

US-Japan Collaborative Research on Probe Data: Assessment Report

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Final Report — November 2013

Publication Number: FHWA-JPO-13-091



U.S. Department of Transportation
Research and Innovative Technology Administration

Produced by Noblis, Inc.
U.S. Department of Transportation
ITS Joint Program Office
Research and Innovative Technology Administration

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Technical Report Documentation Page

1. Report No. FHWA-JPO-13-091	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle US-Japan Collaborative Research on Probe Data: Assessment Report		5. Report Date November 2013	
		6. Performing Organization Code	
7. Author(s) Meenakshy Vasudevan and Amy Jacobi (Noblis); Gene McHale (FHWA R&D), and Dale Thompson (RITA ITS JPO); Koichi Sakai, Ryoichi Watanabe, and Yoshihiro Tanaka (MLIT/NILIM).		8. Performing Organization Report No.	
9. Performing Organization Name And Address Noblis, Inc., 600 Maryland Ave, SW, Suite 755, Washington, DC 20024 National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Japan		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTFH61-11-D-00018	
12. Sponsoring Agency Name and Address ITS-Joint Program Office Research and Innovative Technology Administration 1200 New Jersey Avenue, S.E. Washington, DC 20590		13. Type of Report and Period Covered Probe Data Assessment Report	
		14. Sponsoring Agency Code HOIT-1	
15. Supplementary Notes			
16. Abstract The United States (US) Department of Transportation (USDOT) and the Road Bureau of Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan have a long history of sharing information on ITS (Intelligent Transportation Systems) activities. A US-Japan ITS Task Force was established specifically to facilitate the exchange information and identify areas for collaborative research for the development and deployment of ITS in the US and Japan. The Task Force identified the following four high-priority areas for conducting collaborative research: 1. International Standards 2. Evaluation Tools and Methods 3. Probe Data 4. Automation in Road Transport This report summarizes the collaborative research effort in the "probe data" high-priority area. Through this effort the Task Force has: <ul style="list-style-type: none"> • Jointly developed a high-level definition of probe data to help define the scope of the project, and to identify technologies and systems that deliver these data • Shared data and research findings, experiences, and lessons learned from development and deployment of probe-data enabled applications and probe data systems • Jointly identified 19 applications that may be developed using probe data as defined by the US-Japan ITS Task Force • Prioritized three applications of mutual interest for future collaboration 			
17. Key Words Probe data, probe systems, cooperative systems, connected vehicle, ITS Spot, BSM, mobility, environmental, weather		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 128	22. Price

Preface/Acknowledgements

The authors wish to acknowledge several contributors to this study:

US-Japan Probe Data Research Key Content Review Team: Steve Beningo (RITA/BTS), Brian Cronin (RITA/ITS JPO), and James Pol (RITA/ITS JPO), for their review and comments.

Marcia Pincus (RITA/ITS JPO), for a summary of AERIS applications, and review.

Gabe Guevara (FHWA), for a review of the weather data and applications.

Walt Fehr (RITA/ITS JPO), Greg Krueger (SAIC), and Ayeshah Abuelhiga (SAIC), for information on the connected vehicle testbeds, and review.

Sponsors of the Noblis Task: Kate Hartman (RITA/ITS JPO) and Brian Cronin (RITA/ITS JPO), for their support.

Noblis: Karl Wunderlich for his review, JD Schneeberger for a summary of the AERIS applications, and Taylor Sandelius, Drennan Hicks and Aretha Howard for 508-conversion.

Yasuhiro Okumura (MLIT), Takashi Nishio (MLIT), Masahiro Nishikawa (MLIT), Fumihiko Kanazawa (MLIT/NILIM), for their review and comments.

Yasuyuki Sawada (MLIT/NILIM), and Satoru Nakamura (MLIT/NILIM), for a review of probe systems, probe data, and probe data enabled applications in Japan.

Takahiro Tsukiji (MLIT/NILIM), Ken Iwasaki (MLIT/NILIM) and Shingo Mawatari (MLIT/NILIM) for their support.

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Executive Summary

The United States (US) Department of Transportation (USDOT) and the Road Bureau of Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan have a long history of sharing information on ITS (Intelligent Transportation Systems) activities. A US-Japan ITS Task Force was established specifically to facilitate the exchange information and identify areas for collaborative research for the development and deployment of ITS in the US and Japan. The Task Force identified the following four high-priority areas for conducting collaborative research:

1. International Standards
2. Evaluation Tools and Methods
3. Probe Data
4. Automation in Road Transport

This report summarizes the collaborative research effort in the “probe data” high-priority area. Through this effort the Task Force has:

- Jointly developed a high-level definition of probe data to help define the scope of the project, and to identify technologies and systems that deliver these data
- Shared data and research findings, experiences, and lessons learned from development and deployment of probe-data enabled applications and probe data systems
- Jointly identified 19 applications that may be developed using probe data as defined by the US-Japan ITS Task Force
- Prioritized three applications of mutual interest for future collaboration

The next steps for future collaboration on probe data include:

- Expand probe data collaboration from a bi-lateral to a tri-lateral effort with European Union (EU) as the new partner
- Conduct research on the three high-priority applications identified jointly by US and Japan
- Identify and prioritize research gaps for future collaboration
- Address and refine cross-cutting issues related to probe data such as standards, security, privacy, quality assurance, metadata, storage and access, and data ownership and intellectual property rights (IPR)

1 Introduction

The United States (US) Department of Transportation (USDOT) and the Road Bureau of Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan have a long history of sharing information on ITS (Intelligent Transportation Systems) activities. This information sharing includes an annual US-Japan ITS Workshop held in conjunction with the ITS World Congress. Building on this relationship, the USDOT and the MLIT signed a Memorandum of Cooperation in 2010 to promote bilateral collaboration in the field of ITS, especially cooperative systems. This Memorandum aims to enhance cooperation between both agencies and further the development and implementation of global ITS activities. The agencies formed a US-Japan ITS Task Force to exchange information and identify the areas for collaborative research to foster the development and deployment of ITS in both the US and Japan. The Task Force identified the following four high-priority areas:

1. International Standards
2. Evaluation Tools and Methods
3. Probe Data
4. Automation in Road Transport

This document summarizes the collaborative research effort in the “probe data” high-priority area. The USDOT and MLIT are promoting research and development (R&D) and deployment of cooperative systems. As part of this effort, the USDOT and MLIT are engaged in conceptualizing probe data systems, which capture and gather vehicle data, and generate a wide range of information related to road traffic for use by public sector transportation systems management. The private sector has already made significant strides in capture and use of probe data, primarily for traveler information dissemination and fleet management. For example, in Japan, automobile manufacturers use vehicle telematics to generate road traffic information.

Probe data affords the potential to develop transformative applications that can improve roadway operations (e.g., overweight vehicle monitoring, traffic signal timing, queue warning, curve speed warning); planning, and maintenance based on traffic conditions (e.g., work zone planning and management); and inform travelers of travel conditions (e.g., public transit information, travel time information). In addition to probe data from vehicles, data may also be collected from mobile devices, such as smart phones, wherein travelers act as “probes.”

2 Research Purpose

As a part of the probe data collaborative research, the US-Japan ITS Task Force has:

- Jointly developed a high-level definition of probe data to help define the scope of the project, and to identify technologies and systems that deliver these data;
- Shared data, research findings, experiences, and lessons learned from the development and deployment of probe-data enabled applications and probe data systems;
- Jointly identified 19 applications that may be developed using probe data as defined by the US-Japan ITS Task Force; and
- Prioritized three applications of mutual interest for future collaboration.

The result of this research effort will help identify the future direction of research, development, and deployment of cooperative systems in the US and Japan.

3 Research Outcomes

MLIT has been conducting probe data research and development in Japan to enhance the efficiency of road administration, including traffic surveying, road management and program/project evaluations, through utilizing probe data. USDOT has been conducting connected vehicle research to explore the potentially transformative capabilities of wireless technologies to make surface transportation safer, smarter, greener, and enhance livability in the US. The US-Japan ITS Task Force envisions significant benefits through the probe data collaborative research effort between USDOT and MLIT. The expected research outcomes include:

- Promotion of probe data research and development in both the U.S. and Japan through the mutual exchange of information on advanced approaches to probe data;
- Reduced costs for research, development, and testing of applications through shared experiences and collaborative/coordinated research;
- Expedited or immediate transferability of lessons learned from the Japanese experience in the US and vice versa;
- Increased understanding and quantification of prospective benefits of deployments similar to Japan's ITS Spot for sharing with domestic public and private sector partners (e.g., original equipment manufacturers) in the US;
- Global marketability of products due to consistency and compatibility of data, probe systems, technology, and practices, and harmonization of data standards;
- Sustained global competitiveness for auto manufacturers and device makers; and
- Availability of effective strategies that improve roadway operations, planning, and maintenance, provide better traveler information than what is currently available, and mitigate negative environmental impacts.

4 Probe Data Definition and Scope of Research

This chapter provides a high-level definition of probe data for purposes of this collaborative research. Probe data are data generated by vehicles (light, transit, and freight vehicles) about their current position, motion, and time stamp. Probe data also include additional data elements provided by vehicles that have added intelligence to detect traction information, brake status, hard braking, flat tire, activation of emergency lights, anti-lock brake status, air bag deployment status, windshield wiper status, etc. Probe data from vehicles may be generated by devices integrated with the vehicles' computers, or nomadic devices brought in to the vehicles.

Probe data does not include data that have been derived outside of the vehicle, even if these data were aggregated from data generated by vehicles. For example, travel times that are derived from position and motion data are not classified as probe data.

Probe data may be transmitted at various frequencies (i.e., every 10th of second, every 1 minute, whenever a vehicle enters a roadside Dedicated Short Range Communication (DSRC) communication area, whenever an event is triggered, etc.), using a range of wireless communication technologies, including DSRC, cellular, Wi-Fi, WiMAX, etc.

Figure 4-1 illustrates a high-level scope of the probe data that is included in this research effort. The figure shows illustrative examples of applications that may be examined under this research effort. The high-level scope was developed jointly by USDOT and MLIT at the Task Force meeting in November 2011 and revised based on a meeting on January 25, 2012. Probe data from vehicles will be processed, cleaned, and aggregated to generate information required by the applications. For example, probe data from vehicles may be used for a traveler information application. Instantaneous location and speed data collected from multiple vehicles that act as probes (blue box), will be cleaned and aggregated (yellow box) to generate link travel times (green box). In parallel, probe data from vehicles will also be used to generate origin-destination information (demand). The origin-destination information and link travel times will be used by the traveler information application to generate guidance on mode, route, and departure times (purple box), which will then be displayed on congestion maps, transmitted to vehicles for in-vehicle display, and transmitted to travelers on their personal communication devices (salmon box).

The collaborative research effort documented in this report will focus only on applications that can be developed using public sector probe data that are generated by vehicles, i.e., by devices that are integrated with the vehicles' system or by nomadic devices brought in to the vehicle. At this stage, data from external sensors (e.g., weather stations), transit and freight-specific data (e.g., transit schedules, truck loads), private sector probe data, and data from travelers' personal communication devices are outside the scope of this report. This report will focus on applications that can be developed using probe data that are within the scope.

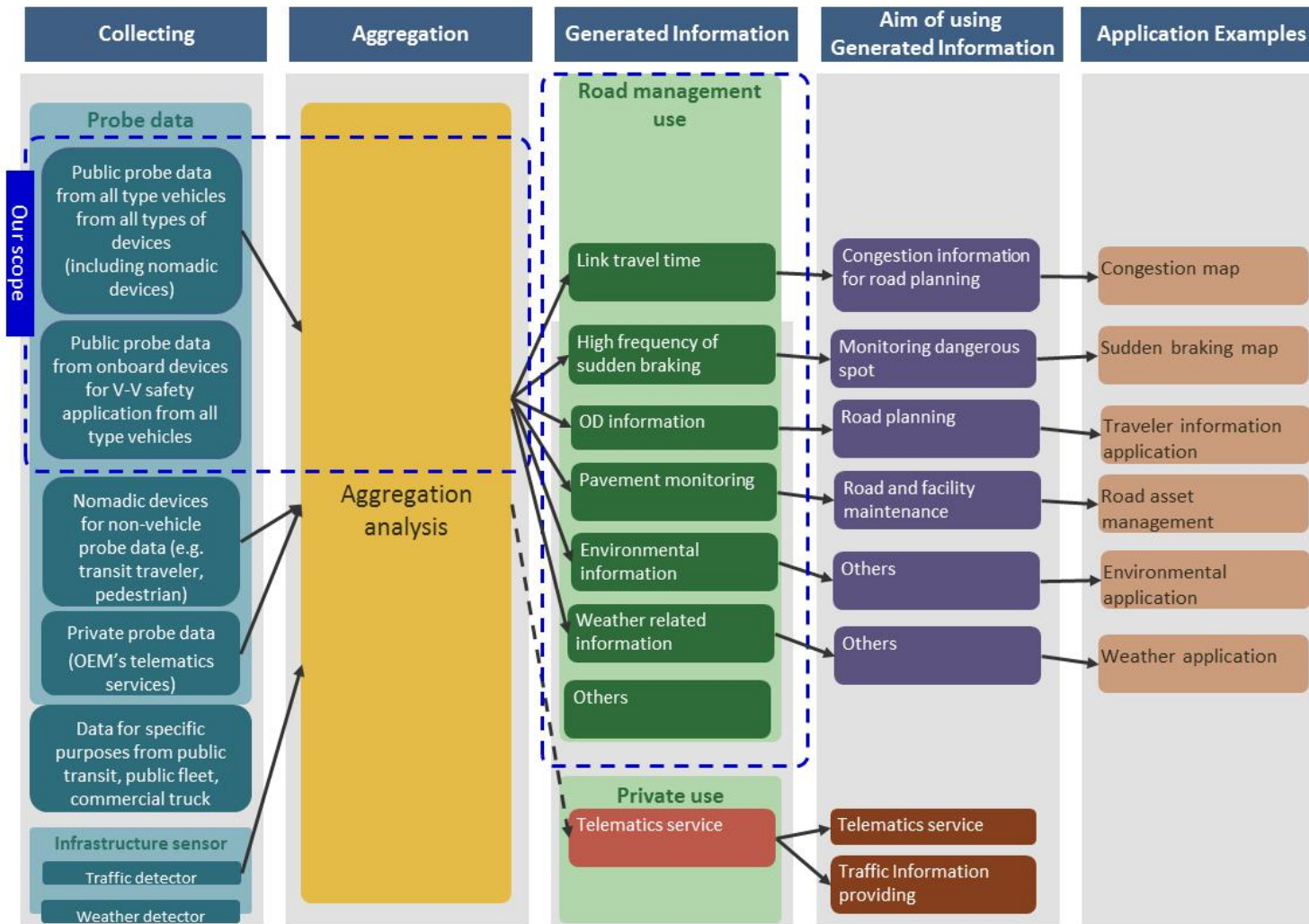


Figure 4-1. US-Japan Probe Data Scope

5 Summary of Probe Systems

This chapter summarizes the current status of research and development (R&D) efforts and deployments of probe systems by the public and private sectors in the US and Japan.

