The Connected Driver: Integrated Mobile Observations 2.0: 2014-2015

Project Final Report

March, 2016

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Technical Report
Documentation Page

1. Report No. UMTRI-2016-6	**2. Government Accession No.** N/A	**3. MDOT Project Manager** Steven J. Cook, P.E.
4. Title and Subtitle The Connected Driver: Integrated Mobile Observations 2.0 (IMO 2.0), 2014-2015		**5. Report Date** March, 2016
		6. Performing Organization Code N/A
7. Author(s) Bruce M. Belzowski		**8. Performing Org. Report No.** UMTRI-2016-6
9. Performing Organization Name and Address The Regents of the University of Michigan		**10. Work Unit No. (TRAIS)** N/A
		11. Contract No.
		11(a). Authorization No. Z1 / R1
12. Sponsoring Agency Name and Address Michigan Department of Transportation (MDOT) Research Administration 425 West Ottawa Street Lansing MI 48933		**13. Type of Report & Period Covered** Final Report 4/1/14 to 10/31/15
		14. Sponsoring Agency Code Federal Highway Administration (FHWA)
15. Supplementary Notes		

16. Abstract

This project is a continuation of the original Integrated Mobile Observations (IMO 2.0) project that ran from January, 2013 through March, 2014. The Connected Driver: Integrated Mobile Observations, 2014-2015 project ran from April, 2014 through October, 2015. The main goal for the project was to show the applicability and capability of a smartphone based data collection system to provide accurate and timely micro-level road condition data to weather analysts in order to generate road condition warnings for drivers via electronic road signs, website, and mobile phone application (apps). The project employed an Android-based customized smartphone software program called DataProbe to gather information from the phone (date, time, latitude and longitude, altitude, number of satellites, speed, accelerometer data, and compass heading); the vehicle through its controller area network (CAN) (air and coolant temperature, odometer, barometer, tachometer, speedometer, throttle, brakes, anti-lock braking system (ABS), electronic stability control (ESC), engine traction control and braking traction control); and through external sensors, Surface Patrol, that measure road surface and air temperature, humidity, and dew point. When looking at the two IMO 2.0 projects combined over 31 months of data collection, vehicle operators drove 901,126 miles (363 gigabytes) and took 99,569 photos (45 gigabytes). Finally, the demonstration project at the 2014 ITS World Congress displayed the ability of UMTRI and NCAR researchers to combine the data collected from DataProbe sensors with an NCAR-developed Motorist Advisory Warning (MAW) phone application that delivered timely warnings to drivers of rain, slippery roads, and rough roads on their phone as well as on electronic signs in an area of 400 feet on the test track. This demonstration clearly showed that it

is possible to provide micro-level weather reports in a timely manner. Project completion for this phase was October 31, 2015.			
17. Key Words CAN bus, OBD Key, IMO, GPS, CSV, DataProbe, surface patrol, smartphone, weather		**18. Distribution Statement** No restrictions. This document is available to the public through the Michigan Department of Transportation.	
19. Security Classification - report Unclassified	**20. Security Classification - page** Unclassified	**21. No. of Pages**	**22. Price** N/A

Acknowledgements

We would like to acknowledge all the people who provided support to the project over the past 31 months. Gabe Guevara from the FHWA Road Weather Management Program; Ralph Robinson, Cody Hyman, Michelle Rausulis, Robert Schultz, and Yuanyuan Zhao from UMTRI; Steve Cook, Collin Castle, Tim Croze, Matt Pratt, Rod Hauenstein, Mark Gove, Mark DeVries and Tyler Sommers, and all 60 drivers who participated in the project from MDOT; Brenda Boyce, Ram Kandarpa, and Sudharson Sundararajan from Booz, Allen, Hamilton; Gary Weiner, Sheldon Drobot, and Padhrig McCarthy from NCAR; and Lee Mixon from Mixon Hill.

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Introduction

Connected vehicles are fast becoming part of the lexicon of the federal government, as well as state governments, as they begin to test the capability and applicability of new connected vehicle technologies to improve safety by providing critical information to drivers. The basic theory of the connected vehicle is that vehicles in front of other vehicles provide information that allows the following vehicles to better respond to potential road safety issues such as traffic jams, accidents, slippery roads, etc. The communication among vehicles can be via Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I), and projects testing these technologies are in progress throughout the world.

One method used to support drivers is through the use of cell phone technology, which is currently used extensively through numerous mapping and traffic applications.[1] Drivers using mapping applications receive information about traffic jams because the mapping companies receive anonymous data from all the cell phones in the area about the speed of the vehicle driving in that area. The mapping companies match the reported speed with the posted speed limits for that area and color code their maps to show drivers where there are traffic backups or jams.

The Integrated Mobile Observations project uses cell phones to gather weather-related data from vehicles and transmits this data to state level traffic monitors who provide information to drivers via electronic road signs, website, and mobile phone apps. The strength of this method is that it potentially can provide near real-time weather-related information at micro levels of up to 400 feet, such as wet or slippery pavement as well as rough roads.

The goal of reducing accidents by providing near real-time micro-level weather information to drivers began with the first Integrated Mobile Observations 2.0 (IMO 2.0) project that ran from January 1, 2013 through March 31, 2014[2]. The technology used was an advanced version of technology used in MDOT/UMTRI's Slippery Road project (2012)[3], where Android-based smartphones were programed and installed in vehicles to gather information from the phone (e.g. latitude/longitude), vehicle (e.g. speed, rpm), and external sensors (e.g. surface temperature).

The project report for IMO 2.0 detailed the software and hardware used to collect the data, as well as the detailed data collection process and the lessons learned during the project. Through extensive testing and analysis, the first IMO 2.0 project setup the process for accurately providing data to weather analysts throughout the U.S. in a timely manner. One of the main takeaways from the project was that the vehicles that were part of the study were too few and too spread out across a large area to provide enough data for the weather analysts to make conclusive decisions about what was happening on the road at a particular place and time.

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[1] Belzowski, B.M., Ekstrom, A., 2014. "Stuck in Traffic: Analyzing Real Time Traffic Capabilities of Personal Navigation Devices and Traffic Phone Applications. Sponsor: TomTom Corporation. UMTRI-2014-4: http://hdl.handle.net/2027.42/102509

[2] Belzowski, B.M. King, S. 2014. "Integrated Mobile Observations 2.0. Sponsor: Michigan Department of Transportation. UMTRI-2014-19: http://hdl.handle.net/2027.42/117506

[3] Robinson, Ralph, 2012. "Slippery Road Detection and Evaluation." Sponsor: Michigan Department of Transportation. MDOT RC-1573. UMTRI-2012-39: http://hdl.handle.net/2027.42/117505

This report focuses on the second IMO 2.0 project, The Connected Driver: Integrated Mobile Observations (IMO) 2.0: 2014-2015 project that ran from April 1, 2014 through October 31, 2015. For The Connected Driver: IMO 2.0: 2014-2015 project, with funding from the U.S Department of Transportation's Federal Highway Administration (FHWA) and in-kind match funding from the Michigan Department of Transportation (MDOT), the University of Michigan Transportation Research Institute (UMTRI) Automotive Futures Group focused on two major data collection goals: continuing to improve the data collection process to support weather-related analysts throughout the U.S., who were charged with designing applications that make use of the data collected and using the project technology to support a three day demonstration of the IMO system at the 2014 ITS World Congress in Detroit.

