REALIZING THE POTENTIAL OF VEHICLE-BASED OBSERVATIONS

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The potential availability of millions of weather and road condition observations from passenger vehicles and fleets represents a huge opportunity for the weather community. Whether this opportunity is acted upon or missed (at least initially) will depend greatly on the weather community’s technical understanding and eventual adoption of these unique datasets and their level of participation in connected vehicle initiatives within the transportation community. All sectors of the weather enterprise (e.g., public, private, and academic) must become involved to help define, shape, and support the effort to bring these data to bear on the weather and transportation communities. For this reason, the American Meteorological Society (AMS) Board on Enterprise Planning (BEP), under the Commission on the Weather and Climate Enterprise (CWCE), established an Annual Partnership Topic (APT) Committee in 2009 focused on mobile observations and their potential for use by the weather and transportation communities. Bringing this topic forward as an APT provided an opportunity for a deliberate discussion among stakeholders about its potential, technical challenges, research needs, implementation strategy, and other issues related to mobile observations.

BACKGROUND. It is common knowledge in the atmospheric science community that weather observations provide a critical source of data for weather analysis and forecasting. Surface observation networks are deployed and operated not only by the National Oceanic and Atmospheric Administration (NOAA) and the Federal Aviation Administration (FAA), but also by hundreds of smaller federal, state, local, and private agencies and organizations. Several recent studies and discussion groups have focused on the national surface observing network and the need to improve both measurements of the atmospheric boundary layer and Earth’s surface (e.g., land surface characterization), leveraging the many different public and private surface observation networks by sharing data through public–private partnership arrangements (NRC 2004, 2009). A summary of related studies and discussion groups and their relationship to mobile observation initiatives is given in Mahoney et al. (2010). These
activities clearly demonstrate that there is a strong national interest in establishing and maintaining a robust surface observing network and exploring unique opportunities to expand the network. One approaching opportunity to expand the network is the pending availability of measurements from large commercial and public vehicle fleets, as well as passenger vehicles. The availability of hundreds of millions of direct and derived surface observations based on vehicle data will have a significant impact on the weather and climate enterprise. The potential improvements in weather analysis, prediction, and hazard identification should have a large positive effect on all weather-sensitive components of the U.S. economy and the capability to sense the lower atmosphere at finer scales than traditional observation systems, which will improve the detection and diagnosis of extreme weather events that affect lives and property. For example, vehicle-based air temperature observations could provide additional temporal and spatial specificity required to more clearly identify rain/snow boundaries; also, anti-lock brake and vehicle stability control event data could support the diagnosis of slippery pavement conditions. Even the most common components of the vehicle can begin to tell a story about the near-surface atmospheric and pavement conditions through the intelligent utilization of vehicle data elements, such as windshield wiper state, external air temperature, headlamps, atmospheric pressure, sun sensors, vehicle stability control, and the status of an antilock breaking system (Petty and Mahoney 2007; Stern et al. 2007, 2008; Chapman et al. 2010; Drobot et al. 2009, 2010). Figure 1 illustrates data elements that are now commonly available within the controller area network (CANbus) on passenger vehicles.

**COMMITTEE CHARGE.** The APT Committee on Mobile Observations, cochaired by the authors, was given an overarching charge to discuss the application and utilization of mobile weather and road condition data in the context of supporting the weather and transportation communities and how these data could be used to improve safety and mobility across the nation’s surface transportation system. The committee was asked to help articulate a clear vision for mobile data that captures the immense opportunities for these data to improve surface transportation weather services. The results were documented in the committee report (Mahoney and O’Sullivan 2011), which is summarized in this article.

The committee membership, listed in the acknowledgements, was designed to encapsulate a cross section of experts and stakeholders within the weather and transportation communities. There was an attempt to include at least one representative from the automobile industry, but the committee was unsuccessful in recruiting from this industry, probably because of the severe economic conditions that were experienced by the auto industry from 2008 to 2010. However, the committee was successful in engaging the Vehicle Infrastructure Integration Consortium (VIIC), which represents several automotive companies. The VIIC reviewed the draft report and their feedback was incorporated. The VIIC reported that their automotive industry representatives endorse the findings of the report and look forward to working more closely with both the meteorological and transportation stakeholders to move the “vehicles as weather sensors” concept forward. To aid in the process of addressing the primary topic areas, five subcommittees were formed around the topics and subcommittee chairs were identified for each. The subcommittee topics and chairs are listed below:

- Potential benefits—Richard Clark (Millersville University)
• Barriers to acceptance—Jud Stailey (Office of Federal Coordinator for Meteorology)
• Research needs—Leon Osborne (Meridian Environmental Technologies and University of North Dakota, Surface Transportation Weather Research Center)
• Data quality and metadata—James M. O’Sullivan (NOAA/NWS)
• Business models—Jim Block (Telvent DTN)

The committee work plan included preparing a BAMS In-Box article introducing the topic of vehicle-based observations and various related activities (Mahoney et al. 2010); preparing and administering a web-based driver preference survey to assess driver attitudes about having their vehicles used as weather probes and to learn what driver preferences were with respect to in-vehicle weather and road condition hazard products; addressing the committee charge topics listed above, reporting on progress at the AMS annual meetings and summer community workshops; preparing a committee report; and summarizing the results in a BAMS article (this article).

With regard to the above-mentioned survey, several questions were posed, including:

• How do drivers feel about using their personal vehicle as a data probe?
• How critical are privacy concerns?
• How important are certain weather/road condition hazard products if provided in the vehicle?
• Would drivers change their behavior if provided with in-vehicle hazard information?
• What are drivers willing to pay for in-vehicle weather/road condition hazard information?

To address these issues, a list of questions was prepared as part of a web-based survey, which was administered by a third party under contract to the AMS with financial support from the Federal Highway Administration (FHWA) Road Weather Management Program. The survey results are being analyzed in more detail and will be described in a future article.

SUBCOMMITTEE REPORTS. The five subcommittees prepared reports documenting the results of their discussions on the Committee charge topics and the reports are summarized in the following sections.

Potential benefits of mobile observations. On average, between 1995 and 2008 there were over 6,301,000 vehicle crashes each year and 24% of these crashes—approximately 1,511,000—were weather related (FHWA 2012). Weather-related crashes are defined by the FHWA as those crashes that occur in adverse weather (i.e., rain, sleet, snow, and/or fog) or on slick pavement (i.e., wet pavement, snowy/slushy pavement, or icy pavement). According to these FHWA statistics, on average, 7,130 people are killed and approximately 629,300 people are injured in weather-related crashes each year.

High-quality weather information about the roadway environment, including both current observations and forecasts, communicated in a timely and effective manner can help drivers to make better, safer decisions regarding travel plans and to react properly when faced with potentially compromised conditions. Providing improved road weather information to those who construct, operate, and maintain the nation’s roadways will enable them to operate more efficiently and respond more quickly and appropriately to weather problems. Both drivers and transportation professionals will benefit from new technologies for vehicles, roadway infrastructure, and communications (NRC 2004). The observations, products, and capabilities augmented by mobile data have the potential to significantly benefit the weather, surface transportation, emergency management, energy, agriculture, and other communities and other industries sensitive to surface weather. The idea of smart vehicles in constant communication with weather information providers and traffic control centers, commercial fleets adjusting their routing to avoid anticipated storms, and road maintenance personnel being guided continuously by telemetered road weather information is rapidly advancing. Over the course of the next decade a focused road weather research program could deliver this as a reality to the nation, saving thousands of lives and billions of dollars. The Committee anticipates that the road weather system of 2020 may include a robust observation and communication infrastructure, models to support decisions, smart vehicles, enhanced roadway maintenance, and enhanced traffic and emergency management. Surface weather and road condition observations and their derived products and applications will have direct and indirect benefits stemming from their potential for improvements in several principal areas including weather information and product improvements, road and rail condition, in-vehicle information systems, transportation system management decision support, and emergency management.