5.1 Summary of Probe Systems in the US

5.1.1 Assessment of Research, Development, and Deployment of Connected Vehicle Systems in the US

This section summarizes the results of a scan of R&D and deployments of public sector-sponsored *connected vehicle systems* in the US.

The USDOT initiated the connected vehicle research program to explore the potentially transformative capabilities of wireless technologies to make surface transportation safer, smarter, greener, and enhance livability for Americans. The connected vehicle research program is a multi-modal research initiative that aims to create safe, interoperable connectivity between vehicles (automobiles, trucks, motor coaches, transit vehicles, and other fleets), infrastructure, and travelers' communication devices. The components of a connected vehicle system are [1]:

- Applications that provide the functionality to realize safety, mobility, and environmental benefits;
- Core Systems, which provide the functionality needed to enable data exchange between and among mobile (e.g., vehicles, travelers' communication devices) and fixed transportation (e.g., signal controllers, roadside equipment (RSE)) users;
- Communications (wireless and wire line), which facilitate the data exchange; and
- Support systems, including security credentials certificate and registration authorities that allow devices and systems to establish trust relationships.

Multiple Core Systems will be deployed and managed regionally, but will follow national standards to ensure that they are compatible and interoperable. Figure 5-1[2] illustrates the context in which a Core System resides, including the major entities:

- *Field*: Roadside Equipment (RSE), sensors, controllers and other devices capable of communicating via a Core System;
- *Mobile devices*: All vehicle platforms and portable devices carried by travelers; and
- *Centers*: Public and commercial transportation or non-transportation systems.

Connected vehicle safety applications rely on Basic Safety Message (BSM), which is one of the messages defined in the Society of Automotive Engineers (SAE) standard J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary, November 2009. BSM is one of the messages within the J2735 standard, which also includes Signal Phase and Timing (SPaT), Map Data, etc. The J2735 standard may also be used by forms of communications technology other than DSRC, such as 3G cellular.

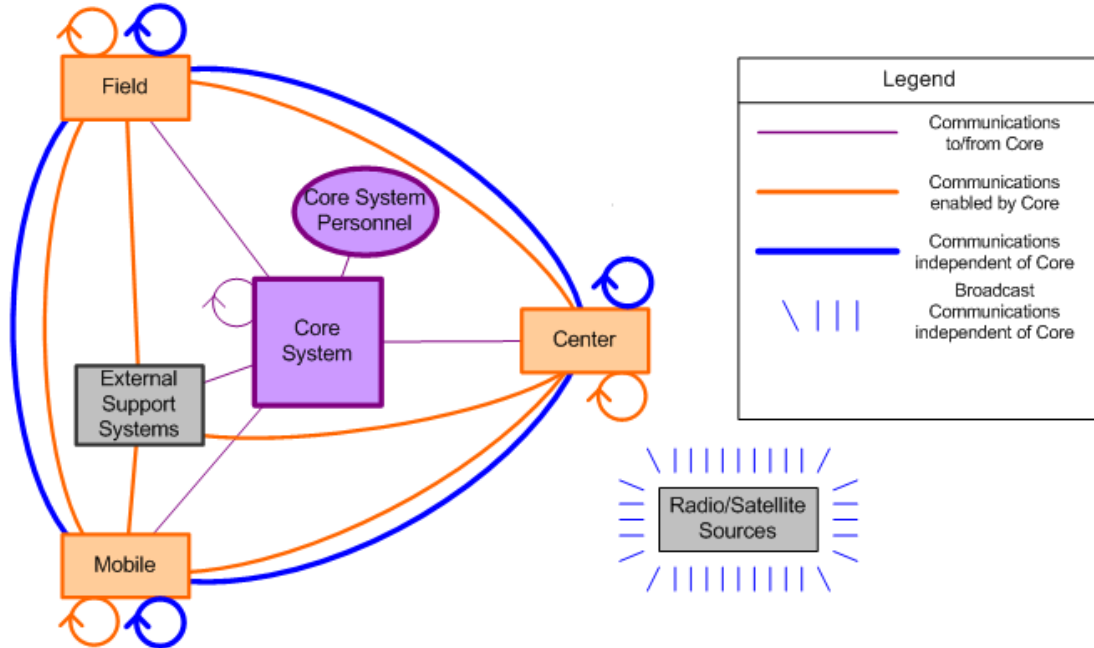


Figure 5-1. Core System Context Diagram (Source: USDOT)

The BSM is broadcast from vehicles over the 5.9 GHz DSRC band. Transmission range is in the order of 1,000 meters. The BSM consists of two parts:

- BSM Part 1 contains core data elements, including vehicle position (longitude, latitude, elevation, position accuracy), motion (speed, heading, acceleration), control (status of brake, traction control, stability control, ABS, Brake Boost, and Auxiliary Brake), and size (vehicle length, vehicle width). BSM Part 1 is designed to be transmitted at an adjustable rate of about 10 times per second and current research in the US is focused on a transmission rate of 10 times per second.
- BSM Part 2 contains a variable set of data elements drawn from an extensive list of optional elements. They are added to Part 1 and sent as part of the BSM message, but are transmitted less frequently in order to conserve bandwidth. BSM Part 2 consists of two message structures: vehicle safety extension and vehicle status.
 - Vehicle safety extension is used to transmit:
 - information about events as they occur, such as hard braking, flat tire, or activation of emergency response status, anti-lock brakes, air bag deployment, windshield wipers, etc.;
 - information about the vehicle's immediate past trajectory; projections for the near-future trajectory; and
 - GPS corrections.
 - Vehicle status is used to transmit:
 - status of vehicle systems (wiper status, light status, braking status);
 - environmental sensor readings;
 - confidence values for vehicle-based values;
 - road obstacle detection values;
 - vehicle physical dimensions;

- vehicle identification and description information;
- detailed physical information for trucks; and
- GPS quality.

Some of the data elements in the vehicle status are duplicates of Part 1 data elements.

BSM Part 1 that is broadcast 10 times per second via DSRC is critical to safety applications. However, BSM Part 1 does not provide all of the data needed for mobility or environmental applications, which also require data from travelers and the infrastructure. BSM Part 1 and Part 2 together can support some of the mobility and environmental applications. However, transmitting BSM Part 1 and Part 2 every tenth of a second via DSRC will overload the bandwidth, and is unnecessary. Moreover, due to the large number of RSEs that will need to be deployed, DSRC is not a feasible option for complete roadway coverage. Hence, the USDOT is examining both DSRC and non-DSRC technologies (e.g., cellular, Wi-Fi) as a means of providing an open connected vehicle platform to support safety, mobility, and environmental applications.

Figure 5-2 illustrates one instantiation of the data exchange in a connected vehicle system. In this figure, vehicles broadcast BSM Part 1 every tenth of a second, and receive BSM Part 1 generated by other vehicles in the vicinity. Whenever an event is triggered, some elements of Part 2 are generated and broadcast. When a vehicle comes within range of an RSE, broadcast BSM are received by the RSE, which then sends the messages via a backhaul network (either wireless or wireline) to the back office or center. Applications residing at the back office or center process the data and send information back to the RSE for broadcast to vehicles. The RSE broadcasts the information to vehicles that are in range. If the RSE is integrated with a traffic signal controller then SPaT information is also sent to the vehicles.

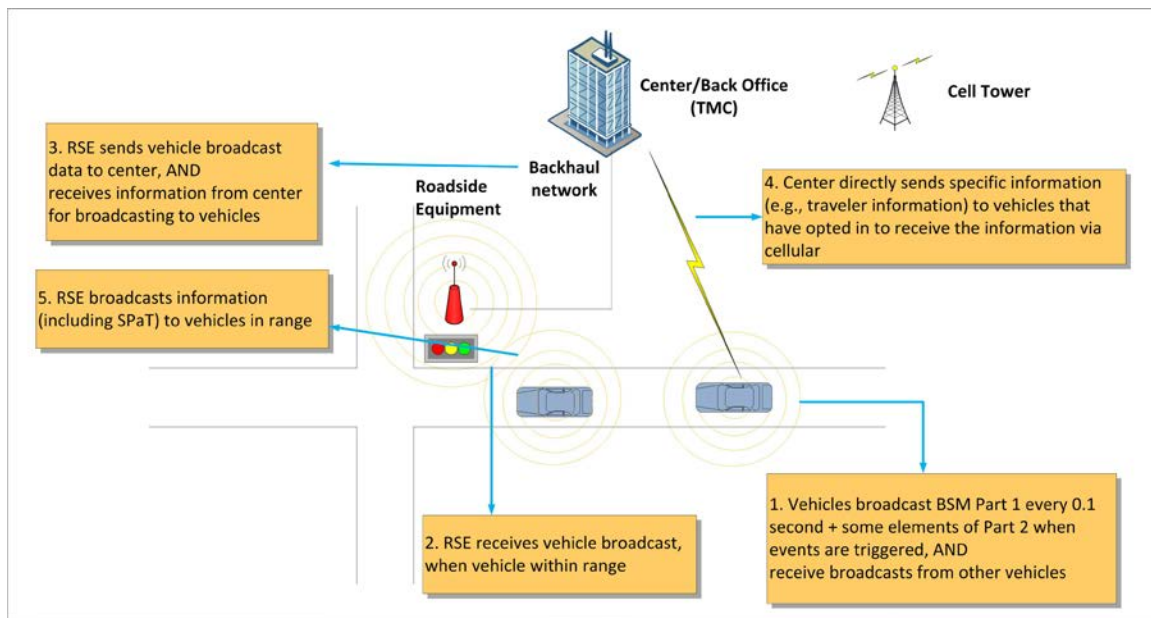


Figure 5-2. An Example Data Exchange in a Connected Vehicle System

5.1.1.1 Connected Vehicle Test Beds

The Connected Vehicle Test Beds in Michigan (5.1.1.1.1), in Virginia at the Turner-Fairbank Highway Research Centers (TFHRC)(5.1.1.1.2), California (5.1.1.1.3), Florida (5.1.1.1.4), New York (5.1.1.1.5), Minnesota (5.1.1.1.6), and Maricopa County (5.1.1.1.7) are real-world, operational Test Beds that offer the supporting vehicles, infrastructure, and equipment to serve the needs of public and private sector testing and certification activities (Figure 5- 3,[2]). The vision for the Test Beds is to establish multiple locations as part of a connected system that can support research, testing, and demonstration of connected vehicle concepts, standards, applications, and innovative technologies and products. Test environments will also serve as precursors or foundations for state and local deployments using connected vehicle technologies.



Figure 5-3. Connected Vehicle Test Beds (Source: USDOT)

5.1.1.1.1 Michigan Connected Vehicle Test Bed

Purpose

The Connected Vehicle Test Bed in Michigan allows researchers the capability to test safety, mobility, and environmental applications, services, and components in a robust and secure connected vehicle environment. The Test Bed can accommodate third party applications, a range of on-board equipment, and a variety of vehicle types [2].

Summary

In 2005, the USDOT initiated the development and test of the Vehicle Infrastructure Integration (VII) proof-of-concept (POC), which made use of 5.9 GHz dedicated short-range communications (DSRC) [3][4]. The POC was implemented in the northwest suburbs of the Detroit, Michigan. In 2010, the USDOT launched the upgrade of the POC test site to become the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Test Bed for conducting connected vehicle research. The Test Bed was centered in the cities of Novi, Farmington, Farmington Hills, and Livonia with expansion into Southfield, and covered 116.5 square kilometers (45 square miles), comprising 120.7 center-line kilometers (75 miles) made up of 32 kilometers (51.5 miles) of Interstate and divided highways, and 69.2 kilometers (43 miles) of arterials (Figure 5-4).