As with the prior IMO 2.0 project, this project used an Android-based smartphone combined with customized software, called DataProbe, and Bluetooth-enabled external temperature sensors (called Surface Patrol) and internal vehicle data collectors [On Board Diagnostics (OBD keys)]. The DataProbe software was designed to collect data from the phone and all available sensors and data collectors in one second intervals. Data files were created in one minute intervals and sent via cell phone to an UMTRI server that sorted files into valid and invalid files and sent valid files to five weather analysts throughout the U.S.

From an overall project perspective, the goals for MDOT/UMTRI were

1) to continue to gather information via the 60 MDOT vehicles instrumented with DataProbe smartphones and internal and external data collection devices/sensors and collect data for nineteen months
2) to collect accurate and timely data from each of the devices, including photos taken by the cameras on the smartphone, which can be triggered by the driver, through the web portal, and through vehicle ABS (Automated Braking System), ESC (Electronic Stability Control), and traction control events
3) to deliver all data to the weather analysts in a timely manner
4) to keep track of vehicles in service through a web portal, including the ability to trigger photos and send messages from the portal
5) to design a demonstration showing the applicability and capability of the technology at the 2014 ITS World Congress

This report details the efforts of the combined UMTRI, MDOT, and FHWA team to accomplish these goals. The IMO 2.0: 2014-2015 project not only provided an opportunity to improve the technology, but also to improve the interactions with maintenance supervisors and IMO 2.0 drivers (MDOT fleet vehicles) in the field. To call this a team effort is an understatement. Without the continued support of MDOT maintenance supervisors and IMO 2.0 drivers, the combined IMO 2.0 projects would not have logged 901,126 miles, taken nearly 99,569 photos and collected more than 363 gigabytes of valid data.

Scope

The Connected Driver: Integrated Mobile Observations 2.0 (IMO 2.0), 2014-2015 project displayed the capability of an inexpensive Android-based smartphone to gather weather-related data from the phone, the vehicle, and external sensors from a fleet of 60 MDOT vehicles. The purpose of the project was to continue to gather the information from the vehicles, transfer it to the University of Michigan Transportation Research Institute for processing and dissemination to a group of five weather analyst organizations throughout the U.S. in order for them to develop useful weather-related applications. The 2014 ITS World Congress demonstration showed the applicability of the technology to provide micro-level weather and vehicle event information in a timely manner to drivers.

This project included continuing:

- to supervise the continuous improvement of the DataProbe software
- to monitor the system of 40 light duty cars and trucks vehicles and 20 winter maintenance trucks (WMTs) including phone and sensor equipment replacements
- to house and manage the server that acted as the intermediary between the data collected via Android-based smartphones and the weather analysts who received the data.
- to support data monitoring, analysis, and vehicle interactions as needed

The main goals of the project included continuing

1) to maintain all eligible vehicles with Android phones with the latest DataProbe software, OBD keys, and Surface Patrol sensors (where applicable)
2) to capture all data available by the DataProbe phone, including automatic photos taken during ABS, ESC, or Traction Control events
3) to test to see that all data available (Basic, CAN, and Surface Patrol) from the DataProbe phone is accurate[4]
4) to design the DataProbe program to send data to UMTRI in a timely[5] manner
5) to send all valid files in a timely manner from UMTRI to the weather analysts throughout the country
6) to improve the DataProbe web portal in order to visualize vehicles in service as well as to take photos and send messages from the site
7) to design a demonstration of the capability and applicability of the DataProbe technology at the 2014 ITS World Congress.

[4] "Accurate" in this sense means that the data collected must be within a range of accepted values.
[5] "Timely" in this sense means that the data collected must continually be delivered to the weather analysts within the minimal amount of time needed to collect the data, send it to UMTRI for verification, and have the data received by the weather analysts. Our research in this area showed that "timeliness" for this project meant seven to nine minutes from the time the file was created to the time it was received by the weather analysts.

Project Overview

Like the first IMO 2.0 project, IMO 2.0: 2014-2015 project is a closed loop data collection project where data is collected at the vehicle level and data is provided to drivers based on the knowledge gained from the original data collection. The technology overview from the first IMO 2.0 project can be seen in the Appendix. This system architecture is shown visually in Figure 1.

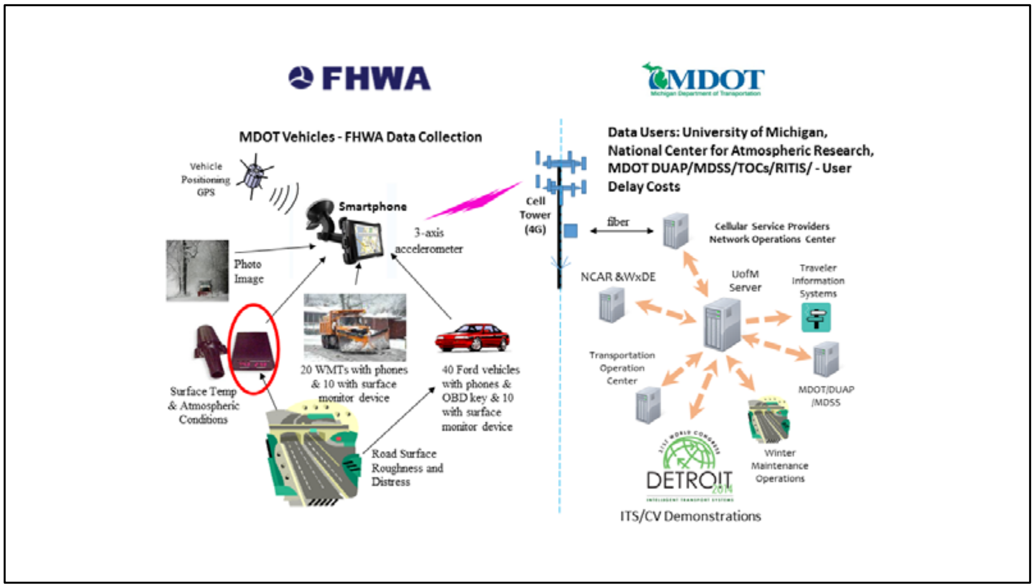

Figure 1 - IMO 2.0 System Architecture Overview

Forty MDOT cars and trucks and twenty MDOT winter maintenance trucks (WMTs) were equipped with Android-based smartphones using UMTRI's DataProbe software that generated the following data:

- time
- latitude, longitude: GPS coordinates
- altitude via GPS
- number of visible Global Positioning System (GPS) satellites
- compass heading
- the speed of the vehicle based on GPS
- 3-axis (x, y, and z) accelerometer readings sampled at 100 Hz per axis
- photos taken by the driver, through the project web portal, or when an autonomous event such as ABS or traction control activation occurs.