Vehicle manufacturers have demonstrated the feasibility of a wide variety of onboard computing and telecommunications tools and have begun to move
some of these to the marketplace. Accompanying these advances in meteorology and transportation are improvements in communications, computational capabilities, and geographic information systems—technologies that have applications to the road weather problem. Adding in situ surface and near-surface mobile weather observations, metadata, and derived products with high spatial and temporal resolution to the existing national weather data stream has far-reaching implications that are expected to result in direct short- and long-term benefits for the research and operational communities. A high-resolution mobile weather network has value in all of the following:

- Providing meteorological observations and inferred meteorological conditions (e.g., precipitation rate and type, obstructions to visibility) at the surface and near surface that will enhance the national mesonet and play a key role in filling gaps where observations are sparse;
- Creating a new data/information resource for improving the precision and accuracy of short-range forecasts and warnings—including the articulation of rain/snow change lines and other sharp weather-related discontinuities;
- Providing important new information for initializing (and perhaps eventually validating) numerical model fields;
- Assisting forecasters in a full spectrum of activities, from aviation and hydrologic forecasts to articulating microclimates in our communities; and
- Supporting nowcasts for road, rail, transit, and environmental hazards.

Improvements in observations, modeling, forecasts, and data/information availability are critical components for ensuring a road, rail, and transit management and decision support infrastructure that aims to increase safety, mobility, and efficiency. In the long run, it is expected that a more comprehensive scientific investigation of the roadway and rail environment will ensue, which would lead to new concepts in road weather forecasting through development of a better scientific understanding of the relationships/interactions of the atmospheric surface layer with the roadway and railway environment (pavement, subpavement, roadside vegetation, etc.).

A principal benefit to users of road weather information is improved situational awareness. Through the communication infrastructure and the in-vehicle notification capability, road condition, traffic, and weather alerts and warnings can be communicated directly to passenger and fleet vehicles to keep operators abreast of impending road, traffic, and weather hazards, including but not limited to tornadoes, severe thunderstorms, hail, flash flooding, blizzard conditions, black ice, fog, thick smoke, and precipitation amount and type, as well as associated traffic congestion, accidents, road maintenance areas, etc. Improved assessments of travel conditions will lead to more effective travel advisories and enable better en route and pretravel planning. Improved situational weather awareness is likely to save lives and increase travel mobility and efficiency. A simulation study (Toppen et al. 2002) found that drivers using traveler information arrived at their destination within 15 minutes of the target arrival time 79% of the time; this drops to 42% without traveler information. Having in-vehicle access to critical weather, road, and traffic information, including advisories, will help travelers and fleet operators conduct better trip planning or adjust their plans en route to accommodate changing weather, road, and traffic conditions.

A mobile observation capability and the in-vehicle routing and hazard avoidance products that it would enable could also be used to improve driving efficiency and hence reduce emissions. Information on vehicle type and location could also be used in air quality analysis and prediction models to improve real-time estimates of the emission sources. A dynamic map of vehicle data would provide a rich source of new data for air quality models. Vehicle-generated air temperature data in the urban corridor could help identify microclimates and characterize boundary layer inversions for example, which are both very important factors in air quality monitoring and prediction. Improved estimates of precipitation would improve calculations of pollution sinks.

**Barriers to acceptance of mobile observations.** Taking weather observations is a complex endeavor. Specifically, tasks such as developing, siting, or maintaining observing equipment and disseminating the observational data are very complex. Traditionally, near-surface weather observations have been generated by stationary platforms. Taking observations from mobile platforms, particularly passenger and fleet vehicles, introduces new dimensions of complexity. This subcommittee discussed some of those challenges in terms of barriers to acceptance, and suggested some possible ways to overcome those barriers. For ease of discussion, the barriers are grouped into three general categories: technical, fiscal, and institutional. None of these categories should be viewed
as more important or more difficult than the others and the barriers in all categories must be effectively addressed for mobile weather observing to achieve its full potential. In fact, the barriers within the categories interact with barriers in other categories, so most cannot be effectively addressed individually. A litany of barriers to acceptance to mobile weather observations may leave the reader with the impression that mobile weather observing is too difficult, too costly, or otherwise too problematic to achieve on any useful scale. To counteract this impression, some potential solutions are also proposed. The intent is not to solve all the potential problems associated with mobile observations, but rather to illustrate that the barriers can be overcome.

Technical Barriers. In spite of significant advances in mobile sensing capability and navigation and communication capabilities, challenges to broad deployment of accurate, reliable, and accessible data from mobile sensors remain. Both sensor and communications barriers must be overcome for mobile observations to become a reality on a broad enough scale to be meaningful for road weather or other applications.