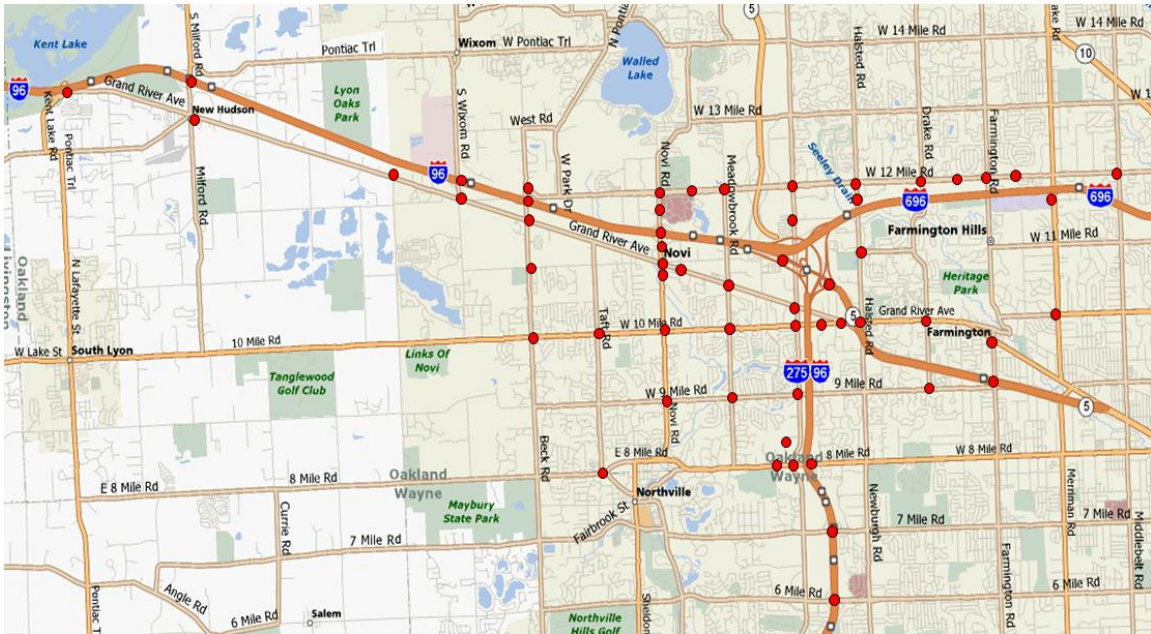


Figure 5-4. Michigan 2010 V2V and V2I Test Bed (Source: USDOT)

In 2012, the Connected Vehicle Test Bed consisted of a network of 50 Roadside Equipment (RSE) installed along the most used corridors of live interstate roadways, arterials, and signalized and unsignalized intersections, in Novi, Michigan (Figure 5-5). The Test Bed includes three key subsystems [2]:

- On Board Equipment (OBE) – this component is installed in test vehicles to communicate with the infrastructure (V2I) and other vehicles (V2V);
- Road Side Equipment (RSE) – this component is installed along the roadside, and specifically includes the wireless equipment necessary for vehicle to infrastructure (V2I) communications, as well as the network interlink; and
- Network Subsystem – this component is the backhaul network necessary to connect roadside devices to one another and to connect roadside devices to the various central processing locations.



Figure 5-5. Michigan 2012 Connected Vehicle Test Bed (Source: USDOT)

The RSEs are connected via one of the three backhaul communications (WiMAX, Wireline, or 3G) to a back office data center. Each RSE has a Dedicated Short Range Communications (DSRC) gateway to enable the RSEs to communicate with DSRC-equipped vehicles. The USDOT has 10 vehicles outfitted with onboard equipment (OBEs), including DSRC radios which are available for testing purposes. The Test Bed is also equipped with 22 RSEs with Signal Phase and Timing (SPaT) and Geometric Intersection Description (GID) along Telegraph Road.

The Test Bed supports the following services [2]:

- *In-Vehicle Signage:* In-vehicle messages can be displayed to provide traveler services. Back office servers can transmit messages received from other applications to the appropriate RSE, which can then broadcast the information to the vehicles. The broadcast information, when received by an OBE installed on a vehicle, is displayed when the vehicle enters a geographic area or at appropriate locations or times.
- *Signal Phase and Timing (SPaT) Services:* The RSE can be integrated with a traffic signal controller and transmit signal phase and timing data to OBE-equipped vehicles.
- *V2I Communication Services:* The OBE can connect through an RSE to the Internet to receive or transmit data to other systems while connected.
- *V2V Communication Services:* The OBE can broadcast basic safety messages (BSM) to other vehicles and receive those broadcast from other vehicles.
- *RSE application hosting:* Additional applications can be installed on the RSE and integrated with the DSRC communications. These applications can reach back through the network to reach internal and external components for added functionality.
- *Equipment Testing:* Testing equipment such as vehicle awareness devices (VADs), aftermarket safety devices (ASDs), in-vehicle safety devices (ISDs), radios, and roadside equipment (RSEs).
- *Security Certificate Credential Management (SCMS):* The Test Bed SCMS provides developers with the assurance that their system can obtain properly formatted 1609 Certificates.

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

Data generated are compliant with the Society of Automotive Engineers (SAE) J2735 standard.

Storage

Data that are generated by tests conducted at the Test Bed are stored by the Test Bed manager until the test conductor determines the data were collected to their satisfaction, at which point the data are no longer stored by the Test Bed manager. Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement. A subset of the data may be anonymized and made available for research through the Data Capture and Management (DCM) Research Data Exchange (RDE).

Sponsor Agency

The USDOT partnered with Michigan Department of Transportation (MDOT), and Road Commission of Oakland County (RCOC) to sponsor the development of the Test Bed. USDOT funded the acquisition of the RSEs and 10 vehicles with OBEs.

Ownership and Intellectual Property Rights (IPR)

The USDOT owns the Test Bed hardware and software.

Information on the IPR for the probe system and accompanying software is not publicly available.

Information on data ownership is not clearly identified. It is also unknown who will be responsible for verifying the data quality and anonymizing the data (e.g., removal of personally identifiable information (PII) from the data).

Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement. A subset of the data may be anonymized and made available for research through the DCM RDE.

Cost

The cost of using the Test Bed for conducting small-scale connected vehicle research is limited to just the cost for the drivers, if paid drivers are needed to conduct the tests. Data will be made available at no cost, and equipment may be loaned at USDOT's discretion. For larger-scale tests, there might be additional cost for monitoring the system.

5.1.1.1.2 TFHRC Connected Vehicle Test Bed

Purpose

The TFHRC Test Bed will enable FHWA to explore technologies that enable connected traveler-vehicle-infrastructure communications and applications, and to assess the potential of new transportation services based upon cooperative communication [5].

Summary

The Cooperative Vehicle-Highway Test Bed (Figure 5-6), which is located at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center in McLean, Virginia, is one of the affiliated test beds. TFHRC Test Bed is equipped with two RSEs and two vehicles outfitted with OBEs. FHWA is in the process of procuring three additional vehicles for the Test Bed. Furthermore, the Test Bed may be expanded in the future through partnerships with state and local agencies. Data collected at the Intelligent Intersection are transmitted to the Indoor Laboratory via a fiber-link connection.



Figure 5-6. TFHRC's Cooperative Vehicle Highway Test Bed (CVHT) Intelligent Intersection (Source: Turner-Fairbank Highway Research Center, FHWA)

Security

Information on how security is handled is not publicly available.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

Data-generated are compliant with the SAE J2735 standards.

Storage

Data that are generated by tests conducted at the Test Bed are stored by the Test Bed manager. Data from tests that are federally sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement. A subset of the data may be anonymized and made available for research through the DCM RDE.

Sponsor Agency

The USDOT sponsored the development of the Test Bed and acquisition of the two RSEs and two vehicles with OBEs.

Ownership and Intellectual Property Rights (IPR)

The USDOT owns the Test Bed hardware and software.

Information on the IPR for the probe system and accompanying software is not publicly available.

Information on data ownership is not clearly identified. It is also unknown who will be responsible for verifying the data quality and anonymizing the data (e.g., removal of PII from the data).

Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement. A subset of the data may be anonymized and made available for research through the DCM RDE.

Cost

Information on the cost associated with using the Test Bed for conducting connected vehicle research is not publicly available.

5.1.1.1.3 California Connected Vehicle Test Bed

Purpose

The California Test Bed was implemented to inform state and regional stakeholders on the value of connected vehicles in the San Francisco Bay Area, and to serve as a test site for connected vehicle applications development and testing [6].

Summary

The California Test Bed was launched in 2005 by Partners for Advanced Transit and Highways (PATH) under the sponsorship of California Department of Transportation (Caltrans) and the Metropolitan Transportation Commission's (MTC) VII (Vehicle Infrastructure Integration) California program to conduct driving studies, prototype infrastructure interfaces, and test communication interferences (e.g., the impact of "urban canyon effect"). In 2008, as part of its SafeTrip-21 Initiative, the USDOT entered into a cooperative agreement with Caltrans to make the San Francisco Bay Area the first SafeTrip-21 field test site [7]. Under this agreement, the Test Bed is also being re-vitalized to continue to conduct connected vehicle research. The USDOT and the Cooperative Transportation System Pooled Fund Study (CTS PFS) have selected the California Test Bed as one of the sites (the other being the Maricopa County Connected Vehicle Test Bed in Arizona) to develop and test a Multi-Modal Intelligent Traffic Signal System, which is one of the high-priority connected vehicle application identified by USDOT's Dynamic Mobility Applications (DMA) Program.

The California Test Bed includes 96.6 kilometers (60 miles) of highways, comprising three parallel, 32.2-kilometers (20-miles) long North-South highways of US 101, SR 82 (El Camino Real), and I-280 [8]. The VII California infrastructure includes three main components:

- RSEs that communicate with the vehicles using DSRC,
- Backhaul network that transports data to and from the RSE and a central location, and
- Computer server that stores the traffic data from the cars and sends messages to the driver.

The Test Bed includes 40 RSEs along freeways and at intersections. The backhaul communications can be wireless (3G, WiMAX, Wi-Fi) or wired (T1 lines). There are two back end servers, one at the 511 Traffic Information Center in Oakland, and one at PATH in Richmond [6].

5.1.1.1.4 Florida Connected Vehicle Test Bed

Purpose

The Florida Test Bed was implemented to demonstrate the connected vehicle initiative in Orlando, Florida, during the 18th Intelligent Transportation Systems (ITS) World Congress in October 2011[9]. The USDOT Test has entered into an agreement with Florida Department of Transportation (FDOT) to continue the operation of the Test Bed for connected vehicle research and testing.

Summary

The Florida Test Bed was launched by FDOT, its partners, and USDOT to demonstrate the connected vehicle initiative during the 18th ITS World Congress in Orlando, Florida. The FDOT Test Bed is the only transportation management center-based operational test bed in the US. As part of the demonstration, FDOT deployed 29 RSEs along 40.2336 kilometers (25 miles) of Interstate 4, International Drive, and John Young Parkway (Figure 5-7). The RSEs are connected to FDOT's District Five SunGuide® advanced transportation management software through the District's fiber optic network. FDOT deployed 42 vehicle awareness devices in 10 Lynx transit vehicles, 17 I-Ride Trolley buses, 5 FDOT vehicles, and 10 demonstrator vehicles and 2 OBEs [10]. The RSEs receive basic safety messages from the vehicle awareness devices and probe data messages from the OBEs. The RSEs send the data to the SunGuide® software, and receive travel advisory messages

(e.g., incident ahead, amber alerts) from the SunGuide® software. The RSEs then broadcast the advisory messages to vehicles with OBEs that are in the designated area.

As part of an agreement between FDOT and USDOT, FDOT continues to operate the Test Bed following the conclusion of the World Congress. The RSE infrastructure remains in place receiving basic safety messages and probe data messages from vehicles and sending them to the SunGuide® software, and transmitting travel advisory messages created and sent by the SunGuide® software [11]. The USDOT is working with FDOT to establish a data sharing agreement to acquire data captured during the World Congress as well as data currently being generated at the Test Bed [12].

