Road Weather Management Program (RWMP) Connected Vehicle-Infrastructure (CVI) Research

Final Report

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Final Report – April 30, 2016
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U.S. Department of Transportation
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16. Abstract

This report provides insight into how existing vehicle sensor data (e.g., location, heading, road surface and atmospheric conditions) can be utilized by the CVI environment to support transportation safety through road-weather applications. Of special interest are those road-weather infrastructure applications that compile relevant information for key potential end-users. A set of road-weather related vehicle variables was identified using the SAE J2735-2015 Basic Safety Message (BSM) as a reference for parameter definition. The availability of these variables to support road-weather applications was analyzed for a set of representative high volume production vehicles. Subsequently, a Dynamic Road Surface Mapping (DSRM) system concept was proposed that would crowd source vehicle-based assessment(s) of road surface conditions using wireless communications for aggregation and distribution locally to improve vehicle based safety application performance and to back-end infrastructure to support road-weather applications.

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Executive Summary

This document presents the Final Report for the Road Weather Management Program Connected Vehicle-Infrastructure Project (RWMP-CVIR). The period covered by the report is May 1, 2015 through April 30, 2016. The project explored the potential use of vehicle sensor data (e.g., location, heading, road surface and atmospheric conditions) to assess local road and atmospheric conditions to improve environmental analyses supporting road-weather management operations and to augment the performance of vehicle-based safety systems.

RWMP Concept of Operations

The Concept of Operations for Road Weather Connected Vehicle Applications (Final – May 31, 2013 FHWA-JPO-13-047) and documents provided by FHWA on the Pikalert System were reviewed to gain understanding of proposed connected vehicle (CV) road-weather system operations. Comments were gathered from the perspective of the vehicle manufacturers on the project team to assist in the future evolution of the concepts.

Road-Weather Related Vehicle Parameters

The project team worked with FHWA to develop an understanding of the types of vehicle data that may be of interest to road-weather research and applications. A list of candidate road-weather-related variables and weather data categories was developed and a set of road-weather related vehicle variables was identified using the SAE J2735-2015 Basic Safety Message (BSM) as a reference for parameter definition. The availability of these variables to support road-weather applications was analyzed for a representative set of high volume production vehicles. Preliminary analysis indicates that many of the road-weather parameters of interest identified are present in the production vehicles examined. However, additional specificity is needed regarding the required accuracy, precision and timing of collecting this data from the vehicle fleet in order to understand the feasibility of extracting it.

Dynamic Road Surface Mapping

A Dynamic Road Surface Mapping (DRSM) system concept was proposed that would crowd source vehicle-based assessments of road surface conditions, using wireless communications for aggregation and distribution both locally to improve vehicle-based safety application performance and to back-end infrastructure to support road-weather applications. This concept may leverage research performed by the Virginia Tech Transportation Institute (VTTI) exploring the use of vehicle-based measurements of micro-slip to directly assess local road surface conditions in real time. Further research to explore the potential of the proposed system is recommended.

1 Introduction

This report describes work performed by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium in conjunction with the Eco-Transportation and Alternative Technologies Group (ETAT) at the Virginia Tech Transportation Institute (VTTI). The participating companies in the V2I Consortium are FCA US LLC, Ford, General Motors, Hyundai-Kia, Honda, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi. The project is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH611H0002, Work Order 0004.

1.1 Project Description

The U.S. Department of Transportation (USDOT), through the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) and the Federal Highway Administration (FHWA), has worked to promote safety, mobility and productivity on the nation's surface transportation system by advancing road-weather research through the FHWA Road Weather Management Program (RWMP). The objective of the RWMP-Connected Vehicle Infrastructure (CVI) Research project is to assess how weather, road condition and related vehicle data may be collected, transmitted, processed and used in road-weather applications and services.

1.2 Organization of the Report

Project work is comprised of four major tasks:

- Task 1: Technical Program Management
- Task 2: Coordination of Vehicle System Technical Assistance
- Task 3: Technical Support, Reporting and Pilot Demonstration Proposal
- Task 4: Representation at RWMP Events

A summary of the major activities and accomplishments is presented in the following sections for each task in the project.