Sensor Barriers. Two types of sensors (using the term sensors loosely) are being considered for providing weather information from mobile platforms. Sensors placed on vehicles specifically to provide weather/road condition information are one type, and constitute what we normally think of as weather sensors. The other type includes systems that are native to the vehicle itself, but can provide useful information (e.g., antilock brakes). The challenges associated with these two types of sensors are inherently different. Many of the normal concerns associated with dedicated weather sensors—siting, maintenance, and calibration—are exacerbated with mobile sensors, especially when large numbers are to be sited on a wide variety of vehicles driven by people with varying interest in those sensors. The best place to site a temperature sensor on a particular model of car may not be the best location for a pressure sensor, and the best place for a particular sensor on one model of car might not even exist on another model (Mitretek Systems 2006). Sensor-by-sensor and model-by-model studies to determine optimum siting location may be prohibitively expensive, especially as new models are introduced each year, requiring new siting studies. Ideally, the optimum siting location would provide accurate data under a wide variety of conditions, but accuracy in even the best location could be compromised by vehicle speed and ambient conditions. At least these issues are being studied today with standard sensors, the technology for which is fairly mature. Accurate, mobile, low-cost sensors for other important variables such as humidity and pavement temperature have not been widely deployed; they may cost more and there is less experience with siting them on mobile platforms. Maintenance, testing, and calibration of sensors are particularly problematic. In theory, this type of work could be done as part of routine automobile maintenance, but it is not clear that the public would be willing to absorb the cost.

Sensor evaluation studies in the mobile environment may provide vehicle manufacturers and others with standards regarding elements such as optimal sensor type and placement. To allow manufacturers the flexibility to select the optimal location for a given model, it may be necessary to articulate standards in terms of principles and guidelines rather than specific locations and other requirements. Costs for maintenance and calibration of dedicated sensors could be reduced to an acceptable level by incorporating those routines as much as possible into existing automated vehicle diagnostic processes.

Deriving reliable, consistent weather information from existing vehicle systems presents a different suite of challenges. “Normal” atmospheric observations taken on many vehicles today to support engine operations (e.g., temperature and pressure) may not be representative of ambient conditions, may not be as accurate as needed for weather applications, and may not be calibrated to provide data in accepted units of measurement. “Observations” derived from vehicle operations—such as windshield wiper speed, fog light setting, and antilock brake operation—present different problems. There is no human standard for when to turn on and at what speed to operate windshield wipers, when to turn on fog lights, or how hard to brake in a given situation. Because this type of information could be made available quickly without deployment of new sensors, it is considered to be the “low-hanging fruit” of mobile weather sensing. However, it presents some very challenging calibration issues and may ultimately not provide consistent enough information for weather applications.

Human factors studies may be able to determine information concerning how the general population uses onboard systems in different situations (when people turn on lights, windshield wipers, etc.). However, advancements in vehicle technology, some of which are underway, may be needed to address these issues. For example, many vehicles now use ambient
light measurements to control when headlights are turned on. This takes the control out of the hands of the human and results in a more "standard" measurement of ambient light. These types of automated control processes used in other vehicle systems (windshield wipers, antilock braking, etc.) may standardize measurements of other operational parameters.

**Communications and data management barriers.** With the present coverage of cellular phones and growing availability of wireless data services, it is easy to assume that connectivity will be readily available to get mobile weather observations to the user. However, exploiting these technologies presents some challenges, as does processing and fusing the large amounts of data captured from vehicles to enable timely and reliable access for production of products. Recent changes to intelligent transportation system (ITS) strategy, exploiting the viability of secure dedicated short-range communication (DSRC) between vehicles without the support of roadside infrastructure may eliminate the planned nationwide, homogenous means of collecting weather observations from vehicles. This change would require use of non-DSRC communications pathways (e.g., cellular networks and Wi-Fi) and could lead to a patchwork of communications capability with more limited coverage. In addition, aggregating and processing data from a variety of collection systems would be more complicated than managing data from a comprehensive system of compatible communications nodes. In any case, managing the volume of data that could be provided by a robust deployment of sensing capability on vehicles presents significant challenges. Business activity involving mobile observations supporting highway maintenance activities and traffic estimation has increased significantly in recent years. However, data formats from the supported mobile platforms have remained unique to the individual businesses, and available data standards [e.g., National Transportation Communications for ITS Protocol (NTCIP) 1204] have not been broadly adopted by industry.