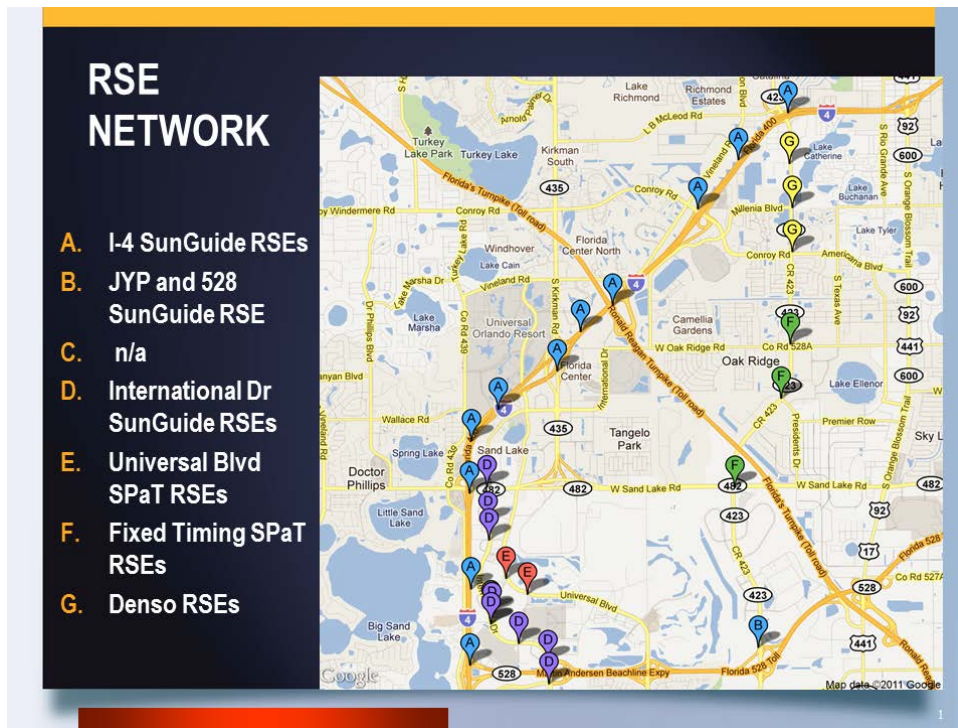


Figure 5-7. Florida Test Bed RSE Coverage (Source: FDOT)

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

Data generated are compliant with the SAE J2735 standard.

Storage

Data that are generated by tests conducted at the Test Bed are archived by FDOT's SunGuide® system. Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement with FDOT. A subset of the data may be anonymized and made available for research through the DCM RDE.

Sponsor Agency

The Test Bed is jointly sponsored by the USDOT, FDOT, Orange County, the City of Orlando and other local agencies in the Central Florida region.

Ownership and Intellectual Property Rights (IPR)

FDOT, and its partners, own the in-vehicle devices and the software. USDOT owns the RSEs.

Information on the IPR for the probe system and accompanying software is not publicly available.

Information on data ownership is not clearly identified. It is also unknown who will be responsible for verifying the data quality, and anonymizing the data (e.g., removal of PII from the data).

Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement with FDOT. A subset of the data may be anonymized and made available for research through the DCM RDE.

Cost

Information on the cost associated with using the Test Bed for conducting connected vehicle research is not publicly available.

5.1.1.1.5 New York Connected Vehicle Test Bed

Purpose

The New York Connected Vehicle Test Bed was implemented to leverage existing investments to expand development, deployment, testing and operations of connected vehicle technology, with a focus on (i) improved, quality, quantity and timeliness of transportation related data and information, and (ii) explore and assess the crash avoidance capabilities [13].

Summary

The Test Bed covers Long Island's Northern and Southern corridors, consisting of the island's major east-west highways and their busiest north-south connecting routes, including the Long Island Expressway (LIE/I-495), Northern State Parkway (NSP) and Southern State Parkway (SSP).

Thirty one RSEs are deployed along the Interstate, and eight at traffic signals. Most of the first generation RSEs are co-located with existing traffic monitoring equipment, and are installed on poles, and connected to fiber. The Test Bed includes one standalone enhanced e-screening site with two

RSEs, and one standalone CVII (Commercial Vehicle Infrastructure Integration) testing with one RSE. There are four plow trucks retrofitted with DSRC-based OBE devices, and 20 aftermarket devices.

The short term goal of the New York Test Bed is to advance the research and development of heavy vehicles (trucks, buses, and maintenance vehicles) with connected vehicle technology; and support development of aftermarket 5.9 GHz DSRC devices. The Test Bed has been used to develop, install, and test commercial vehicle OBE system and driver interface with in-vehicle signage and traveler information; wireless vehicle safety inspection (brake condition, tire pressure, light status, etc.) of commercial vehicles; and maintenance communication. The Test Bed was also used to develop and test grade crossing driver warnings, heavy vehicle to light vehicle driver safety warnings (hard braking, tailgate warning, blind spot, and unsafe pass and merge).

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

The Test Bed conforms to the existing connected vehicle standards including 1609 and 802.11, except for the RSEs. NYSDOT will upgrade the RSEs to meet existing requirements.

Storage

Data collected will include probe, road weather, vehicle/fleet, and inspection data. However, it is unknown if the data will be stored.

Sponsor Agency

The Test Bed is sponsored by New York State Department of Transportation (NYSDOT), and its partners, including the I-95 Corridor Coalition, NYS Thruway Authority, NYS Bridge Authority, NYS Energy Research and Development Authority, and the Commercial Vehicle Infrastructure Integration (CVII) team headed by Volvo Technology of America.

Ownership and Intellectual Property Rights (IPR)

Information on the ownership and IPR of the Test Bed hardware, software, and data are not publicly available. It is also unknown who will be responsible for verifying the data quality. NYSDOT has developed a privacy policy for collecting and using data including PII. However, the specifics are unknown.

Cost

Information on the cost associated with using the Test Bed for conducting connected vehicle research is not publicly available.

5.1.1.1.6 Minnesota Connected Vehicle Test Bed

Purpose

The Minnesota Connected Vehicle Test Bed was implemented to: (i) demonstrate the technical feasibility of mileage-based user fees (MBUF), (ii) develop and test CICAS-SSA (Cooperative Intersection Collision Avoidance Systems – Stop Sign Assist) to improve safety at rural intersections, and (iii) demonstrate how weather, road condition, and related vehicle data may be collected, transmitted, processed, and used for decision making [14].

Summary

The Test Bed has been used to conduct three types of test (MBUF, CICAS-SSA, and mobile weather data). The MBUF demonstration was conducted to help transportation officials and policymakers understand if a mileage-based user fee (MBUF) would work in lieu of gas tax. There were five hundred volunteers in the study who used GPS-enabled smartphones in their cars or trucks. The phones were programmed for motorists to submit information that was then used by Minnesota DOT (MnDOT) to evaluate whether the device provided timely, reliable travel data from that specific trip. In addition, the test examined whether other applications, such as real-time traffic alerts providing information on construction zones, crashes, congestion and road hazards, were effective in communicating safety messages to motorists [15].

CICAS-SSA was developed to help drivers make better decisions and prevent collisions at rural highway intersections. The system uses multiple sensors and advanced computer algorithms to track vehicles moving along a rural divided highway. This information is then used to warn drivers stopped on a secondary rural road when gaps in highway traffic are too small to merge or cross safely [16]. Driver type clinics were held for the demonstration.

The mobile weather data test is discussed in Section 6.1.1.5.

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

The SAE J2735 message set is used for over the air interface. CICAS-SSA uses Generic Interface Definition (GID).

Storage

MBUF test accumulated miles by category and anonymous probe data. CICAS-SSA test did not collect any data. However, it is unknown if the data will be stored.

Sponsor Agency

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

The Test Bed is sponsored by Minnesota Department of Transportation (MnDOT) and USDOT. The MBUF test was specifically funded by the Federal ITS Earmark, and State Legislative Earmark. The CICAS-SSA test was funded by USDOT CICAS program, and MnDOT. The mobile weather test was funded by USDOT sponsored research on connected vehicles and Clarus.

Ownership and Intellectual Property Rights (IPR)

Information on the ownership and IPR of the Test Bed hardware, software, and data are not publicly available.

Cost

Information on the cost associated with using the Test Bed for conducting connected vehicle research is not publicly available.

5.1.1.1.7 Maricopa County Connected Vehicle Test Bed

Purpose

The Maricopa County Connected Vehicle Test Bed provides the capability to develop, test, and evaluate the benefits of connected vehicle applications that are aligned with the Maricopa County Department of Transportation (MCDOT) SMARTDrive Program [17].

Summary

MCDOT partnered with the University of Arizona and the Arizona Department of Transportation (ADOT) to develop the Maricopa County Connected Vehicle Test Bed in Anthem, Arizona as part of the SMARTDrive Program. The Test Bed was initially implemented to develop and test priority control for transit and emergency vehicles in a connected vehicle environment. The Test Bed consists of six intersections, each equipped with RSEs that are connected to traffic signal controllers, along Daisy Mountain Drive in Anthem. All intersections are connected to the MCDOT traffic management center where they can be remotely accessed. Key components of the Test Bed include [17]:

- Six signalized intersections equipped with DSRC radios, WiFi, and Bluetooth readers;
- Traffic signal priority application;
- Representative emergency and transit vehicles;
- Pedestrian crosswalk application using smartphones; and
- Collection of vehicle and traffic operations data for post-operational analysis.

The Test Bed will be expanded to include a total of nine intersections that will form a loop so that equipped test vehicles can circulate more easily around the network (Figure 5-8), [18].

The USDOT and the Cooperative Transportation System Pooled Fund Study (CTS PFS) have selected the Maricopa County Connected Vehicle Test Bed as one of the sites (the other being the California Test Bed) to develop and test a Multi-Modal Intelligent Traffic Signal System, which is one of the high-priority connected vehicle application identified by USDOT's Dynamic Mobility Applications (DMA) Program [19].

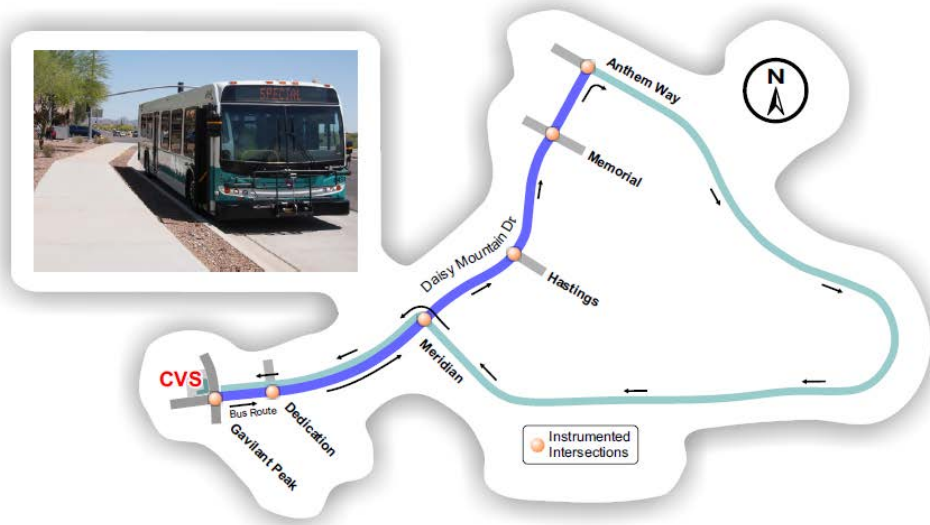


Figure 5-8. Maricopa County Connected Vehicle Test Bed (Source: MCDOT)

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

Data generated are compliant with the SAE J2735 standard.

Storage

Data that are generated by tests conducted at the Test Bed are archived by MCDOT. Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement with MCDOT. A subset of the data may be anonymized and made available for research through the DCM RDE.

Sponsor Agency

The Test Bed is jointly sponsored by MCDOT, ADOT, University of Arizona, USDOT, and CTS PFS.

Ownership and Intellectual Property Rights (IPR)

MCDOT and its partners own the Test Bed hardware and software.

Information on the IPR for the probe system and accompanying software is not publicly available.

Information on data ownership is not clearly identified. It is also unknown who will be responsible for verifying the data quality, and anonymizing the data (e.g., removal of PII from the data).

Data from tests that are federally-sponsored may be available to the USDOT for connected vehicle research depending on the data sharing agreement with MCDOT. A subset of the data may be anonymized and made available for research through the DCM RDE.

Cost

Information on the cost associated with using the Test Bed for conducting connected vehicle research is not publicly available.

5.1.1.2 Safety Pilot

Purpose

The Safety Pilot is being conducted to demonstrate advanced V2V and V2I wireless technologies in a real world implementation; determine system effectiveness and driver acceptance of vehicle-based safety systems; archive basic safety messages from multiple vehicle types (auto, trucks, transit), traffic sensor data, and SPaT data for use by third parties for additional benefits to transportation mobility, environment, and weather impacts; evaluate the feasibility, scalability, security, and interoperability of the DSRC technology; assess options to accelerate safety benefits through inclusion in aftermarket and retrofit devices; and accelerate in-vehicle and aftermarket technology introduction to the marketplace [20]. Findings from the Safety Pilot will inform the National Highway Traffic Safety Administration (NHTSA) on how to proceed with connected vehicle technology, which may range from conducting more testing to allowing automakers to voluntarily install the systems to beginning rule-making actions for mandating it in all new vehicles.

Summary

The Safety Pilot is being conducted in Ann Arbor, Michigan, in a real world environment to examine the effectiveness of connected vehicle technology in real-world, multi-modal driving conditions; to collect data on how ordinary drivers adapt to the use of connected vehicle technology; and to identify the potential safety benefits of connected vehicle technology. The Safety Pilot includes two phases: Safety Pilot Driver Clinics and Safety Pilot Model Deployment. The Safety Pilot Driver Clinics were held from August 2011 through Fall 2012 by CAMP (Crash Avoidance Metrics Partnership), which is a car consortium of eight leading auto manufacturers [21]. The purpose of the driver clinics was to identify how drivers would respond to safety alerts and warnings from in-vehicle wireless devices. Driver clinics for light vehicle drivers were conducted from August 2011 to January 2012 in six sites in the US, in controlled environments, such as test tracks and parking facilities. At least 100 volunteer drivers participated at each site. Driver clinics for truck drivers were held in Ohio in July 2012 and California in August 2012 at a controlled test track facility [22]. Driver clinics will not be held for transit drivers since transit drivers are already highly trained in advanced equipment and data on human factors already exist [21].