2 Summary of Project Activities

2.1 Task 1: Technical Project Management

Activities performed under this task include the general administrative and technical support required to complete project tasks and achieve project goals while maintaining compliance with the schedule and budget. These activities include periodic meetings, other general administrative tasks and the delivery of a final project report.

In order to accomplish this task the following interactions were established and conducted for the duration of the project to coordinate work and ensure timely progress was being achieved:

- Weekly coordination calls were held between the CAMP Principal Investigator (PI) and VTTI Technical Manager (TM)
- Bi-weekly meetings were held by PI and TM with the project Technical Management Team (TMT) to review technical progress and update the project work plan

2.2 Task 2: Coordination of Vehicle System Technical Assistance

Under this task, the CAMP-VTTI team provided technical assistance to the RWMP with respect to vehicle systems, specifically those related to CVI standards and protocols (e.g., SAE J2735) and dealing with the definition of parameters of interest to RWMP. These included vehicle sensors that provide direct observations of particular interest to transportation and meteorological communities from which pavement surface and/or atmospheric conditions can be measured and/or inferred. The results of the technical activities coordinated under this task are summarized in the material that follows.

2.2.1 Subtask 2.1: Identification of Road-Weather Related Variables of Interest

The project team worked with FHWA to develop an understanding of the types of vehicle data that may be of interest to road-weather research and applications. A list of candidate road-weather related variables and weather data categories was developed for subsequent assessment against vehicle data availability. The complete set of road-weather variables identified, shown in Table 1, is based on reference materials provided by FHWA listed below.

- *Integrated Mobile Observations 2.0*[1]
- *The Vision for Use of Connected Vehicle Data in Practical Road Weather Applications*[2]
- *Concept of Operations for the Use of Connected Vehicle Data in Road Weather Applications*[3]
- *The Vehicle Data Translator V3. 0 System Description*[4]
- *Road Weather Management Performance Measures–2012 Update*[5]

- *Concept of Operations for Road Weather Connected Vehicle Applications*[6]
- *Guidelines for Disseminating Road Weather Advisory & Control Information*[7]
- *Use of Mobile Data for Weather-Responsive Traffic Management Models*[8]
- *Best Practices for Road Weather Management. Version 3.0*[9]
- *Road Weather and the Connected Vehicle. Improving Road Weather Awarness*[10]

Included in this comprehensive list are some variables that, although commonly used by road-weather information system (RWIS) environmental sensing station (ESS), are not included in Basic Safety Messages (BSM) Part 1 or Part 2 as specified in the Society of Automotive Engineers (SAE) J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary.[11] Given the vehicle data focus of the project, it was decided to focus on parameters potentially available in Original Equipment Manufacturer (OEM Systems as defined by SAE J2735 as indicated in Table 1. This approach provided a common set of definitions for the data elements to provide consistency in the subsequent analysis.

Table 1. Road-Weather Variables of Interest

BSM Part	Parameter	Indication	Weather Data Category			
			General	Location/ Heading	Road Surface	Atmospheric
1	ID (temp)		x			
1	Vehicle Size/Type	Size	x			
1	GPS Long	Position	x	x		
1	GPS Lat	Position		x		
1	GPS Elevation	Position		x		
1	GPS Positional Accuracy	Position		x		
1	Speed	Motion		x		
1	GPS Heading	Motion		x		
1	Transmission state	Mo			?	
1	Acceleration Long. (X)	Mo			x	
1	Acceleration Lat. (y)	Mo			x	
1	Acceleration vertical (z)	Mo			x	
1	Brake system status	Motion				
1	Steering angle	Motion			x	
1	Yaw rate	Motion			x	
2	Ambient air temp	Tra				x
2	Ambient atmospheric pressu	We				x
2	Precipitation pres	We				x
2	Tire air pressure	Weather				x
2	Vehicle type	Size, config.	x			
2	Wiper status and mode change	Precipitation, fog				x
2	Light status and mode change	Weather, visibility				x
2	ABS Active (> 100msec.)	Traction			x	
2	Traction Control active	Traction			x	
2	Stability Control active	Traction			x	
2	Wheel rotational displacement	Traction			x	
na	Weather info for freight					
na	Road chem type and application rate					
na	Spot Wind Direction					x
na	Spot Wind Speed					x
na	Dewpoint temp					x
na	Surface temp				x	
na	Solar radiation					x
na	Total radiation					x
na	Precipitation intensity					x
na	Precipitation situation (L, M, H)					x
na	Road surface temp				x	
na	Roadway water thickness				x	
na	Roadway snow thickness				x	
na	Adjacent snow thickness (shoulder)				x	
na	Roadway ice thickness				x	
na	Visibility					x
na	Detected Road Friction				x	