Establishing common protocols and data standards and formats would promote ease of use of the communications network. Exploration should begin now on using wireless communication technology that go beyond solely DSRC. Mobile weather observing should leverage the real-time data capture and management initiative of the U.S. Department of Transportation (USDOT) ITS program that will research ways to enable systematic data capture from vehicles and the integration of data from multiple sources.

**Fiscal barriers.** Today’s fiscal environment—characterized by federal deficit reduction, cuts at state and local levels to balance budgets, and external and self-imposed constraints on consumer spending—presents serious barriers to deploying vehicle-based wireless communication technologies on a meaningful scale. The cost of any changes made to automobiles to support mobile weather observing will almost certainly be passed on to the buyer of the automobile. Those costs could include new sensors, onboard capability to collect useful vehicle operations data that are already available, and the wireless communications capability. Ideally, these capabilities would become standard on all automobiles, but it seems unlikely in today’s economic environment that automobile manufacturers would willingly increase base costs for this purpose. Weather sensors/data collection/communications packages could be an option on automobiles for those who are willing to pay to participate, but such an approach would probably result in a limited number of equipped vehicles. Auto manufacturers are currently testing safety systems that include vehicle-to-vehicle communications involving wireless technologies, so it is likely that any weather-related data processing and dissemination would have to fit within the framework of these capabilities and add little, if any, additional cost.

Just as cellular phones have become a “necessity,” industry experts indicate that connectivity in vehicles will become a critical consumer buying influence within five years. If that happens as expected, it may be possible to leverage that connectivity. Pilot projects that demonstrate both the ability to collect, manage, and apply mobile observational data and to produce and supply useful decision assistance from those data may be crucial to broad deployment of observing capability on vehicles. In addition, it may be easier to justify mobile weather sensing in fleet operations, when the sensor data could be directly tied to a decision support system capability that would be designed to reduce overall operating costs. Innovative weather-oriented connected vehicle pilot projects could provide the best early opportunity to develop a solid business case showing the cost benefit of deploying and maintaining the infrastructure for mobile observations and for augmenting the database with sensor information from public vehicles.

**Institutional barriers.** Technical and fiscal barriers present significant challenges, but ways to overcome those barriers are available. Institutional barriers may be much more difficult to address because they are often associated with human or organizational behavior, neither of which is easy to change. Despite
the broad popular involvement in social media, a substantial portion of the population remains concerned about privacy. Those individuals would likely not want to have a device in their cars that reveals their location at any time. How detailed identifying information about the observing platform (other than its location) will be allowed by users is not clear, but it seems likely that there will be some requirement to identify the platform in some cases. Even the public perception of vehicle tracking in a connected system may result in public outcry and refusal to participate. In addition, widespread lack of understanding of overall benefits may also limit the public acceptance of a mobile weather observation program.

Cybersecurity is also a concern that impacts individual acceptance of mobile observations. A recent study by Koscher et al. (2010, p. 13) concluded that control systems in cars are “fragile and easily subverted.” At this time, physical access to communications ports is required to interfere with vehicle operations, so the lack of connectivity is a good thing. Widespread connectivity will require robust security to ensure safe operations.

The USDOT strategy of a connected vehicular network is by design mandating anonymous data collection, which should help to alleviate some privacy concerns. Cybersecurity could be enhanced by isolating the in-vehicle weather data collection system through strategic application of firewalls or separating outgoing weather data from incoming products and services. The USDOT in coordination with the VIIC has several robust technology teams addressing the privacy issue.

**Auto company and fleet concerns.** Automotive and fleet-oriented companies may determine that it is beneficial for them to use their vehicles as mobile weather observing platforms, either because data from those platforms can be used internally for decision making or because the data contribute to a broader effort to support external road weather applications that provide information that enhances the profitability of the business. However, it is not clear at this point that a sound business case can be built for either construct. In the first situation (internal use of data for decision making) the company has control over the variables, but may not have enough decision space to exploit the information to enhance profit. In the second situation (contribution to road weather applications) decision support products from external sources must provide the information necessary to consistently improve operations enough to fund the data collection effort.