The Safety Pilot Model Deployment is being conducted by the University of Michigan in Ann Arbor, MI under the sponsorship of NHTSA using connected vehicle equipment in everyday vehicles in a real world environment. The Safety Pilot will take place from August 2012 to late 2013 and will test connected vehicle technology in an everyday environment using 2836 vehicles equipped with wireless devices and 29 RSEs deployed along 117.5 lane-kilometers (73 lane-miles) of roadway (Figure 5-9),

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Intelligent Transportation System Joint Program Office

[23]. Twenty one RSEs are deployed at signalized intersections (12 are at SPaT-enabled traffic signals), three on curves (to provide curve warnings) and five on freeway interchanges [24][25]. Wireless devices include:

- **Integrated Devices:** Installed during the manufacturing process, these devices integrate directly with the vehicle's computers, thus providing the ability to draw on a wide range of data. In addition to emitting and receiving basic safety messages (BSM), vehicles with integrated devices can further communicate data on speed, acceleration and deceleration, yaw rate, turning, wiper activity, and braking, among others. These devices can issue visual and audible warnings and alerts to drivers.
- **Aftermarket Safety Devices (ASD):** These devices do not connect to the vehicle's computers; they draw data only from the environment (e.g., GPS, safety messages from other vehicles) to support applications. Aftermarket devices can emit the basic safety message to warn equipped vehicles of the vehicles presence as well as warn drivers of potential conflicts. These devices can issue visual and audible warnings and alerts to drivers. This option is being examined as a means of increasing user adoption, and hence benefits, especially in the existing fleet of over 250 million vehicles.
- **Retrofit Devices:** These devices are similar to ASDs, except that these devices can connect to the vehicle databus and provide information from the in-vehicle sensors.
- **Vehicle Awareness Devices (VAD):** These devices only broadcast BSM Part I, and are incapable of issuing warnings to the driver.

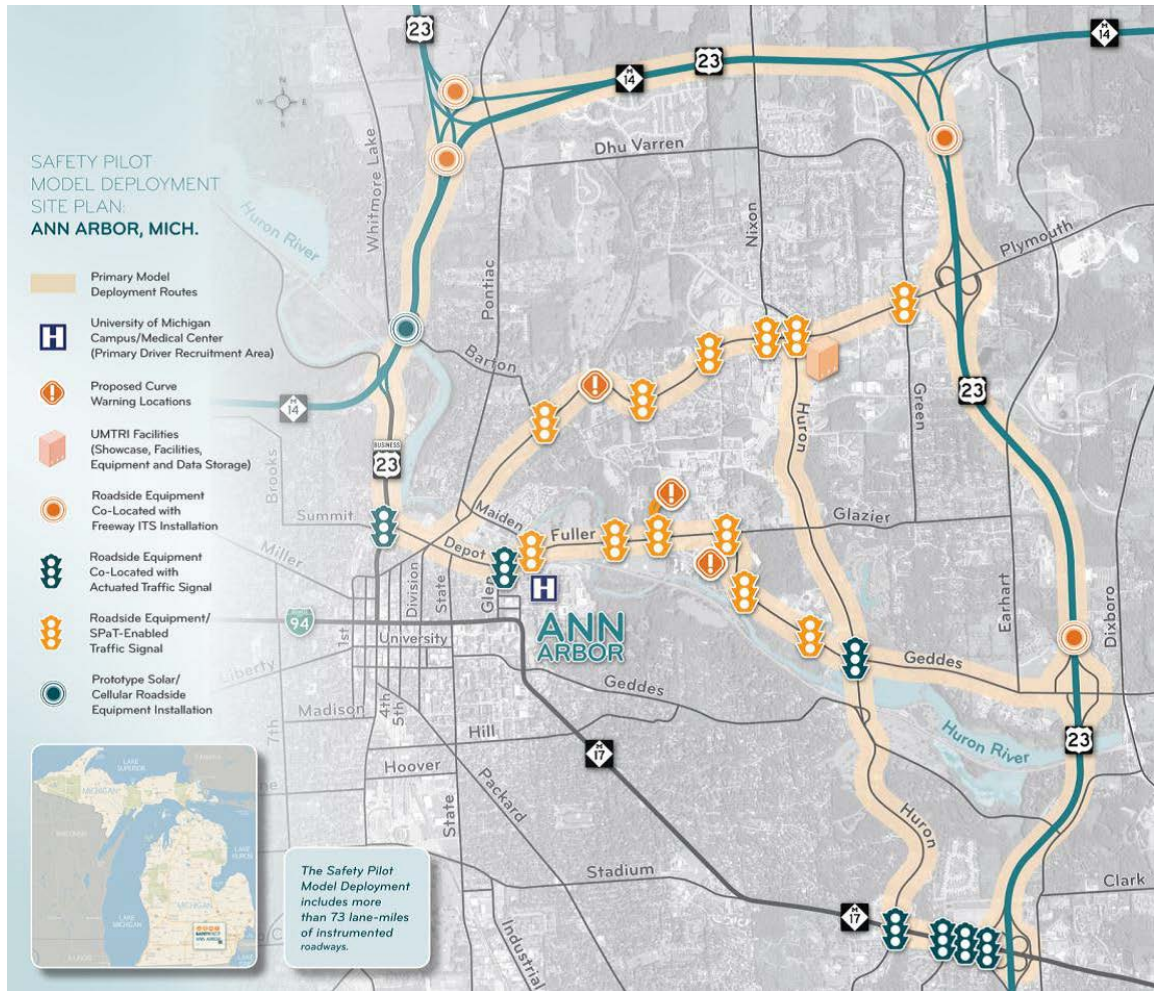


Figure 5-9. Safety Model Deployment Site (Source: MSDOT)

Table 5-1. Safety Pilot Vehicles and Devices (Source: UMTRI) shows the number and types of devices and vehicles available for the Safety Pilot [25].

Table 5-1. Safety Pilot Vehicles and Devices (Source: UMTRI)

Vehicle Type	Integrated Devices	Aftermarket Safety/Retrofit Devices	Vehicle Awareness Devices	Total Number of Vehicles
Passenger Cars	64	300	2200	2564
Heavy Trucks	3	16	50	69
Transit Vehicles		3	100	103
Medium Trucks			100	100
Total Number of Devices	67	319	2450	2836

Security

Information on how security is handled is not publicly available.

Robustness

Information on the robustness or resiliency of the system, including processes and procedures on handling disruptions to communications, is not publicly available.

Standards

Data generated are compliant with the SAE J2735 standard.

Storage

Data that are generated by the Safety Pilot will be archived by UMTRI and USDOT's Volpe Center. As part of the data sharing agreement, all data will be made available to USDOT in support of NHTSA's rule-making decision. A subset of data that are anonymized will be made available after the conclusion of the NHTSA analysis to the DCM Program for making it available for research on the DCM RDE.

Sponsor Agency

The Safety Pilot is sponsored by USDOT.

Ownership and Intellectual Property Rights (IPR)

UMTRI, CAMP, and its partners own the Safety Pilot hardware and software.

Information on the IPR for the probe system and accompanying software is not publicly available.

UMTRI and CAMP own the data. It is unknown who will be responsible for verifying the data quality and anonymizing the data (e.g., removal of PII from the data).

As part of the data sharing agreement, all data will be made available to USDOT in support of NHTSA's rule-making decision. A subset of data that are anonymized will be made available after the conclusion of the NHTSA analysis to the DCM Program for making it available for research on the DCM RDE.

Cost

The site will not be available for additional connected vehicle research and testing for the duration of the Safety Pilot.

5.1.2 Assessment of Research, Development, and Deployment of Probe Systems by the Private Sector in the US

In 2009, the USDOT sponsored an effort to assess the real-time traveler information market in the US [26]. The effort revealed that with unprecedented growth in mobile computing power and mobile communications, the private sector is making use of in-vehicle devices to capture traffic data. The

commercial vehicle industry, already fairly mature in its deployment of in-vehicle telematics applications, is projected to increase their on-board communications devices. Initially, only the large long-haul operators were able to fund the substantial capital costs associated with implementing on-board systems, but with the addition of new vendors to the market, as well as the improvements to wireless communications, costs have decreased. Smaller and short-haul companies are able to migrate from radio-based communications systems to public carrier push-to-talk services and in-vehicle telematics that include integrated AVL and data applications. Furthermore, more trucking companies are using telematics systems for proscribed routing and geo-fencing for their vehicles to track and monitor shipments, particularly for high-value and hazardous materials cargo [26].

A study conducted by Noblis for SHRP II L14 project revealed that methods for measuring travel conditions have evolved beyond traditional technologies such as loop detectors and infrared sensors to Global Positioning System (GPS) enabled devices, cell phone tracking, and Bluetooth monitoring [27]. In concert, methods for integrating multiple data are becoming more sophisticated and complex, blending multiple sources of data, including real-time and historic data that are both quantitative and qualitative in nature [27]. Data providers have started to crowdsource data from travelers' mobile devices to gather traffic information [28]. Private sector sources are progressively being used and trusted by public sector organizations [29].

5.1.2.1 Data Capture Technologies and Methodologies

GPS Enabled Devices: The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 active satellites placed into orbit by the U.S. Department of Defense. Studies have demonstrated that GPS-based estimation of travel time and roadway speeds far exceed existing granularity and accuracy and that a market penetration around 2% in the vehicle fleet is sufficient for quality estimates of travel time and speed [27]. Application of GPS technology for fleet management has become common for both public and private fleet operators ranging from goods delivery vehicles to public transit [27]. Trucking companies use GPS to monitor their vehicles at all times to ensure deliveries are made on time and to direct vehicles to the most cost-effective routes. More than 22,000 shipping and logistics companies rely on ALK Technologies' routing, mileage, and mapping solutions, enabled by GPS software [30]. Dispatchers for taxi companies use GPS to know where their vehicles are so they can get the most efficient use of them. Private sector traveler information providers leverage real-time GPS reports from commercial and consumer vehicles/devices, including mid to high end mobile devices with GPS capability (e.g., Smartphones), in providing estimates of speed and travel time [27]. INRIX blends real-time road sensor data with billions of real-time data points from over one million GPS-enabled commercial and consumer devices in taxis, service vehicles, airport shuttle services, cars and long haul trucks [31]. NAVTEQ, a wholly owned subsidiary of Nokia, aggregates anonymously collected GPS data from Nokia handsets with other traffic data sources and integrates it with NAVTEQ Traffic™ products [32]. Google uses crowdsourced, anonymous data from GPS-enabled mobile devices to provide travel times and typical travel patterns, estimated using real-time and historical data [33][34]. Waze, which is a free and open source traffic and navigation application, uses a novel way of using data from GPS-enabled smartphones [35]. Local driving communities are created by people sharing their travel experiences either passively by allowing an application to run on their GPS-enabled smartphones while driving or actively by reporting incidents, speed traps, and other hazards on their routes to warn other drivers in their driving community.

Cell Phone Tracking: AirSage collects and analyzes real-time cell phone signals that produce more than three billion anonymous locations every day, and is found to correctly detect congestion 84% to

93% of the time [27]. Cellint's TrafficSense combines their cellular data with GPS probe and other external data streams, and provides real-time traffic information, including speeds, travel times, and incident alerts, in Atlanta, Kansas City, Israel, and Sweden [36].

Bluetooth Readers: Bluetooth tracking has been applied as an alternative to floating car or other probe vehicle tests, and can supplant such tactics in computing "ground truth" [27]. In June 2009, TrafficCast introduced BlueToad (Bluetooth Travel-time Origination And Destination) traffic monitoring technology that traces anonymous Bluetooth signals to derive travel times, road speeds and vehicle movements [37].

Crowdsourcing: Crowdsourcing is the practice of tapping into the collective intelligence of the public at large to complete tasks that an agency or company would normally either perform itself or outsource to a known entity (blend of crowd and outsourcing) - in this case, the travelers. Crowdsourcing is most beneficial for data collection activities that need massive amounts of data, and continuous temporal and universal spatial coverage. There are many examples of crowdsourced traffic applications. Inrix provides traffic information using crowdsourced traffic data, traditional sensor data, and other relevant data (e.g., incidents, weather, construction, special events). Waze provides 100% crowdsourced, free real-time traffic information on mobile devices by crowdsourcing data from GPS-enabled vehicles of volunteers for real-time traffic information. Beat the Traffic, a leading provider of mobile traffic information, crowdsources and shares real-time traffic data from many sources, including hundreds of thousands of motorists who use Beat the Traffic's application to report traffic incidents from the road [38]. Google's probes are mainly members of the public carrying a cell phone and driving in a car. Users who allow their mobile devices to send location information back to Google receive real-time free traffic updates on their mobile phones. Google uses the location information to improve the accuracy of traffic information that it sends back to the mobile users. The information is also published on the Google Maps website in the form of color-coded roads. The data and mobile phone application are free, as long as users allow Google to use their data in Google's traffic prediction algorithms [39].

