UTC
MORGAN STATE UNIVERSITY
VirginiaTech Transportation Institute
University of Virginia