To the extent that business interests may be leveraged to support deployment of mobile observing systems, issues of proprietary information and liability arise. Today, the distribution of some weather observations is limited to preserve the competitive advantage of the business taking and/or collecting the observations. Businesses may also face real or perceived liability risks in providing data from mobile observing platforms on a regular basis. Erroneous, late, or missing data could be cited in lawsuits as contributing to a harmful event, and those who routinely provide the data could become targets of litigation.

An analysis of legal precedent for weather information based on state Department of Transportation (DOT) road weather information systems (Klein and Pielke 2002) found no cases where lawsuits were pursued in court based on erroneous, late, or missing data. However, a study by the National Conference of State Legislators (Rall 2010, p. 15) found that “RWIS-related liability is a largely unexplored question of law, with few relevant precedents.” In any case, legal decisions related to state or federal government liability in this context may not provide useful insight into the liability a business may face in allowing the use of their mobile observations to support public decisions affecting highway safety.

**Weather enterprise concerns.** Management of highways and the traffic they carry involves a large number of active participants, including the federal government, states, counties, municipalities, and regional authorities. In addition, the immature nature of road weather management offers numerous opportunities for entrepreneurial innovation, opening the door for commercial entities with potentially unconventional approaches to deploying mobile weather sensors and managing and exploiting the data from those sensors. At this point, it is not clear that, with all the various participants with their differing needs and agendas, the mobile weather observing enterprise is manageable in the normal sense of the word. In any case, there is no overall authoritative vision for the deployment, operation, management, and governance of mobile weather observing capability, let alone a high-level strategy, concept of operations, or implementation plan.

The USDOT has provided some leadership to steer the road weather initiative in a consistent direction, and could lead efforts to articulate strategies and plans for implementation of mobile observations. However, without a mandate for direct control, industry, through its communication standards, holds
the greatest potential for moving the fledging mobile observation program in a coordinated direction.

**Research needs.** To provide a sharper focus on road weather understanding and applications, it will be important to define a rich set of research objectives permitting sustained growth in the value of mobile observations supporting road weather. These research areas will need to continue an affiliation with present connected vehicle-related nonmeteorological development efforts, but will also need to provide a focus on specific areas of meteorological interest. These areas include research on sensor design; sensor integration with vehicles; data communications and standards; data management and quality checking; interpretation of observed mobile data and proper assimilation methods for incorporation of mobile data with other observed and modeled data; and improved methods for information display and delivery, including an understanding of human factors associated with user interpretation. It is anticipated that research in the above-mentioned areas will yield direct benefits on the acquisition and utilization of mobile observations and also stimulate new research endeavors, further expanding the understanding of the physical nature of the roadway environment. This section presents a high-level description of current mobile observation research needs that should be addressed to foster an improved understanding of road weather and better apply road weather management strategies.

Sensor design research should include the following:

- Development of mobile sensors to provide reliable measurement of pavement state, including pavement temperature, detection of pavement condition relative to ice, water, and snow (including percent coverage per lane mile);
- Development of innovative yet cost-effective sensors providing additional atmospheric and pavement condition information, including parameters such as solar radiation and atmosphere and terrestrial longwave radiation, relative humidity, and precipitation detection;
- Refinement of sensors or diagnosis algorithms currently installed on vehicles that control how the car reacts to conditions on the roadways (active suspensions, antilock brakes, traction control, and stability control); and
- Development of imaging techniques to take advantage of vehicle cameras, which may be useful for diagnosing pavement conditions.

Sensor and vehicle integration research should include the following:

- Analyses to increase understanding of the best methods to integrate sensors on mobile platforms in order to optimize the quality of data, maximize the quantity of data observed, and minimize noise in the data while not impeding on driving/riding experience for the occupants; and
- Development of low power consumption processing units that collect and quality control data in an efficient manner so that data can be used by the vehicle computers and transmitted using the defined standardized communication technique.

Data communication and standards research should include the following:

- Continuation of current research into the use of wireless communications, including DSRC, cellular networks, and Wi-Fi is needed if an appropriate conduit for data retrieval from mobile platforms is to be achieved. The communication system is required to have adequate coverage areas including both urban and rural areas.
- As vendor-driven activities expand in the wireless communication area, the need for clear guidelines and standards on how the meteorological data are conveyed to the community will be necessary. Present ad hoc formats in use require anordinate amount of effort to discover and interpret data from systems that vary drastically from each manufacturer and model-to-model from the same manufacturer.