5.1.2.2 Geographic Coverage

The probe-based data capture technologies and methods mentioned in the previous section have allowed the private sector to expand their geographic coverage in both urban and rural areas. The private sector now has the ability to collect speed and flow data on corridors that are not instrumented with traditional road sensors. The coverage statistics for private-sector probe systems include [26]:

- SiriusXM displays navigation information from XM NavTraffic in 130 metropolitan markets [40].
- Total Traffic Network, the traffic information arm of Clear Channel, provides navigation data to in-vehicle devices in 95 markets.
- INRIX provides incident data through a partnership with Clear Channel in 113 markets.
- AirSage provides real-time, historical, and predictive traffic information for 127 US cities.
- TrafficCast provides flow data in 28 markets, incident data in 138 markets, and construction data in 146 markets.
- SpeedInfo, a private infrastructure-based provider, is a partner in 14 metropolitan areas.

As of June 2012, INRIX has partnered with more than 200 customers including auto manufacturers (Audi AG, BMW, Ford Motor Company, Nissan, Toyota), navigation system manufactures and

providers (e.g., MapQuest, NAVIGON, Tele Atlas, Telmap, TeleNav), mobile service providers (e.g., O2, Vodafone), the I-95 corridor coalition, Microsoft, etc., to provide real-time traffic information [41].

5.2 Summary of Probe Systems in Japan

5.2.1 Status of Government R&D on Probe Systems

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has been conducting research and development of “Smartway” as a new vehicle-to-infrastructure cooperative system, in collaboration with academia and industry. “Smartway” is the next generation of advanced road traffic systems to evolve, based on integrated ITS technologies. “Smartway” links people, vehicles and roads through information, directed to road safety, congestion mitigation and protection of the environment. As a part of this “Smartway” project, the next generation of ITS services was initiated in 2011 through the deployment of ITS Spot, which is a high-speed, large-capacity road-to-vehicle communication system.

In Japan, “ITS Spot Service” has been developed as one implementation of the cooperative ITS, which communicates, shares and exchanges information between vehicles and/or between infrastructure and vehicles, to give advice, to facilitate actions or to control vehicles with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems.

ITS Spot can provide various ITS services, including electronic toll collection (ETC), car-navigation, and vehicle information and communication system (VICS), with a single on board unit; although these services had been provided by separate on board units so far. ITS Spot Services are provided by ITS Spot equipment installed on the roadside and an ITS Spot-compatible car navigation system installed in vehicles. ITS Spot services include currently three basic services, namely “dynamic route guidance”, “safe driving assistance” and “electronic toll collection (ETC)”. In addition, other future services will include internet access at expressway’s service areas (already available by some model of car navigation systems), cashless payments, tourist information, and logistics operation support. ITS Spot is a system developed as a platform for various ITS services.

One of the main characteristics of ITS Spot is the quick and mutual transmission of large amounts of data between ITS Spot equipment installed on the roadside and ITS Spot-compatible car navigation systems installed in vehicles. ITS Spot enables not only road infrastructure to provide vehicles with traffic information but also enables vehicles to transmit their probe information to the road infrastructure. All of this enables ITS Spot to function as a probe system.

MLIT has been conducting research and development on utilizing this ITS Spot probe system for driver’s services such as traffic information and safe driving assistance, study and research on road traffic, and road management.

Public sector probe systems in Japan comprise the ITS Spot and a National Police Agency’s system. This report covers only the ITS Spot system.

Outline of the system of Road Traffic Probe Data

ITS Spot uses DSRC in the 5.8 GHz band, which is the same frequency bandwidth used for ETC. ITS Spot is capable of two-way communications between a roadside unit and an on board unit on this 5.8

GHz band. ITS Spot-compatible car navigation systems can upload its accumulated probe data when a car equipped with it passes under an ITS Spot roadside equipment.

Scope and roads covered

Approximately 1,600 ITS Spots have been deployed nationwide, primarily on expressways (see Figure 5-10). Locations of roadside units deployed on expressways are based on the following guidelines:

- Just before exit/entrance ramps of junctions and where major roads divide, and where drivers approach major bottlenecks
- Locations where it benefits drivers to receive timely traffic information
- Areas near major bottlenecks, where highway information is available by radio

Based on these guidelines, intercity expressways have ITS Spots approximately every 10-15 km (6.2-9.3mi), and inner-urban expressways have ITS Spots every 4 km (2.5mi). In addition, about 50 ITS Spots are installed in service-areas along expressways and Michi-no-eki (parking and rest areas) along general roads. Also, 20 ITS Spots have been deployed in general road areas where road closure information is provided.

ITS Spot-compatible car navigation systems have the capacity of storing and uploading probe information accumulated over approximately 80 km (50mi). While ITS Spots are deployed mainly on expressways, data uplinked to ITS Spots can include data on not only expressways but also general roads. Probe data can be obtained only for Basic Roads, which are roads with a road width greater than 5.5 m (18ft). These are the roads in the digital road maps (DRM) issued by the Japan Digital Road Map Association. The total length of such Basic Roads is 390,000 km (242,000mi). The total length of all public roads in Japan is approximately 1.2 million km (745,000mi).

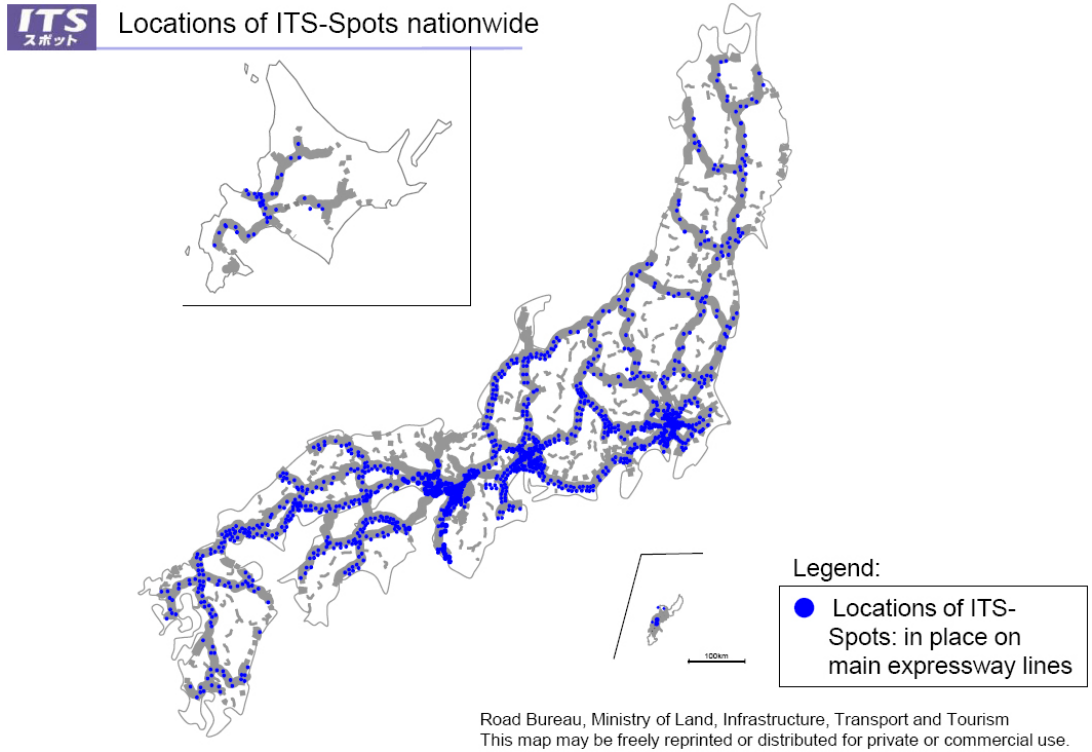


Figure 5-10. Locations of ITS Spots (Source: MLIT) [42]

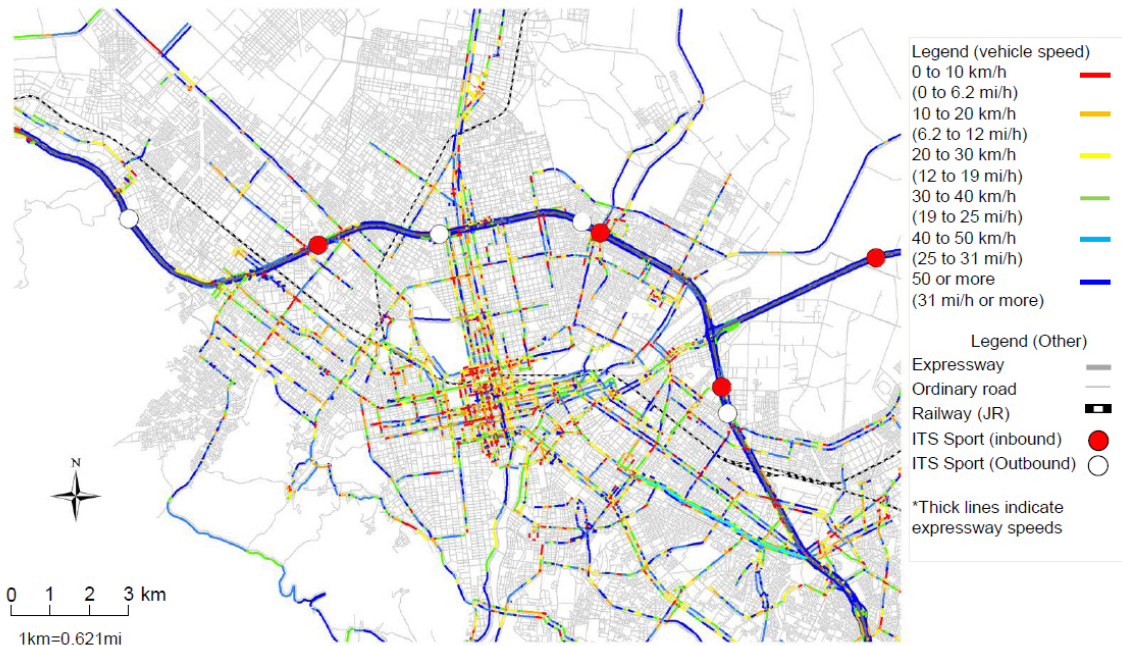


Figure 5-11. Collected probe data in downtown Sapporo City for the 3 months of June-August 2011 (Source: MLIT)

Figure 5-11 describes vehicle speed data collected by the ITS Spot probe system in downtown Sapporo City. Red and white circles in these figures indicate locations of ITS Spot roadside equipment. Although ITS Spots are installed only on the expressways, vehicle speed data collected by ITS Spots includes data on the general roads. While vehicle speeds on the expressways are generally above 50 km/h (31mi/h), those on general roads in the central downtown are relatively lower, less than 20 km/h (12mi/h).

Conceptual diagram of the probe system

The probe system consists of: ITS Spot-compatible car navigation systems installed in vehicles; ITS Spots established on the roadside; and probe servers whose functions include collection, aggregate calculation, and storage of probe data (See Figure 5-12). An example of ITS Spot-compatible car navigation system and ITS Spot roadside equipment are as shown (Figure 5-13).

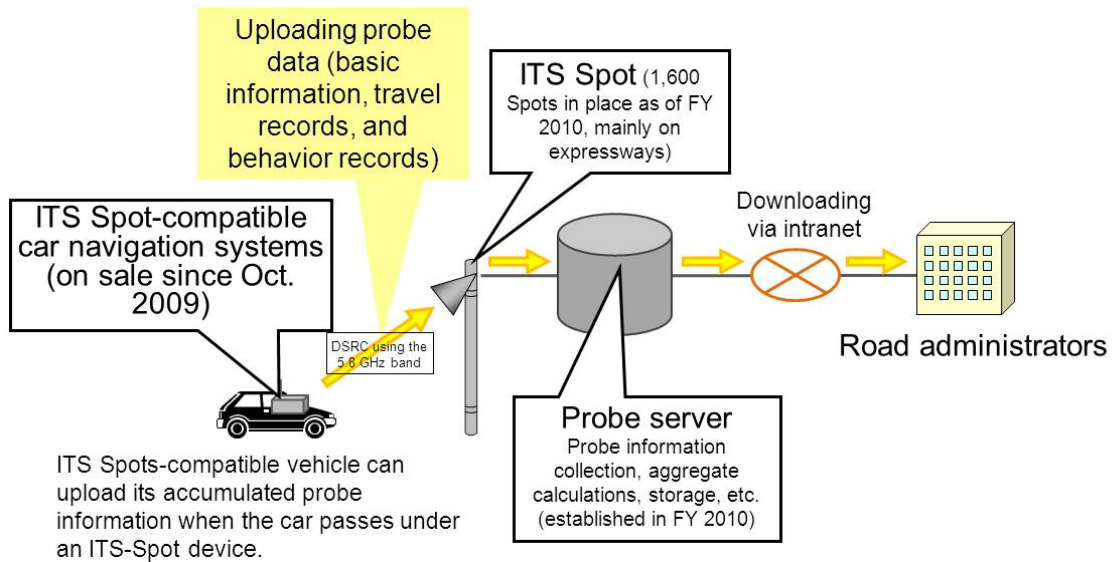


Figure 5-12. Conceptual Diagram of probe system (Source: MLIT)



Figure 5-13. An ITS Spot-compatible car navigation system (left) and ITS Spot roadside equipment (right) (Source: MLIT)[43]

Components of the probe system (summary)

ITS Spot-compatible car navigation systems: ITS Spot-compatible car navigation systems are devices capable of collecting and accumulating probe data and then transmitting that stored data to an ITS Spot. No special monitoring devices are installed to gather probe data; instead, probe data is collected by means of the conventional functions of a car navigation system such as a GPS receiver, acceleration sensor, and gyro sensor.