Ten cars and trucks and ten WMTs (20 vehicles total) were equipped with Bluetooth-enabled Surface Patrol external environmental sensors that measured

- road surface temperature
- dew point
- ambient air temperature

- humidity

Forty cars and pick-up trucks were outfitted with Bluetooth-enabled OBD keys that collected

- tachometer (RPM)
- vehicle speed
- throttle (position)
- brake activation
- anti-lock braking system activation (ABS)
- electronic stability control activation (ESC)
- traction control system activation (TSC)
- windshield wiper activation

Data is collected in the form of one minute locally-cached segments of text-based sensor data stored in a comma separated value (CSV) file and in photographic data collected from the phone's camera. Text data is continuously collected while the system is in operation while photographs are taken either manually by drivers, manually by administrators through a remote-access web portal, or automatically via a triggered event such as ABS, traction control, or stability control events. After local collection and caching, data is uploaded via a cellular 3G/4G data network and the internet to University of Michigan servers where the data is validated and sent to analysts from the following groups:

- National Center for Atmospheric Research (NCAR)
- MDOT/Mixon-Hill / Data Use and Analysis Processing (DUAP)
- MDOT/Atkins/ Regional Integrated Transportation Information System (RITIS)
- MDOT/Iteris / Maintenance Decision Support System (MDSS)
- Leidos & Synesis Group / FHWA Weather Data Environment (WxDE)

These analysts were charged with using the data to develop weather models and other applications from the data related to traffic management, traveler information systems, winter maintenance operations, and state departments of transportation asset management systems. For the 2014 ITS World Congress, UMTRI worked with NCAR to apply the mobile app developed by NCAR that showed how the different weather and road events were communicated to drivers.

Outside of the World Congress demonstration, the instrumented vehicles traveled primarily along the I-94 corridor in southern Michigan, as seen in Figure 2.

Figure 2 - The IMO 2.0 Southern Michigan I-94 Corridor (9-counties shown)

Data Flow

Figure 9 shows the data flow for the project with vehicles using DataProbe on the smartphones to capture and assemble the data files and photos, and transfer them to the server at the University of Michigan, where the server is programmed to sort the files into valid and invalid files (anomalies)[6]. The valid files make up the project database and are sent to the weather analysts, while UMTRI backs up the data and summarizes the data received on a weekly basis to review progress and identify issues that need improvement/trouble shooting.

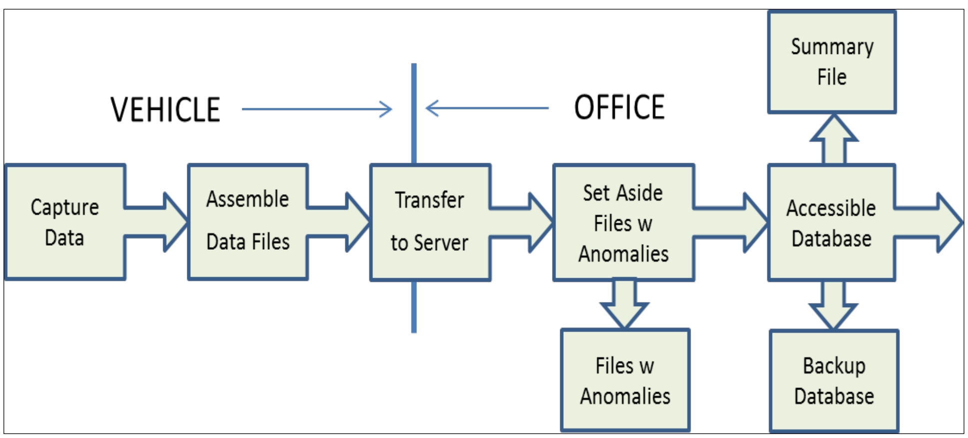

Figure 3 – IMO 2.0 Data Flow Diagram

[6] Invalid file/anomalies occur from a variety of circumstances: If less than three GPS satellites are used for the first sixty seconds of a file; if after the initial sixty seconds there are less than three GPS satellites used for more than fifteen seconds; if the speed generated from the GPS is less than five miles per hour for more than 295 of the 300 maximum number of seconds in a file; if any of the accelerometer values in the 5th row of data are marked as missing (10001); if there are more than 335 columns in the file

Data Collected

Over the course of the 18 months of data collection from April 2014 thru October 2015, the IMO 2.0: 2014-2015 project received 1,123,669 files (286 gigabytes of data). Of those files, 377,826 files (34 percent (77 gigabytes of data)) were considered invalid because of flaws in the data collected (e.g. vehicles not in motion for long periods of time). Valid data was collected, stored, and sent to the six weather analyst groups throughout the country, resulting in 745,843 files (211 gigabytes of data). 54,975 (25 gigabytes) photos were also taken throughout the data collection period. These data files represent 529,671 miles driven by MDOT vehicle operators over the 18 month period. When combining the two IMO 2.0 projects over 31 months of data collection, vehicle operators drove 901,126 miles (363 gigabytes) and took 99,569 photos (45 gigabytes).

2014 ITS World Congress

Preparation for the September 7-11, 2014 ITS World Congress demonstration on Belle Isle in Detroit offered the perfect opportunity to show the power of the IMO technology. Work began in April to design the demonstration. To replicate the closed loop IMO system design, data needed to be collected, sent in one minute intervals to the UMTRI server where it was sorted and sent to the weather analysts servers at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. The NCAR program would then send alerts to a phone app that alerted drivers of oncoming weather or road events including wet roads, rough roads, and slippery roads.

The route chosen for the demonstration was a short 400 foot loop on Belle Isle, a large park area in the Detroit River. Figure 4 shows Belle Isle, and Figure 5 shows the test loop on Belle Isle. What made the demonstration a success was that it focused on the ability of the NCAR researchers to geocode the 400 foot loop and create a Motorist Advisory Warning (MAW) phone app that generated the alerts exactly as the vehicle approached a simulated weather or road event.

This warning was possible because the IMO project design is based on vehicles ahead of the demonstration vehicle sending data to NCAR about road and weather conditions. A lead vehicle, as well as the demonstration vehicle, continually circled the track in order to generate the data that was sent to NCAR. This collected data was geocoded and linked to NCAR's geocoding of the track, so as a demonstration vehicle approached one of the simulated weather or road events, its geocoding would trigger an NCAR designed alert on the MAW phone app in the two demonstration passenger vans that were used to transport ITS World Congress participants. The two vans were outfitted with identical IMO technology in order to be used simultaneously if many World Congress attendees arrived for the test drive at the same time.