Data management and quality checking research should include the following:

- Expansion of the USDOT Clarus System (or its replacement), which ingests, quality checks, and disseminates state and local authority road weather sensor data, to handle and process mobile observations.
- Development and testing specialized data quality checking algorithms that are on the vehicle and on the data collection server end that address the unique data flows from mobile platforms. The potential volume of data and the diverse sources of these data present a major challenge for data management and distribution.
- Continuation of the development of the prototype vehicle data translator (Drobot et al. 2010) that will
provide a framework for developing, testing, and demonstrating the utility of quality checked and statistically processed vehicle datasets.

- Improvement of data mining methods to provide effective means of extracting desired features will be needed to maximize the value of mobile observations matched to user applications.
- Establishment of innovative connected vehicle test beds that cover large geographic regions (e.g., statewide scales) to support the development and testing of weather-related vehicle-enabled road weather products and services.

A growing concern by the weather enterprise is the manner by which end users receive and interpret information provided by the weather community. This challenge extends to the users of road weather information as indicated by recent studies conducted by the FHWA (FHWA 2010). Human factors research should be conducted to better understand and define ways to overcome the barriers associated with conveyance of road weather-related hazard information to users of the highway system.

**Data quality and metadata.** The need for metadata is vital to make the most of the connected vehicle environment. Researchers and operational personnel will want to know the characteristics of the sensors used and assess the data obtained from the vehicles to make informed decisions as to the utility and quality of the data. As fleets are instrumented with sensors, the broader weather and transportation communities need to know the standard environmental metadata such as sensor range, accuracy, and resolution, as well as the instrument metadata (e.g., model number, installation, and maintenance information) in order to run the full breadth of quality checks. Consequently, new metadata fields including vehicle type, location of sensors on the vehicle, sensor model, etc., should be included. Metadata dictionaries have been developed for Clarus that break out critical and optional metadata needs. A similar approach to developing mobile sensor metadata should be taken. Publishing any metadata concerning the vehicle has the additional concern of maintaining privacy to any private individuals or organizations allowing their fleets to transmit mobile observations.

Mobile observations and their utility will be new to many users. As such, given the potential number of observations transmitted using varying equipment packages, there has to be rigorous quality control and clear definition of the standards and protocols used for the data. Auto manufacturing standards and International Organization for Standardization (ISO) standards are being used in early fleet testing funded by NOAA (Bell and Heppner 2011). Likewise, intelligent transportation system and automobile manufacturing standards are currently being used in USDOT-related efforts. There must be more development of practical quality control algorithms to be used for mobile observations. These algorithms should be tested by researchers and manufacturers as the number of real-time mobile observations increases. Finally, the manufacturers, developers, and operators of the equipment need to inform the user communities about the details (respecting proprietary information) of equipment packages, sensors, and methods of quality control used for the collection and integration of mobile observations.

**Business models.** The mobile observation data system and the weather observations that it will provide will have both costs and benefits, and a business model is necessary to ensure that these costs and benefits are well understood, and shared by all. Since there are still many unanswered questions about a national connected vehicle communication infrastructure and its associated business model(s), this section is focused on the weather and road condition data themselves and how they could be captured, processed, and disseminated on a national scale. Weather data derived from mobile observation platforms will have intrinsic value. However, the real value will lie in the aggregation of thousands of pieces of data, which means that a business model must have a clear statement of goals. For example, the model should provide access to mobile observations for all users; ensure that the mobile observation system remains financially viable and stable enough to encourage continued use and investment; facilitate the creation of standards for the collection, communication, and dissemination of mobile observations; encourage the development of new products and services; and allow for healthy and fair competition among providers. There are several business models that could be successful in achieving the goals outlined above. These include government, public utility, and private network models.

**Government model.** The government model is one where government agencies would pay for the establishment and collection of mobile observations and then provide access to the public. In some instances, data use agreements would be required to protect sensitive or proprietary data. This is the current business model for the official observation network operated by NOAA. It is also the model demonstrated
by the FHWA’s Clarus research and development initiative whereby the state DOTs contributed data and the Clarus prototype system quality checked and disseminated the data to subscribers. This is a simple and well-understood business model, but it is only practical if the government assumes the full costs and responsibility for owning and operating the weather data collection system. A government model would ensure open access and usually financial stability, but may not allow for a lot of flexibility in setting or changing standards.