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

2.2.2 Subtask 2.2: Vehicle Data Element Map

Using the OEM portion of the road-weather variable list developed in Subtask 2.1, an analysis of available vehicle network data was performed for select high-volume production vehicles. Each OEM team member identified a vehicle model from their fleet to explore the availability of the specified data elements. Available variables were cross-referenced with respect to weather-related elements of BSM Parts 1 and 2. A preliminary mapping of subject vehicles and corresponding available data elements was created and reviewed with FHWA. This analysis verified only that the specified variables existed somewhere on the vehicle and not that these variables were necessarily present at the vehicle network diagnostic connector. It was also discovered during this phase of analysis that the data element 'wheel rotational displacement' listed in the RWMP references as being contained in BSM Part 2 is not actually present in the standard. At this point in the analysis, no road-weather related performance requirements were available to assess the suitability of the vehicle data elements, thus the initial mapping identified only a potential to populate the desired data element for each vehicle model selected.

2.2.3 Subtask 2.3: Candidate Research Vehicle Identification

In order to refine the preliminary data availability mapping performed in the previous subtask, FHWA identified desired and acceptable performance criteria for the accuracy, resolution and sampling frequency for a subset of the data elements thought to be of high potential value to RWMP research.

Table 2. Draft Road-Weather Parameter Performance Specifications

Priority	Variable	Unit	Desired Resolution	Acceptable Resolution	Desired Accuracy	Acceptable Accuracy	Desired Frequency	Acceptable Frequency
1	Air Temperature	Celsius	0.1 degree	1 degree	1 degree	2 degrees	once per 10 seconds	once per minute
2	Wiper Status	None	off, on, low, medium, high, intermittent speeds	off, on	correct category	correct category	once per 10 seconds	once per minute
3	Surface Temperature	Celsius	0.1 degree	1 degree	1 degree	3 degrees	once per 10 seconds	once per minute
4	ABS Brake Status	None	off, on	off, on	correct category	correct category	event driven	event driven
5	Dewpoint Temperature	Celsius	0.1 degree	1 degree	1 degree	3 degrees	once per 10 seconds	once per minute
6	**Traction Control active**	None	off, on	off, on	correct category	correct category	event driven	event driven
7	**Stability Control active**	None	off, on	off, on	correct category	correct category	event driven	event driven
8	Wheel Rotational Displacement	Revolutions per second	0.01 revolution per second	0.1 revolution per second	0.01 revolution per second	0.1 revolution per second	once per second	once per 10 seconds
9	**Precipitation sensor**	None	off, on (is there something else?)	off, on	correct category	correct category	once per 10 seconds	once per minute
10	Atmospheric Pressure	HectoPascals (hPa)	0.1 hPa	5 hPa	1 hPa	5 hPa	once per 10 seconds	once per minute
11	**Lights**	**None**	**off, on for low beams, on for high beams, on for fog lights**	**off, on**	**correct category for different types of lights**	**correct category**	**once per 10 seconds**	**once per minute**
12	**Yaw**	**Angle**						
13	**Pitch**	**Angle**						
14	**Solar Radiation**	**Watts per meter squared**	**1 w/m^2**	**10 w/m^2**	**5 w/m^2**	**10 w/m^2**	**once per 10 seconds**	**once per minute**
15	**Total Radiation**	**Watts per meter squared**	**1 w/m^2**	**10 w/m^2**	**5 w/m^2**	**10 w/m^2**	**once per 10 seconds**	**once per minute**