Figure 4 – Belle Isle, Detroit, Michigan

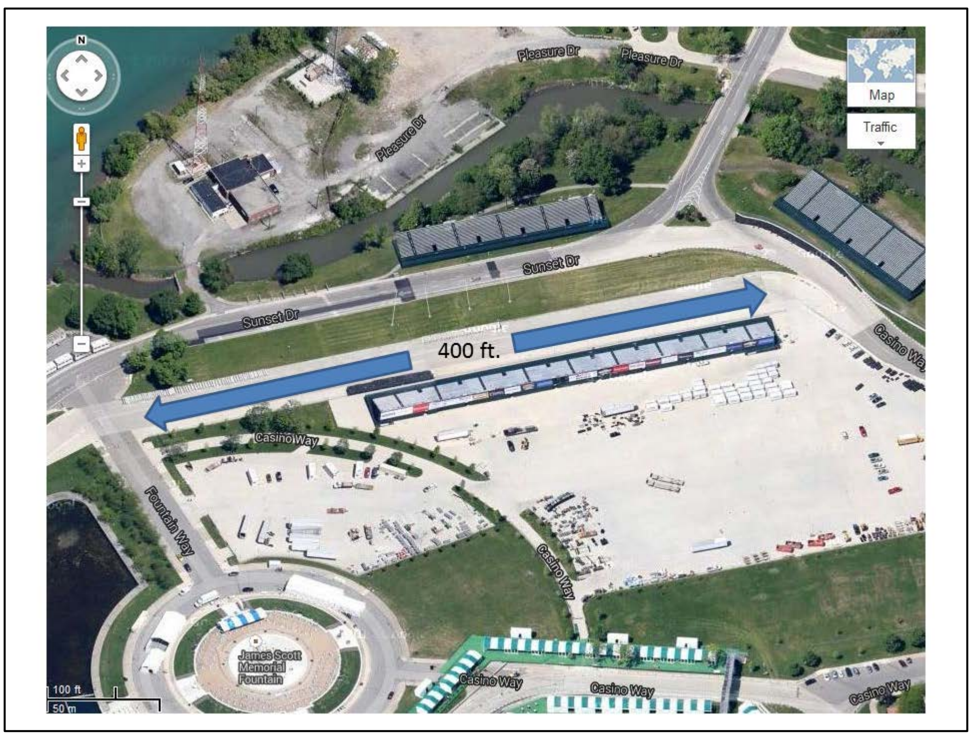

Figure 5 – IMO Test Loop on Belle Isle in Detroit

The interior of each van was equipped with a monitor that allowed the passengers to see all the data that was collected during a loop and exactly when an alert appeared on the screen. The monitor screen is shown in Figure 6. It shows much of the data collected throughout the project for vehicles in the study:

- Time
- Global Positioning Location
- Speed and Heading
- Road Roughness
- Engine RPM and Throttle Position
- Brake Events, Wipers on, and ABS, Traction Control, and Electronic Stability Control Events
- Road Surface Temperature and Air Temperature
- Humidity and Dewpoint

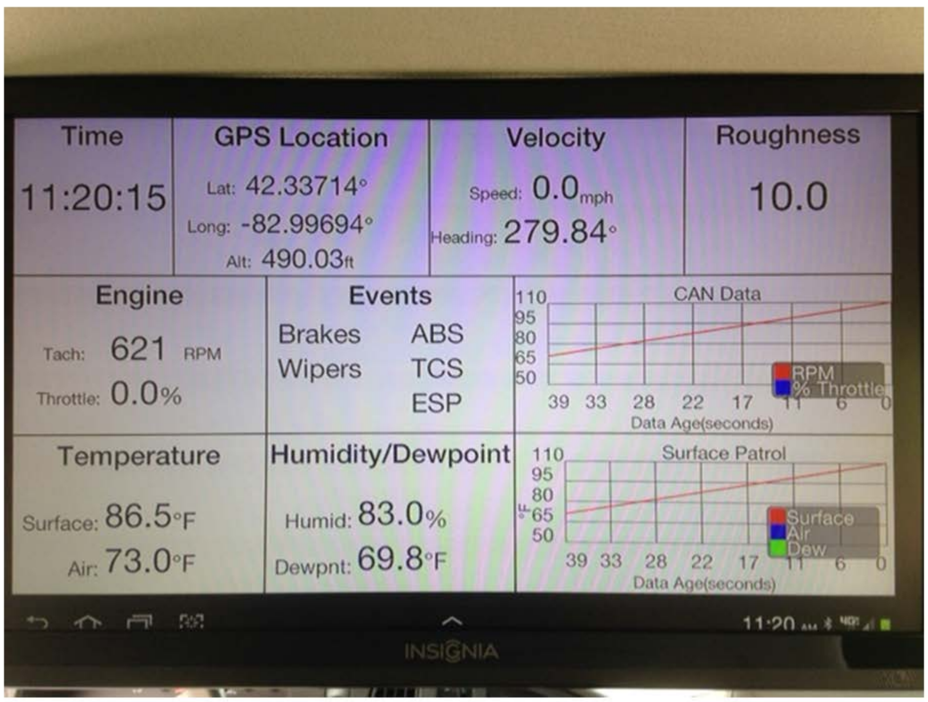

Figure 6 – IMO Monitor Screen in Demonstration Van (in Idle Mode)

The demonstration required that participants sit in the specially instrumented demo van for one loop around the track. During that one loop trip participants saw advisory warnings at different parts of the loop, based on road weather conditions artificially generated on-site. One section simulated rain, one section simulated rough road conditions, and a third section simulated slippery road conditions. The rain section had a fire hose spraying water unto the track from a bracket elevated about ten feet above ground as seen in Figure 7. Note that the message board warns the driver of light rain ahead.

Figure 7 – Rain Simulation on IMO Test Loop

When the lead vehicle turned on its wipers on the part of the track where the hose was simulating rain, the data was gathered, sent to UMTRI, and then sent to NCAR who sent an audio and visual alert via the MAW phone app called the Motorist and Advisory Warning System (MAW) to the passenger van as the van neared the rain simulator. The MAW screen is shown in Figure 8.

Figure 8 – Motorist Advisory Warning (MAW) Phone App Display in Demo Vehicle

Rough road conditions were simulated by driving the test vehicle over rubber barrel rings on the track as seen in Figure 9. A road roughness rating was shown on the monitor in the passenger van as it drove over the barrel rings.

Figure 9 – Rough Road Simulation on IMO Test Loop

Finally, the ITS World Congress participant saw and heard an alert for a slippery road ahead as their van approached a set of wet rubber mats, shown in Figure 10, that were used to simulate an ABS event and a traction control event. For the ABS event the demonstration van broke hard on the mats, skidding slightly. For the traction control simulation the van spun its tires from a full stop on the wet rubber mats.

Figure 10 – Slippery Road Simulation on IMO Test Loop

Over the three day period in September during the 2014 ITS World Congress, over 100 visitors from all over the world toured the IMO test loop in the IMO demonstration vehicles, learning about how sensors on vehicles in an area can share important information about road and weather conditions with each other.

Lessons Learned

Based on the number of lessons learned from the first IMO 2.0 project, the second project was able to improve in the areas of vehicles, hardware, software, communications, and the web portal. Many of the early problems identified during the first IMO 2.0 study were fixed by re-writing the DataProbe program from the first study, such that the version of the software used during the second study was much more stable and reliable.

Vehicles

- Based on the non-disclosure agreement with the manufacturer of the vehicles in the study, the project was able to obtain CAN codes from the manufacturer when older vehicles in the study were replaced with new models. The CAN codes used for this project need to be sourced from the manufacturer because not all of them are available to the public. This issue makes it difficult to imagine a consumer app that has access to the specific codes for ABS, ESC, and traction control.
- The number of vehicles needed to report weather-related incidents or events needs to be increased significantly in order to provide adequate coverage for a highway. The other option is to significantly reduce the area that will be covered and make sure that many

vehicles travel through that area. The perfect example of the need for more vehicles took place in January 9, 2015, on I-94 near Battle Creek, Michigan. A sudden lake-effect snow storm created "white out" conditions so that drivers could not see more than a few yards in front of their vehicles. Some drivers drove too fast through this storm and lost control of their vehicles causing a massive 193-vehicle pileup of heavy trucks and light duty vehicles that closed the freeway for two days. Before and during this snow storm and accident, none of the IMO 2.0 vehicles reported any data, including the winter maintenance trucks in the area.