Accumulated data in an ITS Spot-compatible car navigation system is retained even when a car is not being operated. When accumulated data is uplinked to an ITS Spot, the data is erased from the ITS Spot-compatible car navigation system at the same time, creating space for new data.

ITS Spot-compatible car navigation systems became commercially available from several private firms in the fall of 2009, and are on sale by over twenty companies as of the 5 September 2013 (Table 5-2) [44]. By August 2013, a cumulative total of over 136,000 units had been installed in vehicles.

Table 5-2. Companies Offering ITS Spot-Compatible Car Navigation Systems/On-board Units (Source: ITS Service Promotion Association (Japan))

Automotive Manufactures	Manufactures of Car Navigation Systems/On-board Units
HONDA	Alpine Electronics, Inc. Clarion Co., Ltd. DENSO Corporation JVCKENWOOD Cooperation Mitsubishi Electric Corporation Mitsubishi Heavy Industries, Ltd. Panasonic Corporation Pioneer Corporation
MAZDA	
Mitsubishi Motors	
NISSAN	
SUBARU	
SUZUKI	
TOYOTA	
Alfa Romeo	
Audi	
Citroën	
Fiat	
Ford	
Jeep	
Mercedes-Benz	
Peugeot	
Volkswagen	

ITS Spots: ITS Spots are devices that collect the probe data uploaded from ITS Spot-compatible car navigation systems and transmit it to a probe server.

As stated in the previous section, approximately 1,600 ITS Spots have been installed mainly on expressways. When a vehicle equipped with an ITS Spot-compatible car navigation system passes through a communication area of an ITS Spot (around 20m in length), accumulated probe data is uplinked to the ITS Spot.

The on board storage capacity is limited to 80 km (50mi) of driving. If a vehicle travels less than 80 km (50mi) between ITS Spots, all the data will be uplinked. If a vehicle travels more than 80 km (50mi) without passing under an ITS Spot, the oldest data will be overwritten and only the most recent 80 km (50mi) of data will be uplinked.

Probe server: The probe server is equipment that consolidates probe data obtained from ITS Spots nationwide. In addition to collecting probe data, it can perform aggregating calculations such as travel time for each road section (in units of Digital Road Map (DRM) links), store probe data and the results of aggregating calculations, and provide data to the respective road administrators. The server is currently located in MLIT.

Probe system ownership

The probe system consists of ITS Spot-compatible car navigation systems, ITS Spots, and probe servers. The ownership of each component is as indicated in Table 5-3. The collected probe data is stored in the probe server and managed by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

With regard to providing the probe data to third parties, MLIT and expressway companies provide the following information:

- a) Road administrators might provide third parties, including university research institutes and other users of such information, with statistics only drawn from the probe information, for purposes of road management, research and development, and services for road users, such as provisions for traffic information and safe driving information.
- b) Road administrators might provide ITS Spot and ITS Spot-compatible car navigation system manufacturers with probe information or with statistics only drawn from the probe information in order to allow them to address problems and conduct further research and development.
- c) Road administrators would never provide probe information to third parties for any purposes other than in (a) and (b).

Table 5-3. Probe system ownership

Component	Owner
ITS Spot-compatible car navigation systems	Purchasers of ITS Spot-compatible car navigation systems
ITS Spots	MLIT and Japan Expressway Holding and Debt Repayment Agency
Probe Servers	MLIT
Probe Data	MLIT and the respective expressway companies

Privacy

Probe data includes a portion of the vehicle information provided by the user when setting up an ITS Spot-compatible car navigation system; however, the vehicle number and a portion of the license plate information are concealed, making it impossible to identify the vehicle or the individual. Also, ITS

Spot-compatible car navigation systems do not gather probe data in the vicinity of their origin and destination points (locations where the engine is turned on or off), making it impossible to identify a user's origin or destination point from the collected probe data.

Security

The sending and receiving of information between an on-board unit and a roadside unit as the ITS Spot services is protected by an advanced security system, namely DSRC-SPF (digital short range communications security platform). DSRC-SPF is a common platform for providing protected, secure communications between vehicles and the road infrastructure using DSRC radio waves. DSRC-SPF certifies both information senders and receivers, and the exchanged data.

Robustness

ITS Spot probe system uses the Japanese DSRC communication medium that is in compliance with Association of Radio Industries and Businesses (ARIB) STD-T75 and ARIB STD-T88 standards. Japanese DSRC ARIB STD-T75 and T88 enable vehicles with onboard units to communicate with roadside equipment even if vehicles travel at high speeds under the roadside equipment.

ITS Spot realizes reliable and robust wireless communications through the use of the highly reliable ARIB STD-T75. Moreover, even in communications from roadside units to the center probe servers, the unit is equipped with a communication retransmission function for use in the event of a communication problem. Probe servers are also equipped with data redundancy and backup functions and other mechanisms to prevent data loss.

International Standards

ISO/TC204/WG16 is responsible for standardization of the probe data itself and the standardization further of personal data protection in probe data services and related matters.

The Probe vehicle data format is standardized as ISO22837 (Vehicle Probe Data for Wide Area Communication) and privacy protection rules and guidelines are standardized as ISO24100 (Basic Principles for Personal Data Protection in Probe Vehicle Information Services).

5.2.2 Summary of the Status of Probe System Research, Development and Deployment by the Private Sector in Japan

Table 5-4 shows the status of research and development of major private sector probe systems in Japan.

Major automobile manufacturers and the manufacturers of car navigation systems are deploying car telematics systems for their users. All of these companies are employing the same basic method: they provide traffic information (optimal route guidance, traffic congestion information, etc.) that has been derived from the probe data collected by the car navigation systems mounted in their users' vehicles using cellular telephone networks. As most of the users that employ car telematics services are owners of passenger vehicles, the probe data tend to be data for weekday commutes to and from work and trips taken on non-work days.

Table 5-4. Status of research and development of three major private sector probe systems in Japan (Source: MLIT)

Characteristics	G-BOOK Probe communication traffic information	CARWINGS	Honda Internavi Floating Car Data
Entity implementing project	Toyota Media Service Corporation	Nissan Motor Co., Ltd.	Honda Motor Co., Ltd.
Purpose of data collection	To provide highly accurate optimal route guidance, including congestion information for roads that could not be covered by VICS data	Member services and analysis by Nissan	To provide detailed road traffic information to Internavi Link member vehicles and terminal and improve the accuracy of route guidance
No. of targets for data collection	No. of registered G-BOOK mX navi units: 1.5 million (as of the end of June 2013)	Undisclosed	No. of Internavi Link member vehicles: 1.5 million (as of the end of June 2012)
Quantity of data collected	Undisclosed	Undisclosed	Undisclosed
Data items collected	Information about on-board equipment, time stamp, latitude/longitude, road category, road link, level of congestion, direction, speed	Time of data acquisition, position data (latitude/longitude), Fuel efficiency data (excluding electric vehicles), charge data (electric vehicles), Energy efficiency (electric vehicles)	Travel information needed to generate travel time, information for digital road map (DRM), basic road link units (time stamp, latitude/longitude, direction, speed)
Data collection method	Collected online using cellular telephone network	Collected online using cellular telephone network	Collected online using cellular telephone network

Characteristics	G-BOOK Probe communication traffic information	CARWINGS	Honda Internavi Floating Car Data
Data collection equipment	G-BOOK mX (Cellular telephone connection) G-BOOK mXpro (DCM*) *Data Communications Module: an onboard communication module especially designed from telematics service	Collected by CARWINGS-compatible car navigation systems Transition method: Using member's cellular telephone (other than electric vehicles) Vehicle on-board communications module (electric vehicles)	Collected by compatible car navigation systems (by connecting cellular telephone or using dedicated communications equipment)
Frequency of data collection	At intervals of 8-10 minutes (depends on transition method)	Undisclosed	Variable depending on user setting (as often as every five minutes)
Data accuracy	10 meter units	Undisclosed	Collection on travel time for VICS link units (output per 1-second)

Characteristics	G-BOOK Probe communication traffic information	CARWINGS	Honda Internavi Floating Car Data
Usage Fee	<p>G-BOOK mX: No basic charge but customer must pay communications charges</p> <p>G-BOOK mXpro: No fee for first year, ¥12,000/year (\$120/year) for second and subsequent years</p> <p>* Exchange rate \$1=¥100</p>	<p>No charge for basic service as a bonus for purchasing a new vehicle; operator service fee ¥3,150/year (\$32/year); communication charges not included</p> <p>Normally ¥5,250/year (\$53/year)(including operator service fee; excluding electric vehicles), clerical fee not included, communication charges not included</p> <p>No charge for special program only (electric vehicles)</p> <p>Normally ¥15,750/year (\$158/year) (including operator service fee; electric vehicles), clerical fee not included, communications charges included, additional fees for companies.</p> <p>* Exchange rate \$1=¥100</p>	No charge
Notes/Other		Member registration is required for use.	

(Prepared based on responses from individual companies to a survey by the National Institute for Land and Infrastructure Management)

In addition, taxi companies also collect and use probe data using the taxi radio network (taxi probes). These data are used to determine the location of the taxi and conduct efficient vehicle deployment. Taxis drive for a much longer distance each day than ordinary passenger vehicles, and they normally travel in urban areas, so they are well-suited to determining the traffic situation in the city. For this reason, recently in an increasing number of cases companies provide and market traffic information services that use taxi probe data.

At distribution companies, there is increasing use of probe data gathered using mobile phone networks to record data that is required by law (speed, distance, time), to monitor driver behavior and assist driving safety, to conduct vehicle management in real time and so on. In order to determine driver behavior and check whether the cargo has been subjected to impacts and so on in particular, on-board terminals are often equipped with acceleration sensors, enabling these units to acquire information that cannot be obtained from vehicle telematics probes and taxi probes.

5.3 Comparison of Probe Systems

Table 5-5 compares the characteristics of the connected vehicle systems implemented in the US (discussed in 5.1), and the ITS Spot system deployed in Japan (discussed in 5.2).

Table 5-5. Comparison of Probe systems in the US and Japan

Characteristics	Michigan Test Bed	TFHRC Test Bed	California Test Bed	Florida Test Bed	New York Test Bed	Minnesota Test Bed	Maricopa County Test Bed	Safety Pilot	ITS Spot
Geographic Description	45 square miles, comprising 75 center-line miles (32 highway miles + 43 arterial miles) Planned expansion of 6 arterial center-line miles	1 intersection	60 miles, comprising 3 parallel 20-mile freeway and arterial (I-280, US 101, SR 82)	25 miles (I-4, International Drive, John Young Parkway)	Long Island Expressway (LIE/I-495), Northern State Parkway (NSP), Southern State Parkway (SSP)	Details unknown	6 intersections (+9 planned) along Daisy Mountain Drive in Anthem	73 lane-miles	Major expressways
Number of RSEs	55 (+22 planned)	2	40	29	39 (31 along Interstate+8 at traffic signals)	No information	6 (+3 planned)	29 (21 at intersections+3 on curves+5 on freeway interchanges)	1600 RSEs installed mainly on expressways

Characteristics	Michigan Test Bed	TFHRC Test Bed	California Test Bed	Florida Test Bed	New York Test Bed	Minnesota Test Bed	Maricopa County Test Bed	Safety Pilot	ITS Spot
Type and Number of Connected Vehicles, Connected Travelers	10 vehicles with OBEs	2 vehicles with OBEs (+3 planned)	No information	42 vehicles with VADs (10 Lynx transit+17 I-Ride Trolley buses+ 5 FDOT vehicles+10 demonstrator vehicles) 2 vehicles with OBEs	4 plow trucks retrofitted with DSRC-based OBE 20 aftermarket devices	500 volunteers for MBUF test with smartphones 80 MnDOT snowplows with OBEs Other information unknown	Transit vehicle, emergency vehicle, pedestrian with smartphone (number unknown)	2564 passenger cars (64 integrated +300 ASD+2200 VAD) 69 heavy trucks (3 integrated+16 ASD+50 VAD) 103 transit vehicles (3 integrated+100 VAD) 100 medium trucks (100 VAD)	29,000 ITS Spot compatible navigation systems installed on vehicles (as of September 2012)
Type of Data	BSM Part 1 SAE J2735 Probe data messages	SAE J2735 Probe data messages	BSM Part 1 SAE J2735 Probe data messages	BSM Part 1 SAE J2735 Probe data messages	SAE J2735 Probe data messages Road weather data, vehicle-fleet data, inspection data	Vehicle and environmental data from CAN bus and external sensors (See Section 6.1.1.5) Other messages unknown	SAE J2735 Probe data messages Other messages unknown	BSM Part 1 and other messages to support evaluation	ITS Spot probe data