Source: FHWA RWMP October 2015

Using the preliminary vehicle data element map from the prior subtask, seven high volume production vehicles were further evaluated against the performance criteria provided to generate the Road Weather Parameter Availability map shown in Table 3.

Table 3. Road-Weather Parameter Availability

BSM Part	Weather Parameter	Indication	SAE J2735- 2015 Data Element / Data Field	Weather Data Category				MY 2015 Availability per SAE J2735 (Y/N)							RWMP Data Performance Specifications Provided
				General	Location / Heading	Road Surface	Atmospheric	Vehicle #1	Vehicle #2	Vehicle #3	Vehicle #4	Vehicle #5	Vehicle #6	Vehicle #7	
1	ID (temp)		DE_TemporaryID	X				NA - Part of Message Generation							X
	Vehicle Size/Type	Size	DF_VehicleSize	X				Y	Y	Y	N	N	N	Y	X
	GPS Long	Position	DE_Longitude		X			Y	Y	Y	N	N	N	Y	X
	GPS Lat	Position	DE_Latitude		X			Y	Y	Y	N	N	N	Y	X
	GPS Elevation	Position	DE_Elevation		X			Y	Y	Y	N	N	N	Y	X
	GPS Positional Accuracy	Position	DF_PositionalAccuracy		X			Y	Y	Y	N	N	N	Y	X
	GPS Heading	Motion	DE_Heading		X			Y	Y	Y	N	N	N	Y	X
	Transmission state	Motion	DF_TransmissionAndSpeed		X			Y	Y	Y	Y	Y	Y	Y	X
	Acceleration Long. (X)	Motion	DF_AccelerationSet4Way			X		Y	Y	Y	Y	Y	Y	Y	X
	Acceleration Lat. (y)	Motion	DF_AccelerationSet4Way			X		Y	Y	Y	Y	Y	Y	Y	X
	Acceleration vertical (z)	Motion	DF_AccelerationSet4Way			X		Y	Y	N	N	N	N	N	X
	Brake system status	Motion	DF_BrakeSystemStatus			X		Y	Y	Y	Y	Y	Y	Y	X
	Steering angle	Motion	DE_SteeringWheelAngle			X		Y	Y	Y	Y	Y	Y	Y	X
	Yaw rate	Motion	DF_AccelerationSet4Way			X		Y	Y	Y	Y	Y	Y?	Y	✓
2	ABS Active (> 100msec.)	Traction	DE_EventFlags			X		D	D?	D	D	D	D	D	✓
	Ambient air temp	Traction, visibility	DE_AmbientAirTemperature				X	A	A?	A?	A?	A?	A?	A	✓
	Ambient atmospheric pressure	Weather	DE_AmbientAirPressure				X	A	Does not meet	A?	N	A?	A?	N	✓
	Precipitation sensor	Weather	DE_RainSensor				X	A	N	N	N	N	D if equip	D	✓
	Tire air pressure	Weather	DF_J1939-Data Items				X	Y	Y	Y	N	N	Y	Y	X
	Vehicle type	Size	DE_VehicleType	X				Y	Y	Y	N	N	N	N	X
	Wiper status and mode change	Precipitation, fog	DE_WiperStatusFront & DE_EventFlags				X	A	D?	A	A	A	N	D	✓
	Light status and mode change	Weather, visibility	DE_ExteriorLights & DE_EventFlags				X	D	D?	D	A	A	A	D	✓
	Traction Control active	Traction	DE_EventFlags			X		D	D?	D	N	D	D	D	✓
	Stability Control active	Traction	DE_EventFlags			X		D	D?	D	D	D	D if equip	D	✓
	Wheel rotational displacement	Traction	DE Does Not Exist			X		A	D?	D?	D?	D?	A?	D	✓