Software

- A software program was developed that allowed testing of software changes with MDOT regional project coordinators before the update was pushed via the UMTRI server to all the phones in the fleet. This remote update process made installing software updates manageable and allowed all the vehicles in the study to run the same version of the software.
- The length of time before a file was transferred to UMTRI was changed from every five minutes to every one minute. This minor change allowed for a much improved flow of data from the vehicles and allowed the phones to keep up with the continual data collected while a vehicle was in service.

Hardware

- The additional phones purchased as backups to the original phones in the study were found to help fix some of the software links that broke during the long length of the project. New phones with updated software were sent to drivers, installed, and up and running quickly.
- The additional phones also allowed the project to avoid having to rewrite the DataProbe software for new phones that come into the market every six months.
- Thanks to the support of the Vaisala group, the project was able to replace Surface Patrol devices that malfunctioned in the field without extensive cost. The malfunctions usually took place on the winter maintenance trucks (WMTs) when maintenance personnel cleaned the trucks using high pressure hoses. Some of the sensors cannot be treated in this manner and still perform their functions.

Web Portal

- The web portal was re-designed to allow viewers to see vehicles in service on a map of southern Michigan. It also allowed pictures that were taken via the web portal to be seen on the portal, so users can see what drivers see.

Communication

- The development of the MAW phone app to be used during the 2014 ITS World Congress was a collaboration among UMTRI, FHWA, MDOT, and NCAR. The teamwork shown during the five month preparation for the 2014 ITS World Congress is a testament to all the people involved in the demonstration.

- The working relationship between MDOT IMO supervisors in four MDOT regions strengthened during the second IMO 2.0 project. Supervisors became experts in running the DataProbe system on their vehicles and were able to help troubleshoot any problems with IMO drivers in their region. They became excellent test subjects for new versions of the DataProbe software.

Conclusions

The second IMO 2.0 project continued to improve the data acquisition system that provides weather-related road information to weather analysts throughout the country in near-real time using a fleet of 60 vehicles along the I-94 corridor in southern Michigan. New CAN codes were introduced into the system for new vehicles entering the project, a remote update system was developed to automatically update software on the phones, the speed and accuracy of the data transfer from the smart phones to the UMTRI server were improved significantly. The web portal was also improved to allow vehicles in service to be displayed on a map in real time and photos taken from the website to be shown on the web portal. The project generated 745,843 valid data files (211 gigabytes of data). 54,975 (25 gigabytes) photos were also taken throughout the data collection period. These data files represent 529,671 miles driven by MDOT vehicle operators over the 18 month period.

One of the key goals for the IMO 2.0 project was to show that micro-level weather data can be gathered by vehicles on the road and used to inform vehicles that are coming behind these vehicles of any adverse weather events. The 2014 ITS World Congress demonstration showed that this micro-level weather data can be collected via a smartphone in a lead vehicle on a 400 foot test track in Detroit, sent to weather analysts in Boulder, Colorado 1,200 miles away who send weather alerts via a GPS-based Motorist Advisory Warning phone application back to trailing vehicles driving on the same 400 foot track in Detroit. This test showed the capability and reliability of the DataProbe data collection system. It also showed that weather analysts could accurately pinpoint weather events within a 400 foot area and report those weather events using a GPS-based phone application for three days without any errors. Finally, the World Congress demonstration showed the importance of having a lead vehicle in the same area gathering and sending data to weather analysts, providing them with the certainty they need to send out alerts to drivers behind the lead vehicle about upcoming road conditions or weather events.

Recommendations

The ITS World Congress demonstration showed that micro-level weather data collection from vehicles can be used to generate accurate reporting of weather events within a 400 foot area. Some of these simulated events were within 100 feet of each other, yet the weather analysts pinpointed them so accurately within the 400 foot area that they could send messages to a phone application in a vehicle before it reached the simulated event on the track. This is a remarkable achievement, and it led to more than one World Congress visitor looking under or around the vehicle for a sensor that triggered the alert or continually asking to have us tell them about the simulation program that triggered the alert.

Yet despite this remarkable ability of the program to gather the data, and send alerts to drivers as they approached the weather events using a program that tracked the vehicle 1,200 miles away, the demonstration showed the need for continual input from vehicles ahead of the demonstration vehicle in order to provide accurate weather and road information. In conversations with the weather analysts throughout the project, they continually spoke about the need to verify the readings they received from the MDOT vehicles in the project. Having one vehicle report a traction control event or road temperature reading below freezing was not enough to trigger a warning. There needed to be more mobile readings reported in that same area as well as radar and stationary readings confirming some of the vehicle reports before a weather analyst would consider issuing a warning. With 60 MDOT vehicles spread across 200 miles of southern Michigan, the likelihood that these vehicles would intersect and provide the necessary weather-related verification was low.

The recommendations section of the first IMO 2.0 project noted that the era of micro-level weather reporting is upon us, but there are some challenging headwinds that must be overcome before this technology can work on a large scale. The need for a crowdsourcing model that brought consumers as well as state vehicles into the mix in order to provide the necessary verification was discussed. The Waze program (www.waze.com) provides this type of information for traffic on Google maps. Drivers report on accidents and slowdowns on roads, and this information is shown on the route a driver is taking. One can see this program being adapted to weather conditions on roads as well as for traffic. Verification again will need to be addressed, but state level agencies could tap into this network for additional micro-level, weather-related information. Setting up a program that encourages drivers to input weather-related road information into Waze may be a cost effective way that takes advantage of a national and state-wide system (Google maps and Waze) that is already in place. In the same way that Waze drivers help drivers behind them with traffic, they could also help drivers with weather-related road information. This could also apply to MDOT drivers experiencing weather-related road events. Accidents and major weather-related events do not occur frequently (though winter weather can be a constant in northern states). MDOT drivers could be encouraged to add this information into the Waze program in order to increase the number of verifiable weather-related incidents on a road.

Connected vehicle data could also be part of the crowdsourcing model. As vehicles talk to each other through vehicle to vehicle (V2V) or vehicle to infrastructure (V2I) programs, road weather condition information could be exchanged. Not all vehicles would need to report this information. Some models for V2V and V2I report that only 25 percent of the vehicles in a particular area would need the technology on their vehicle in order to provide reliable information to drivers. But the need to gather weather-related information from the vehicle will continue to be a challenge, as it was for the IMO 2.0 project. Much of the critical information about road conditions such as those gathered from traction control, ABS, and ESC in a vehicle is proprietary for each vehicle manufacturer and would need to be included in the information transferred through V2V or V2I links. Road temperature also is important, and in the IMO 2.0 project this information was gathered through a separate device installed on a vehicle which is not available on any vehicles on the road today.

Finally, one of the potentially fruitful avenues for generating near real-time weather information could come from encouraging trained MDOT drivers to take photos of weather conditions and events on the road and have a program that allows drivers to easily upload them to a mapping program or website that verifies the location. This could support the verification process for any of the methods discussed above as well as providing local agencies excellent visuals for broadcasting current conditions. Though the IMO 2.0 project was not able to initiate it within the timeframe of the project, another photo opportunity would have all the MDOT winter maintenance trucks installed with phones that take photos automatically every five minutes (or whatever timeframe is appropriate) based on the understanding that these vehicles would not be on the road if there were not a need for them to be there. As the photos are sent to MDOT, a program would then interrogate the photos about the road conditions and where the photo was taken and use that information for verification purposes.