Public utility model. A public utility model would grant an exclusive monopoly to a company to establish and collect mobile observations, and charge a fee for their use, all under the oversight of an independent board or commission. The obvious examples of this type of business model are the telephone, electric, and gas utility companies. A public utility would ensure that standards are met and would have incentives to disseminate data, but not necessarily to keep costs at a minimum.

Private network model. An alternative to the public utility model is one where private companies would establish competing data collection systems, and would sell the mobile observations for whatever the market will bear. The closest analogy to this model is the cellular phone industry in the United States, where multiple companies operate duplicative networks. Private networks are extremely costly because of the duplication of network resources, but these costs are borne by outside investors, and shared among users of each network. There are no guaranteed standards in this model, and costs to individual users of the data can be hard to predict or control.

Public corporation model. Another option would be to set up a public not-for-profit corporation to operate a system that will collect and distribute mobile observations. Such a business model was the recommendation of the National Research Council (NRC) report “Observing Weather and Climate from the Ground Up—A National Network of Networks” (NRC 2009). In fact, this NRC report contains a complete discussion of business models for atmospheric data, as well as a very complete description of a public corporation model. The public corporation model is probably best suited to ensuring that all of the goals above are honored, but it is also the most problematic to set up, as it would have to be a new startup and would require legislative action.

Ultimately, the choice of the best business model for managing weather observations from mobile platforms will depend on the business and infrastructure model that is established for the overall national mobile observation data collection and dissemination system, as it will have to exist within this framework. The best choice will be the model that ensures access to all users, is financially stable enough to encourage continued investment and expansion of services, and facilitates data sharing.

SUMMARY REMARKS. Challenges and opportunities associated with the use of vehicle probe data in weather- and road condition–related applications for the weather and surface transportation communities were discussed by the committee and summarized herein. Specific findings and recommendations can be found in the full committee report (Mahoney and O’Sullivan 2011). Advancements in the diagnosis and prediction of adverse weather and road conditions could be quickly realized using data currently available from many vehicles, leading to improvements in road weather products. Moreover, technological improvements in the automotive industry will result in additional environmental and road-related data elements becoming available in the future. One of the most important aspects of this discussion is that a significant amount of research will be required to better understand vehicle-based data, as the characteristics of the data will vary greatly among vehicle manufacturers, vehicle models of the same manufacturer, and sensor types and models. It is unlikely that any single vehicle-based data element will be able to stand alone as “truth” as there will be too many uncertainties about its quality. Vehicle data will need to be processed in a statistical manner to address data outliers and to raise the overall confidence in data quality. Even with those caveats and concerns, the committee strongly believes that vehicle data will contribute in a positive manner to the generation of improved weather and road condition products because of the large volume of data, distribution of observations, and frequent updates.

Given the distributed jurisdictional nature and complexity of the national transportation system, there needs to be national leadership to move the mobile observation initiative forward. There are several ongoing USDOT-related research and development activities that are designed to explore the feasibility of utilizing vehicle-to-vehicle and vehicle-to-infrastructure communications to improve safety and mobility and the result of these projects will be used to develop the factual evidence needed to support
USDOT decision making regarding a 2013 National Highway Traffic Safety Administration (NHTSA) agency decision. Because of the substantial impact that vehicle-to-vehicle and vehicle-to-infrastructure technology could have on safety, NHTSA believes that this technology warrants consideration for possible regulatory action. According to the USDOT Research and Innovative Technology Administration (RITA), NHTSA has stated its intent to make an agency decision on vehicle-to-vehicle and vehicle-to-infrastructure safety communications systems by 2013 (USDOT 2012). Therefore, time is of essence for the weather community to participate in this dialog.

We hope that this discussion will be viewed positively by the weather and transportation communities and that it will be used to support the development of plans for research, development, and demonstration activities. To increase the likelihood that action will be taken to move the concept of a national mobile observation network forward, the committee recommends that the AMS community maintain an active role in the development of the mobile observation system and considers the recommendations put forth herein.

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REFERENCES