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

For each vehicle / variable combination an assessment of parameter availability was performed using the following rating scheme:

For variables where no performance criteria was provided:

- Y - the parameter is available, however performance is unspecified
- N - the parameter is not available on the vehicle

For variables where RWMP performance criteria were provided:

- D - the parameter is available and meets “desired” performance criteria
- A - the parameter is available, however it meets only “acceptable” performance criteria
- ? - only partial vehicle parameter performance information available – analysis incomplete

2.2.4 Subtask 2.4: Support of Ongoing RWMP Projects

Technical support was provided to several RWMP initiatives as indicated:

- *Integrated Mobile Operations Phase 3 (IMO3)*
    - Onsite participation in project meetings
- Assessment of Pavement Conditions Using On-Board Vehicle Sensors
    - TMT project review and consultation
- Vehicle Data Translator (VDT) Development
    - Review of technical reports provided
    - Review of VDT role in RWMP ConOps

2.3 Task 3: Technical Support, Reporting and Pilot Demonstration Proposal

The results of work performed under Task 3 are summarized in the following sections.

2.3.1 Subtask 3.1: RWMP CVI ConOps Review

The CAMP-VTTI project team reviewed each of the proposed Road-Weather Connected Vehicle Applications from the report Concept of Operations for Road Weather Connected Vehicle Applications (Final – May 31, 2013 FHWA-JPO-13-047)[6].

- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet-Management Systems
- Weather-Responsive Traffic-Management Strategies
- Motorist Advisories and Warnings
- Information for Freight Carriers
- Information and Routing Support for Emergency Responders

The project team also reviewed documents provided by FHWA on the Pikalert System (i.e., the VDT) as related to its use in the Integrated Mobile Observations (IMO) project to develop an understanding of the operational requirements and functionality of the system.[1] Comments were developed and reviewed with FHWA staff to provide the team's perspective for consideration in future RWMP initiatives.

2.3.2 Subtask 3.2: Preliminary Follow-on Concept Development

After becoming familiar with the RWMP and exploring the availability of weather-related vehicle parameters, the project team explored potential areas of research related to RWMP's goals of supporting CV safety applications for further investigation.

Initially the project team considered the potential for weather-related vehicle data to enhance the operation of the Pikalert system, including the relative importance of specific parameters established by FHWA through previous VDT data denial experiments. In considering this follow-on concept the project team evaluated current public and commercial offerings that incorporate VDT-like features to make a determination of need and potential concept impact. Three representative offerings were identified as exemplifying the breadth of current offerings:

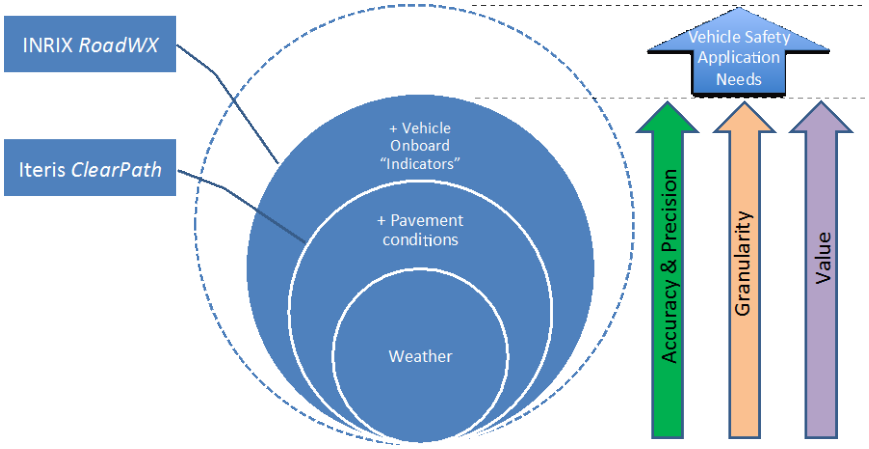
- Iteris *ClearPath* Weather Analytics
- FHWA Weather Data Environment (WxDE)
- INRIX RoadWX™