The title for the second IMO 2.0 report focused on the Connected Driver who can benefit from a variety of sources of micro-level road condition and weather information provided by state and local agencies, but the future may require that the driver and/or his vehicle provide important information that will help drivers coming after him. As drivers become more interconnected, this interconnectedness takes on a “we’re all in this together” theme that can make our roads safer for everyone on them.

Appendix

Technology Overview

The IMO 2.0 project relied on a combination of custom software and commercially available hardware to gather and distribute data from the vehicles in the study.

Software

The software used to gather the information from the smartphones in the study was called DataProbe. This software was developed during the Slippery Roads study, and began as the base software for the IMO 2.0 project. Early in the study it was found that the software needed substantial customization to meet all the requirements for the project. A software programming firm, Intersog, the original designers of the DataProbe software, was hired to support the changes needed in the software. After five months of off-site development and troubleshooting with Intersog, it was decided that UMTRI needed on-site staff to work on continual maintenance of the DataProbe software including programming and managing the testing and rollout of the program. Subsequently, a staff engineer was hired to support the project.

Over the 17 months of the project, the software was updated approximately 15 times to meet the demands of the project. The carryover version from the Slippery Roads project was version 2.20, and the version used by the end of the project was version 3.7.1. Two important software issues arose that made the project more challenging than originally expected:

1. Every time a new vehicle type was brought into the project, a set of automaker–specific CAN messages needed to be programmed into DataProbe for each specific model year and model of vehicle.

Working with the two major automotive manufacturers chosen for the study provided very different results. UMTRI signed a Non-Disclosure Agreement with one of the companies and had contacts within the company who provided insight into how to correctly read the proprietary and not publicly available CAN messages that differed for each vehicle.

Attempts to generate a Non-Disclosure Agreement with the other automotive manufacturer were not as successful. Despite numerous attempts, including a request by the Michigan Department of Transportation Director, the company would not provide the necessary agreement or support for the project. UMTRI attempted to reverse engineer some of this company's CAN codes, but the results were not satisfactory. In addition to the inability to obtain the desired data, on some instrumented vehicles from this company, there were examples of vehicles flashing their interior lights, locking and unlocking the electronic doors randomly, and even making the automatic transmissions difficult to shift. Because of the reluctance of the company to support the project, their vehicles, which represented about half of the light vehicle fleet studied, had to be removed from the project and another set of vehicles from the other company needed to be instrumented and added to the fleet.

This change occurred four months into the project and necessitated a larger commitment by UMTRI and MDOT staffs than originally expected, as MDOT worked to find vehicles that would meet the requirements for the project and UMTRI programmed the requisite CAN message codes into the DataProbe program.

2. Every time a new version of DataProbe was issued, MDOT staff had to go to each of the 60 vehicles in the project and update the program manually on each smartphone.

Updating 60 vehicles manually proved very challenging as DataProbe went through many different versions, especially as the vehicles from one company were dropped from the fleet and the new vehicles were added. It was not until a UMTRI software programmer was hired towards the end of the project to specifically design a remote update program was the problem solved. Now an updated version of DataProbe can be pushed, through the cellular network, to each of the phones in the fleet, with each driver only having to click on two buttons when prompted to install the remotely managed updates.

The DataProbe program provides some output results of its data collection to the driver via the smartphone's screen. The screen is configurable to allow for different data to be shown. Figure 11 shows a typical six box screen. In this instance it shows data received from the Surface Patrol device (ambient temperature, surface temperature, and humidity) and the phone (GPS location and time). The box labeled "MODE" determines what data appears on the boxes. In this case, it shows data in the BS mode where basic phone and Surface Patrol data is collected. The combination of data collected from the various devices can show the following codes in the "MODE" box.

- "B" if the phone is only receiving basic phone data
- "BC" if the phone is receiving only basic phone data and CAN data
- "BS" if the phone is receiving only basic phone data and Surface Patrol data
- "BCS" if the phone is receiving basic phone, CAN, and Surface Patrol data

The different combination of modes can occur for a variety of reasons. For example, if a phone is receiving only basic phone data, then its OBDKey may not be functioning properly and not sending CAN data or simply not be present in that vehicle. If a phone is not receiving Surface Patrol data, it may be normal because that particular vehicle is not equipped with Surface Patrol. All light duty vehicles, at a minimum, should be sending phone and CAN data, and all WMTs should be sending phone data. In addition to providing information to the driver on the smartphone screen, this display also helps the driver confirm proper system functionality and operation. If one or more modes are not present on the smartphone screen, system diagnostics can better be accommodated. Figure 12 shows a DataProbe screen in the BCS mode, and Figure 13 displays a DataProbe screen in the BC mode.

Figure 11 – DataProbe Screen Example in Phone and Surface Patrol Mode Only

Figure 12 – DataProbe Screen Example in Phone, Surface Patrol, and CAN Mode

Figure 13 – DataProbe Screen Example in Phone and CAN Mode Only

Hardware

The main hardware that comprised the data collection system installed in vehicles included the phone, the Surface Patrol sensors, and the OBD key. The other project hardware consisted of the virtual server housed at the University of Michigan that received the data from the smartphones and distributed the verified data to weather analysts. The virtual server was used as a production server exclusively for receiving, sorting, and sending IMO 2.0 data. Though it held significant amounts of data, its main challenge was maintaining services without downtime caused by interruptions in service. It is described in more detail in the Data Collection section of this report.

The Phone

The smartphone used in the project was a Motorola Droid Razr M (XT907) running the Android version 4.1.2 Operating System. All the vehicles in the fleet used the same phone. Backup phones for each of the project phones were able to be procured for a very small amount after a year in service from the University of Michigan's cellular service vendor, Verizon. Over the course of the project, seven phones were replaced primarily due to battery malfunctions, occasionally in hot weather. No phones were replaced due to excessively cold weather, despite the fact that the winter of 2013-2014 was colder than most previous Michigan winters.

Each phone had an unlimited data plan and no voice/calling options. The phone used an active Verizon 3G/4G data service to automatically transfer accumulated DataProbe data to the server at the University of Michigan.

The cost of the data plan for each phone averaged $37 per month, so a 60 vehicle fleet averaged about $2,220 per month. One option that we were able to employ during the summer months was to put the WMT phones on "vacation" where the project was only charged a five dollar fee to keep a phone on the plan instead of the usual $37 per month. This saved $3,840 over the period of six months that the WMTs were out of service.

Most phones were hardwired to the cigarette lighter/accessory fuse with a 12V to 5V voltage regulator that allowed for a key/on, key/off system, though some were connected to the cigarette lighter via a 2-port 12 volt USB cigarette lighter adapter manufactured by Kensington. Most of the phones had a similar "dead" phone problem where the battery discharged to the point of shut down after not being used over the weekend or if the driver was on vacation or just not driving the vehicle very often. The dead phone needed to recharge by driving the vehicle before the operating system and the DataProbe program could be re-initiated. Due to a USB power based automatic activation of DataProbe, the program would not initiate automatically after restarting the phone while driving and the driver would have to manually restart the program. If the driver was not paying attention to the phone, it might not start at all during the trip and only startup during the next trip after the phone was recharged.

The phone was securely mounted in the vehicle by either gluing or screwing a compatible car mount adapter which holds the phone onto the instrument panel or into the headliner near the rear view mirror (which was necessary for the WMTs because an instrument panel mount blocked the driver's view of other instruments). Mounting the phones with a clear view of the road ahead was necessary in order for the cameras in the phones to take clear and accurate photos of weather and road conditions. These photos were also sent to the weather analysts as another data modality.

Each phone mount contained a magnet that triggered a signal to the Android operating system to automatically activate the DataProbe application when the phone was placed in the mount.

The OBD Key

CAN data was collected on all 40 of the light duty vehicles via the Bluetooth-enabled OBD key located under the steering wheel under the instrument panel, as seen in Figure 6. The OBD-II scan tool used is a consumer-level Bluetooth-enabled device based on the popular ELM327 OBD-interface command set. The scan tool accesses vehicle system information via the ISO-15765 high speed CAN bus available on most newer domestic vehicles. The OBD-II scan tools used, depending on the date of install, are the OBDKey130 or OBDKey140 models manufactured by KBM Systems, Ltd. (www.kbmsystems.net). This device is powered directly from a vehicle's SAE-J1962 OBD-II connector during operation and communicates directly via Bluetooth to the DataProbe software running on the Droid Razr M.

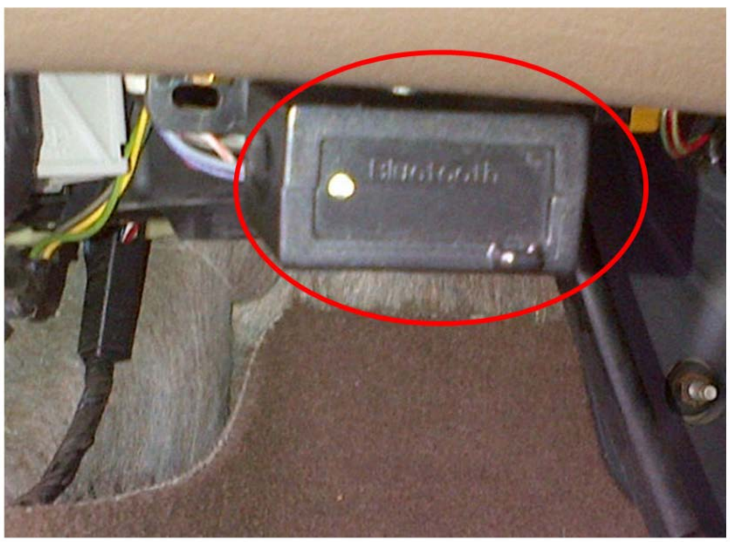

Figure 14 – Bluetooth enabled OBD Key for CAN data

Though generally reliable, the OBD key needed, at times, to be reset by taking it in and out of its socket under the steering column. The challenge was training the drivers to notice that it was not working properly and responding accordingly. There were three ways of noticing if the device was not working properly: 1) if the blue light on the OBD key did not turn on at all, 2) if the blue light on the OBD key remained on and did not flash, or 3) if the “Mode” on the phone screen did not show a “C” while the vehicle was in operation.

UMTRI also monitored each of the phones weekly, examining the data received from each phone. If the phone sent a file to UMTRI that started with only the phone number instead of the Vehicle Identification Number (VIN), this indicated that the vehicle was not collecting or sending CAN data. This applied only to the light vehicle fleet, since the WMT fleet did not send CAN data. If a vehicle was designed to send CAN data, and it did not send CAN data over 10 percent of the time, then UMTRI notified the driver and his/her supervisor that the driver needed to adjust the OBD key.

The Surface Patrol Sensors

The other hardware included on 10 light duty vehicles and 10 WMTs was the Surface Patrol sensors that measured humidity, ambient air temperature, and road surface temperature. The Surface Patrol HD unit is manufactured and sold by Vaisala Corporation. Each Surface Patrol unit was comprised of one road surface temperature device as seen on a WMT in Figure 15 and in a variety of areas on the trucks and cars where it was not affected by the heat within the engine compartment or debris buildup from the road.

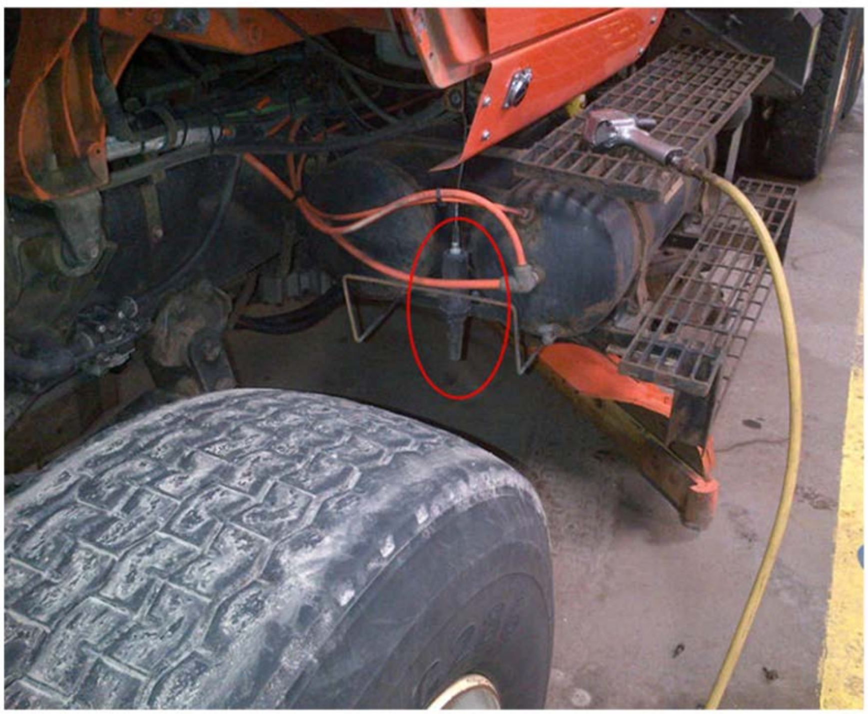

Figure 15 – Surface Patrol Road Temperature Sensor on a winter maintenance truck (WMT)

The final external Surface Patrol sensor, the humidistat shown in Figure 16, gathers ambient air temperature and humidity data. Data from the two sensors are connected to a “spreader” unit that conditions the data. The “spreader” is a unit, circled in red in Figure 1, that takes that takes the data collected via the humidistat and the road surface temperature devices and translates it into data that is readable by the DataProbe application. The Surface Patrol unit, as a whole, is wired directly into the vehicle's 12 volt bus. UMTRI added a Bluetooth adapter to the spreader unit in order to send the data to the phone wirelessly. The Bluetooth adapter, developed by Roving Networks is called a Firefly (RN-240M) RS-232 to Bluetooth adapter. The Firefly requires a VKTech 12 volt to 5 volt USB regulator to supply vehicle-derived power for operation.