The Iteris *ClearPath* Weather Analytics system uses weather and pavement conditions as input data typically applied at discrete locations such as bridges to identify potential bridge icing. Local pavement sensors that monitor pavement temperature and precipitation accumulation as well as weather variables such as temperature, wind speed and direction, precipitation type, visibility and precipitation rate are used. Targeted users include agriculture, state Departments of Transportation (DOT), county agencies, municipal/public works, commercial facilities and weather Application Program Interfaces (API).

The WxDE and INRIX RoadWX systems use mobile sources of data such as vehicles in addition to those utilized in the *ClearPath* class of systems. The WxDE was developed by FHWA, in part, to support development of DOT ITS applications and is compatible with the FHWA Research Data Exchange, a CVI application development data repository and sharing environment. The WxDE incorporates many VDT features, including value-added variables, and provides data quality checks, road segment data, a graphical format and supports database queries. WxDE data is intended for CV research use, but is freely available to other users as well.

The INRIX RoadWX™ product is a recent addition to the market from Global Weather Corporation in partnership with INRIX and is largely based on the National Center for Atmospheric Research's (NCAR) development of the VDT, with some additional capabilities for pavement condition modeling. Global Weather Corporation is a commercialization group that provides licensing of NCAR's intellectual property. RoadWX appears targeted for consumption by automakers, insurance companies and the public sector.

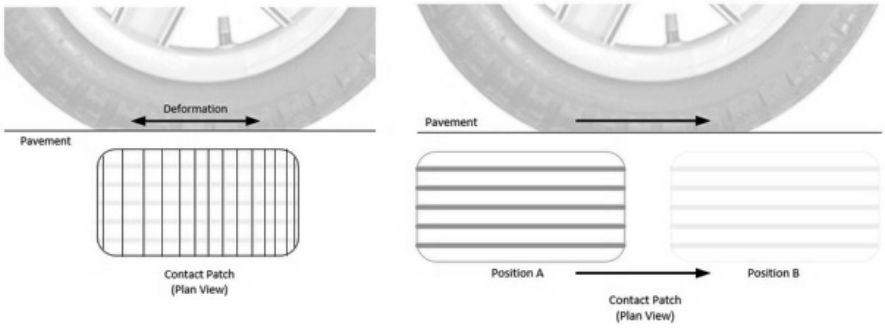
The progressive development of these systems is illustrated in Figure 1, where each system has expanded upon previous offerings to improve accuracy and precision, spatial and temporal granularity, and overall value. While WxDE and INRIX RoadWX are thought to offer improved road condition estimation capabilities, the spatial and temporal granularity of the available road weather data (miles and minutes) falls short of that needed to support vehicle based CV safety applications (feet and milliseconds).



Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Figure 1. Illustration of Gap in Capabilities of Road-Weather Assessment Systems