Figure 16 – Surface Patrol Humidity Sensor Mounted on a Car Trunk

During the winter months, the humidity sensor was particularly sensitive to the extreme, high pressure water used to clean the WMTs that accumulated significant amounts of snow and ice. Vehicle cleaners were given instructions not to use the high pressure water on the humidity sensor after a few of the sensors failed to send data, and it was found that water had entered the sensor enclosure.

The maintenance on the road surface sensor requires occasional re-calibration that can be time-consuming and difficult to determine when it should occur. UMTRI monitored the data received from vehicles using these sensors weekly, in order to determine if the values were out of the ordinary. Extreme values led to re-calibration requests to MDOT garages. A more consistent re-calibration process within the MDOT fleet may be required if the project continues into the future.

IMO Photos

Besides data collected via the phone, OBD key, and Surface Patrol devices, one of the unique features of the IMO project was the ability to capture a roadway weather situation using the camera on the phone. The ability to use the camera to substantiate what weather analysts see in the data is an invaluable tool for near real-time weather analysis. Figure 17 displays four examples of photos taken during the winter of 2014. Notice how clearly one can make out the condition of the road.

Figure 17 – DataProbe Photo Examples

For this project, photos were taken during three different scenarios:

1. The driver can take a photo when he/she sees a weather-related event occurring, such as the beginning of snow storm.
2. Anyone authorized to log onto the DataDroid web portal can take photos with any vehicle in service
3. If a vehicle with CAN data encounters an ABS or traction control event, DataProbe takes a photo.

Of the three scenarios, the ABS/traction control scenario was the most difficult to program. The CAN codes related to ABS/traction control are not easily distinguished from other similar events on the CAN bus. Also because ABS/traction control events do not happen regularly and we are unable to easily see which vehicles have these technologies onboard, it has been difficult to capture the event in data format as well as in photo format. In order to capture more photo information about an event, all the phones were programmed to take three pictures with one push of the camera button by the driver, when a photo was triggered via the website, or when an ABS, ESC, or Traction Control event occurred. In all cases, three photos are taken one second apart to ensure photo clarity and reliability.

Photos in the DataProbe system differ from the data files because they do not have to wait five minutes to complete data collection before uploading to the University of Michigan server. Photos are sent as soon as they are taken (unless DataProbe is in the middle of uploading a data file), increasing the timeliness of the photos.

One can even envision taking more photos and developing a tool to interrogate and interpret what is happening in the photo from a weather perspective. The GPS data connected to the photo can be used to quickly locate where the photo was taken and signage can be updated quicker than through weather models based on vehicle and other supporting data.

DataProbe Web Portal

One of the unique additions to the IMO 2.0 project over the original Slippery Road project was the development of a web portal to track vehicles in service, take photos remotely, and send text messages to drivers. The PHP-based web portal, named DataProbe, was developed using the Apache web server software, making its links to the vehicles in service based on their uploading of data through the Apache web service. Figure 12 displays what a user sees after logging onto the website.

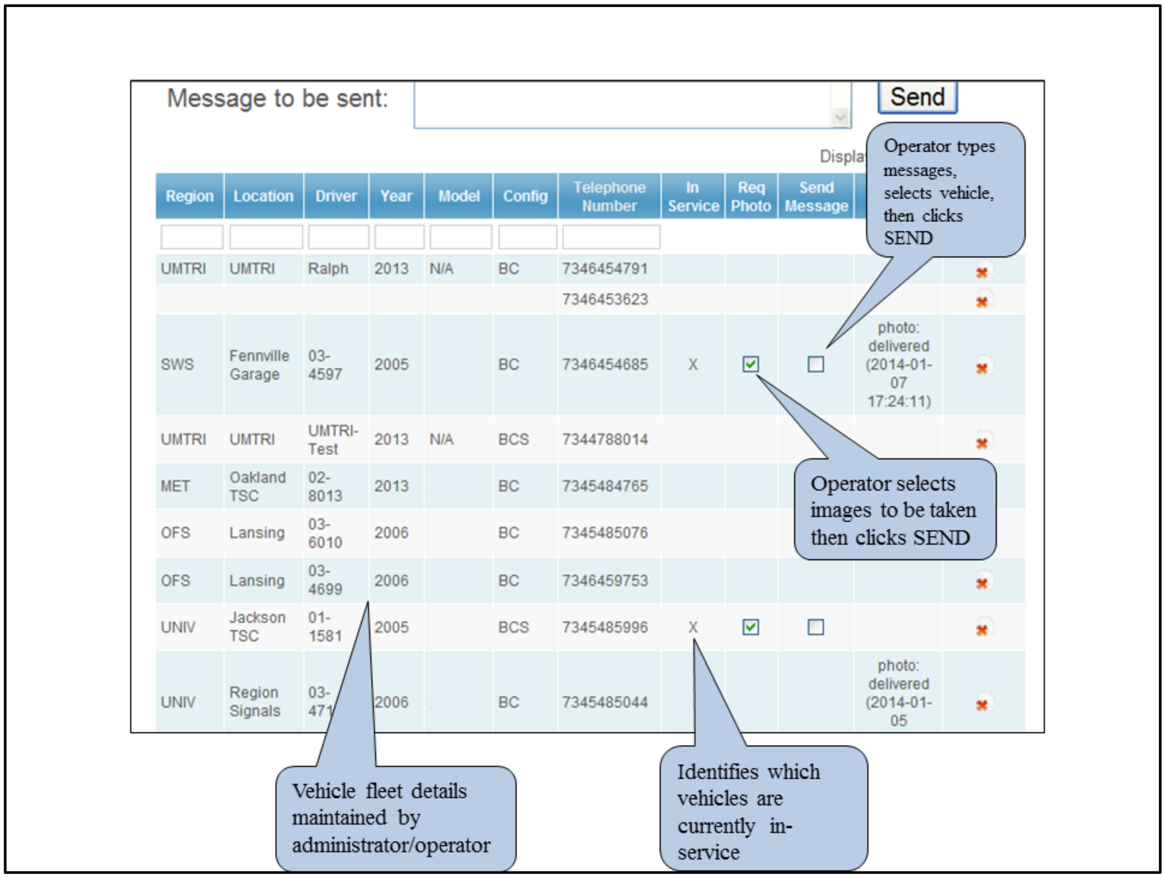

Figure 18 – DataProbe Web Portal Page

The web portal was tested continually throughout the project to see how well it identified vehicles in service, took photos remotely, and sent messages to drivers. In almost all cases, the portal was able to take photos remotely and send messages. Its weakness was its inability to identify all the vehicles in service. It would identify some vehicles in service but not all of them, though it would not provide false positives, saying a vehicle was in service when in fact it was not.

One of the major challenges for the project was knowing when a vehicle was in service. UMTRI researchers had no way of knowing if the DataProbe units were not sending data because the vehicle was not in service or if the DataProbe unit was inoperable. The web portal was an attempt to help sort out this problem, but unfortunately, it turned out not to be as robust as was hoped. Because of this weakness, tracking DataProbe performance was always performed after the fact, reviewing the previous week's data to see which vehicles were not sending data and contacting the drivers and their supervisors to see if the vehicle was indeed out of service the previous week. One of the continuous improvement tasks for the IMO 2.0 team is to improve the web portal to become the ground truth about what is currently occurring on the road. Having ground truth for vehicles in service will allow researchers to be more proactive in addressing hardware and software problems quicker, and getting the systems back up and running when they fail.