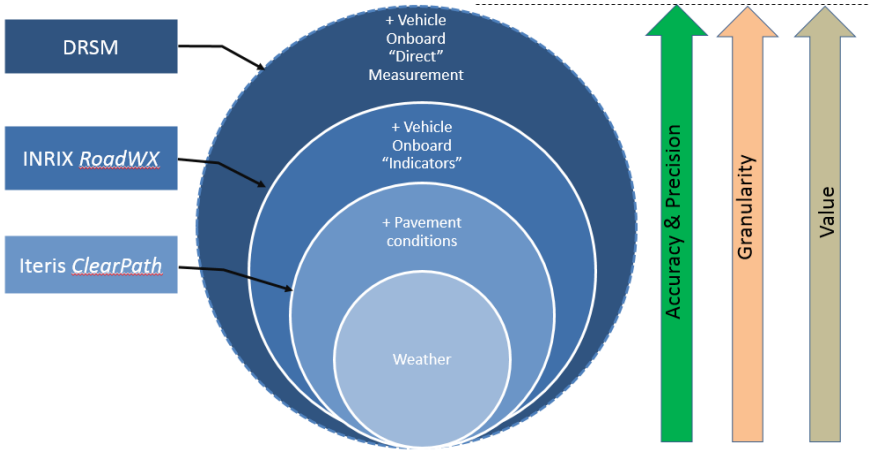
To fill the gap the team turned to recent work performed by VTTI[12] related to the assessment of road conditions using vehicle dynamic data for measurement of tire micro-slip that occurs differentially at driving and free-rolling wheels. The occurrence of tire micro-slip is illustrated in Figure 2, where the left tire deforms longitudinally (y-axis per SAE standard) across the contact patch. The tire on the right is exhibiting macro-slip as the contact patch slides along the pavement surface. Micro-slip occurs when longitudinal forces are applied at levels below those that induce macro-slip. In both cases, the relative rotation of the tire with respect to road travel changes depending upon conditions. In the macro-slip case, vehicle safety systems such as ABS, TC, and ESC may be activated to mitigate slip and maintain vehicle control. Little or no loss of control is consistent with micro-slip occurrence. VTTI's work in this area thus far has established that differential micro-slip between driving and free-rolling wheels using direct measurement by OEM wheel-speed sensors can be used to estimate road conditions, potentially providing the spatial and temporal resolution thought necessary to support CV safety applications.



Source: Virginia Tech Transportation Institute – Used with Permission

Figure 2. Illustration of Tire Contact Patch Behavior: Microslip (left) vs. Macroslip (right)

With these considerations in mind the project team proposed follow-on concept development performing DRSM, based on analysis techniques such as micro-slip. The objective of DRSM is to use detailed, real time, on-board vehicle dynamics information to dynamically "crowd source" road surface condition information. The intent of this concept is illustrated in Figure 3, where the envelope of available data is expanded to include vehicle-onboard direct measures of road condition. This expansion may provide the increased spatial and temporal resolution needed to support vehicle-based CV safety applications, and a dataset of higher overall value.

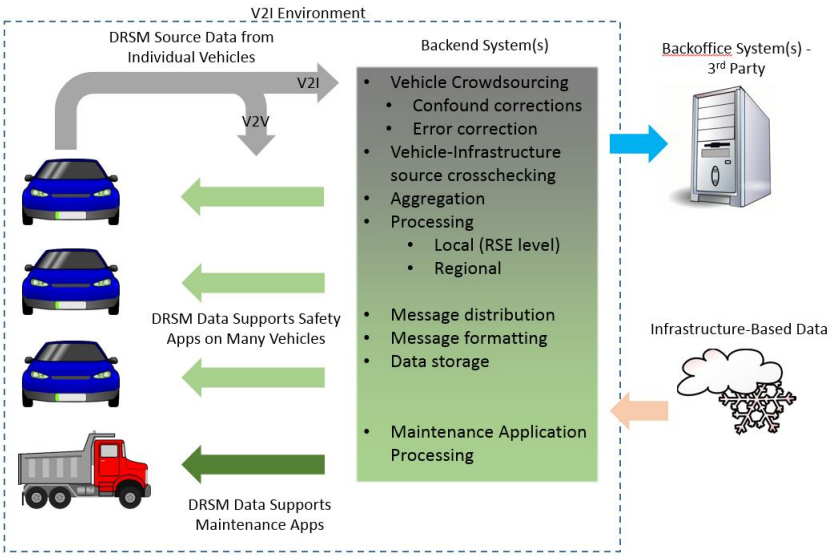


Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Figure 3. Illustration of Expanded Road Weather Assessment System Capabilities

The project team envisions that DRSM will enable real-time, high granularity assessment of road conditions such as ice and snow, hydroplane puddle hazards, high winds, pavement maintenance needs such as potholes, rutting, polished surface aggregates, and contaminated (e.g. dirt, oil) roads. Providing an accurate real-time assessment of local road surface conditions could support improved V2I safety applications such as vehicle-based Curve Speed Warning and Red Light Violation Warning. Also, significant improvements to CV maintenance applications such as the Enhanced Maintenance Decision Support System may result with integration of DRSM data.

A preliminary concept for operations is included in Figure 4, wherein vehicle onboard data is collected from multiple vehicles via V2I and from infrastructure-based systems for processing, storage and distribution to safety and maintenance user applications and back office systems. V2V data sharing is also enabled for strictly local applications.



Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Figure 4. DRSM System Operations Concept

2.4 Task 4: Representation at RWMP Events

A member of the CAMP-VTTI team participated in various project-related meetings and/or activities pertinent to the RWMP to gain exposure to the types of research and discussions that were occurring between stakeholders and within industry, and to enable "Technical Support for RWMP Projects" per Task 2.4. A list of events that were attended in support of this task is shown in .

Table 4. RWMP Events Attended by Project Quarter

Project Quarter	Meeting/Event
Q2, 2015	IMO meeting in Minneapolis, May 28
	NCAR online briefing to CAMP technical team on the VDT, Jun. 26
Q3, 2015	IMO meeting, Lansing, Aug. 17
	RWMP Stakeholders meeting Aug. 25
	MDOT Detroit Traffic Management Center Aug. 13.
Q4, 2015	IMO meeting, Boulder CO, Nov. 17-18
Q1, 2016	Transportation Research Board Annual Meeting, Washington DC, Jan. 10-14
	IMO meeting, Reno NV, Feb. 10-11
Q2, 2016	Midwestern Road Weather Regional Roundtable, Mar. 8

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

3 Conclusions and Recommendations

The Project team's review of completed and ongoing RWMP projects, as well as current and emerging road-weather assessment system capabilities, suggests that a gap exists in the information needed to support vehicle-based CV safety systems. Investigation of how vehicle-based sensor data could be used to provide higher temporal and spatial resolution assessment of pavement conditions to fill this gap may offer benefits for both vehicle-based CV safety applications and road maintenance operations. The potential for a vehicle-based concept such as the Dynamic Road Surface Mapping system proposed to crowd source road condition information should be explored.

4 References

1 Belzowski, B. M. (2014). *Integrated Mobile Observations 2.0* (No. UMTRI-2014-10).

2 Chapman, M., & Drobot, S. (2012). The Vision for Use of Connected Vehicle Data in Practical Road Weather Applications (No. FHWA-JPO-12-040).

3 Concept of Operations for the Use of Connected Vehicle Data in Road Weather Applications (No. FHWA-JPO-13-066).

4 The Vehicle Data Translator V3. 0 System Description (No. FHWA-JPO-11-127).

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Appendix A List of Acronyms

ABS	Anti-lock Braking System
API	Application Program Interface
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partners LLC
CAN	Controller Area Network
CIBSS	Center for Infrastructure-Based Safety Systems
CMC	Consortium Management Committee
ConOps	Concept of Operations
CV	Connected Vehicle
CVI	Connected Vehicle-Infrastructure
DOT	Department of Transportation
DRSM	Dynamic Road Surface Mapping
DSRC	Dedicated Short-Range Communication
ESC	Electronic Stability Control (system)
ESS	Environmental Sensing Station
ETAT	Eco-Transportation and Alternative Technologies
FHWA	Federal Highway Administration
IMO	Integrated Mobile Observations
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
NCAR	National Center for Atmospheric Research
OEM	Original Equipment Manufacturer
PI	Principal Investigator
PIDs	Parameter IDs
PNGs	Parameter Group Numbers
RWIS	Road Weather Information System

RWMP	Road Weather Management Program
SAE	SAE International
SOW	Statement of Work
TC	Traction Control
TM	Technical Manager
TMC	Traffic Management Center
TMT	Technical Management Team
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
VDT	Vehicle Data Translator
VTTI	Virginia Tech Transportation Institute
WxDE	Weather Data Environment

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