Characteristics	Michigan Test Bed	TFHRC Test Bed	California Test Bed	Florida Test Bed	New York Test Bed	Minnesota Test Bed	Maricopa County Test Bed	Safety Pilot	ITS Spot
Communication Technology	5.9 GHz DSRC for V2V and V2I 3G, WiMAX, Wireline for backhaul	5.9 GHz DSRC for V2V and V2I Fiber-link connection for backhaul	5.9 GHz DSRC for V2V and V2I 3G, WiMax, WiFi, Wired (T1 line) for backhaul (2 back end servers)	5.9 GHz DSRC for V2V and V2I Fiber optic network connection for backhaul	5.9 GHz DSRC	5.9 GHz DSRC Cellular	DSRC,WiFi, Bluetooth technology	5.9 GHz DSRC for V2V and V2I Backhaul communication unknown	5.8 GHz DSRC
Security and Robustness	No information	No information	No information	No information	No information	No information	No information	No information	Data exchange between on-board unit and ITS Spot makes use of DSRC-SPF security platform. Probe system compliant with ARIB STD-T75 and ARIB STD-T88 stds.
Standards	SAE J2735	SAE J2735	SAE J2735	SAE J2735	SAE J2735, 1609, 802.11	SAE J2735, GID	SAE J2735	SAE J2735	ISO/TC204/WG 16

Characteristics	Michigan Test Bed	TFHRC Test Bed	California Test Bed	Florida Test Bed	New York Test Bed	Minnesota Test Bed	Maricopa County Test Bed	Safety Pilot	ITS Spot
Data Storage and Cleaning	Anonymized, cleaned data at DCM RDE	Anonymized, cleaned data at DCM Prototype Data Environment (DCM RDE planned)	No information	Anonymized, cleaned data at DCM RDE	No information	No information	Anonymized, cleaned data at DCM RDE	Anonymized data at DCM RDE after NHTSA analysis	Anonymized, cleaned data stored at MLIT
Ownership and IPR	USDOT owns Test Bed hardware, software; IPR unknown Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on DCM RDE	USDOT owns Test Bed hardware, software; IPR unknown Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on DCM RDE	No information	FDOT and its partners own in-vehicle devices and software, USDOT owns RSEs; IPR unknown Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on DCM RDE	No information	No information	MCDOT and its partners own Test Bed hardware and software; IPR unknown Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on DCM RDE	UMTRI, CAMP, and its partners own Safety Pilot hardware and software; IPR unknown UMTRI and CAMP own the data; USDOT will have access to data to support NHTSA's rule-making decision, and subset of anonymized data may be available on DCM RDE after NHTSA analysis	Probe data are owned by MLIT, expressway companies ITS Spots are owned by MLIT and Japan Expressway Holding and Debt Repayment Agency Probe Servers are owned by MLIT

Characteristics	Michigan Test Bed	TFHRC Test Bed	California Test Bed	Florida Test Bed	New York Test Bed	Minnesota Test Bed	Maricopa County Test Bed	Safety Pilot	ITS Spot
Sponsor	USDOT	USDOT	Caltrans, MTC, USDOT	USDOT, FDOT, Orange County, City of Orlando, other Central Florida agencies	NYSDOT, I-95 Corridor Coalition, NYS Thruway Authority, NYS Bridge Authority, NYS Energy R&D Authority, CVII team	MnDOT, USDOT	MCDOT, ADOT, University of Arizona, USDOT, CTS PFS	USDOT	MLIT
Capability to Generate Probe Data (as defined in Section 4)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

6 Summary of Probe Data

This chapter summarizes and examines existing public and private sector probe data in the US and Japan.

6.1 Probe Data in the US

This section summarizes probe data in the US.

6.1.1 Public sector probe data

This section summarizes public sector probe data. Please note that some of these data are generated from the probe systems described in Section 5.1.1. For example, the VIIC POC and NCAR test data sets that are documented in Sections 6.1.1.2 and 6.1.1.3 were generated during field operational tests conducted on the Michigan V2V/V2I Test Bed, which is documented in Section 5.1.1.1.1.

6.1.1.1 DCM Test Data Sets

In 2011, the DCM Program sponsored the Test Data Sets effort, which comprised the cleaning, integration, organization, and documentation of *existing* multi-source, multi-modal data sets to: (i) develop and test innovative data capture and management concepts, and (ii) support the development of mobility applications. The DCM Program was specifically interested in data captured using emerging technologies such as, Bluetooth Sniffers, Global Positioning Systems (GPS), short-range mobile devices, wireless transit vehicle to infrastructure communications, etc., and supplementary contemporaneous data from fixed traffic sensors and weather stations. The Test Data Sets effort resulted in four data sets, of which two included probe data. These two data sets are documented below.

6.1.1.1.1 San Diego Test Data Set

Summary

The data set was developed by Berkeley Transportation Systems (BTS) using data collected on major freeways (I-5, I-8, SR 15, SR 94, SR 125, SR 165, and SR 205) in San Diego from January to December 2010 [45]. The data set includes data from mobile devices (i.e., GPS-based data from ALK Technologies) [46], traffic sensors deployed on the major freeways [47], NOAA (National Oceanic and Atmospheric Administration) weather stations [48], and incidents and lane closures (for I-5) [49].

Probe Data: GPS-based data are available from ALK Co-Pilot in-vehicle navigation devices operating in the San Diego region [46]. Trip data that have been trimmed to remove the origins and destinations are available for 10,000 trips at 3-second intervals. The GPS “breadcrumbs” data includes: UTC time, latitude, longitude, speed, vehicle heading, and date. GPS data were collected by ALK Technologies. A digital map shape file containing ALK’s street-level network data for the San Diego Metropolitan area is also available.

Quality

All data are cleaned and verified for quality. Traffic sensor data were cleaned by PeMS. Procedures used for imputing missing data and cleaning raw sensor data are documented elsewhere [47]. The quality of the weather data is controlled by NCDC and NWS. Incident data were cleaned by CHP. Quality control procedures for weather and incident data are not available.

Privacy

With the exception of probe data, no data included personally identifiable information (PII).

Probe Data: All PII was removed to prevent tracks from being correlated with any individual driver. Data provided by ALK is composed of GPS breadcrumbs collected at 3-second intervals from users of CoPilot, ALK Technologies' Mobile Navigation Software Product. Even though users of this product have consented to the collection and dissemination of data from their systems, ALK does not collect any PII as part of the data it collects. Moreover, ALK takes steps to protect its customers' personal information by discarding any user or device information that could potentially be traced back to a specific individual.

Standards

The data were not formatted to comply with a specific ITS standard.

Metadata

Metadata was made available by BTS for the mobile (or probe), traffic sensor, weather, and incident data. Noblis has also developed a metadata documentation that complies with the metadata standard for the DCM RDE. The Standard Practice for Metadata to Support Archived Data Management Systems (E 2468-05) by the American Society for Testing and Materials (ASTM) has been adopted as the metadata standard for the DCM RDE.

Storage

The data set, with the exception of the ALK trip data, is stored on the DCM RDE and is available to the public for research.

Sponsor Agency

Compilation of the integrated data set and its documentation were sponsored by the USDOT, but the collection and cleaning of the individual data were sponsored by multiple agencies, including Caltrans, NOAA, ALK Technologies, and CHP.

Data Ownership and Intellectual Property Rights (IPR)

ALK Technologies owns the mobile device data. Caltrans owns the freeway, incident, and lane closure data. National Weather Service and the US Navy own the weather data. FHWA has full rights to distribute these data, and the data set is available for research under the Open Data Commons Attribution License through the DCM RDE.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.1.2 Seattle Test Data Set

Summary

The data set was developed by University of Washington (UW), Seattle. The Seattle data set covers the I-5 freeway corridor from the King/Pierce County line in the south to the City of Everett in the north; and the major north-south arterials in the City of Seattle to the west of I-5 and east of Puget Sound. The data set contains data collected for a six month period from May to October 2011. In addition to the freeway and arterial data, the data set also includes incident data collected by Washington State Department of Transportation (WSDOT) Incident Response Program; messages displayed on WSDOT's Active Traffic Management signs; transit data; commercial vehicle data; and weather data [50].

Probe Data: GPS-based data are available from 9200 commercial trucks with fleet tracking devices operating in the Puget Sound metropolitan region. The GPS devices report their positions at a variety of intervals, ranging from every 30 seconds to every 15 minutes. The intervals are a factor of the age and type of device, and the benefit/cost of the data to the commercial trucking company. These data are snapped to a GIS map representation of the highway network. Only the data points that were successfully "snapped" to one of the study roadway sections were included in the data set. The probe data includes: time, date, latitude, longitude, speed, and heading [51].

Quality

All data, with exception of the ATM sign data, are cleaned and verified for quality. A four-step process was used to clean probe data. The probe data cleaning process erred on the side of data removal to ensure that all data identified as collected on a particular road segment were in fact contained by that segment. UW performed a multi-level quality assurance process in which invalid freeway and arterial sensor data were flagged, removed, and replaced (using interpolation) as appropriate. The Automated License Plate Reader (ALPR) travel time data were cleaned in two steps. In the first step, the City of Seattle and WSDOT cleaned the data to include travel times from only successfully matched plates. In the second step, UW flagged outlier travel times and removed them when computing the 5-minute average travel times. Transit data quality checking guidelines were drawn from King County Metro and from the PhD dissertation of Kari Watkins [52]. Rail schedules were reviewed manually before inclusion in the database. For weather data, simple range and value checks were performed to detect obviously bad weather data. No specific quality assurance tests were applied to the WSDOT ATM data other than simple range and value checks, and to see if all VMS were in fact operational and located on I-5. Quality control procedures are described in detail in elsewhere [53].

Privacy

With the exception of probe data and raw ALPR data, none of the data had any PII. The steps that were taken to anonymize the data set before making it available to USDOT are detailed below.

Probe Data: To preserve the privacy of the trucking company participants, only data points that were placed on the arterials and freeways included in the study were provided in the data set. Each GPS trace is assigned a unique identifier (ID), which allows a user to follow the path of a truck as it travels

along an arterial or a freeway, as long as the truck is within the study area. Once the truck leaves the arterial or the freeway, a new ID is assigned even if the second trip is made on the same day, preventing the user from determining the number of trips or types of movements a specific vehicle makes.

Arterial Data (ALPR Data ONLY): All PII were replaced by UW. Each trip ID was replaced with a new ID every day.

Standards

The data were not formatted to comply with a specific ITS standard.

Metadata

Metadata was made available by UW for the probe, freeway, arterial, weather, incident, ATM sign, and transit data. Noblis has also developed a metadata documentation that complies with the metadata standard for the DCM RDE.

Storage

The data set that is available to the USDOT for connected vehicle research is stored on the DCM RDE and is available to the public for research.

Sponsor Agency

Compilation of the integrated data set and its documentation were sponsored by the USDOT, but the collection and cleaning of the individual data were sponsored by multiple agencies, including WSDOT, City of Seattle, NOAA, CHP, King County Metro, and Sound Transit.

Data Ownership and Intellectual Property Rights (IPR)

The University of Washington owns the vehicle probe data. WSDOT owns the freeway sensor data, and the City of Seattle owns the arterial sensor data. King County Metro owns the transit data, and NOAA owns the weather data. The entire data set is, however, available to the University of Washington for distribution. The University of Washington has agreed to release the data set under the Open Data Commons Attribution License.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.2 Vehicle-Infrastructure Integration (VII) Proof of Concept Test Data Set

Summary

The first major test conducted at the Michigan Test Bed was the VII Proof of Concept (POC) test during 2008. The POC test featured 52 RSEs within 116.5 square kilometers (45 square miles), 27 vehicles configured with OBEs, and a DSRC network. The POC test, which was conducted by Booz Allen Hamilton, had three major phases: subsystem test, system integration and test, and public and

private applications test. The public application testing portion of the POC test was conducted during August 2008.

As the vehicles were driven along the road, at designated events defined by the SAE J2735 standard, the OBEs would take a snapshot of the vehicle and environmental information. When the vehicle would come within transmission range of an RSE, the OBE would transmit one or more probe data messages to the RSE using DSRC protocol and the SAE J2735 standard for probe messages. Note that each probe data message can contain up to four snapshots. The RSE would then send the received messages to a Service Delivery Node (SDN), which is where they would become available to connected vehicle applications.

The POC test data set [53] that is documented in this section was integrated and formatted by Noblis for the DCM Program [54].

Probe Data: Raw and processed probe data messages logged by the vehicles OBEs [55] and probe data messages received by the RSEs [56] are available. Although RSE data from the public application tests were available for eight days in August 2008, the POC test data set includes data for only six days since the first and last days had a high number of duplicate records and questionable data values. Probe data messages follow the SAE J2735 standard for probe messages. In addition, the data set also includes the direction of travel and the name of the road section that the vehicle was traveling on when the snapshot was taken.

Weather Data: Cleaned weather data are available from two Environmental Sensor Stations (ESS) that are located within the Michigan Test Bed, and archived in NOAA's Meteorological Assimilation Data Ingest System (MADIS) [57]. Figure 6-1 shows the locations of the RSEs and ESS (identified as C3800 and C4114) [57].

Quality

Probe data were not verified for accuracy. However, Noblis performed logical consistency checks, removed all duplicate messages and duplicate snapshots from the RSE data files, and added data quality flags [54].

Quality checks on the weather data were conducted by MADIS. These quality checks included: validity (within specified set of tolerance limits), internal consistency, temporal consistency, spatial consistency, and statistical spatial consistency [57].

Privacy

The POC test data set does not include any PII.

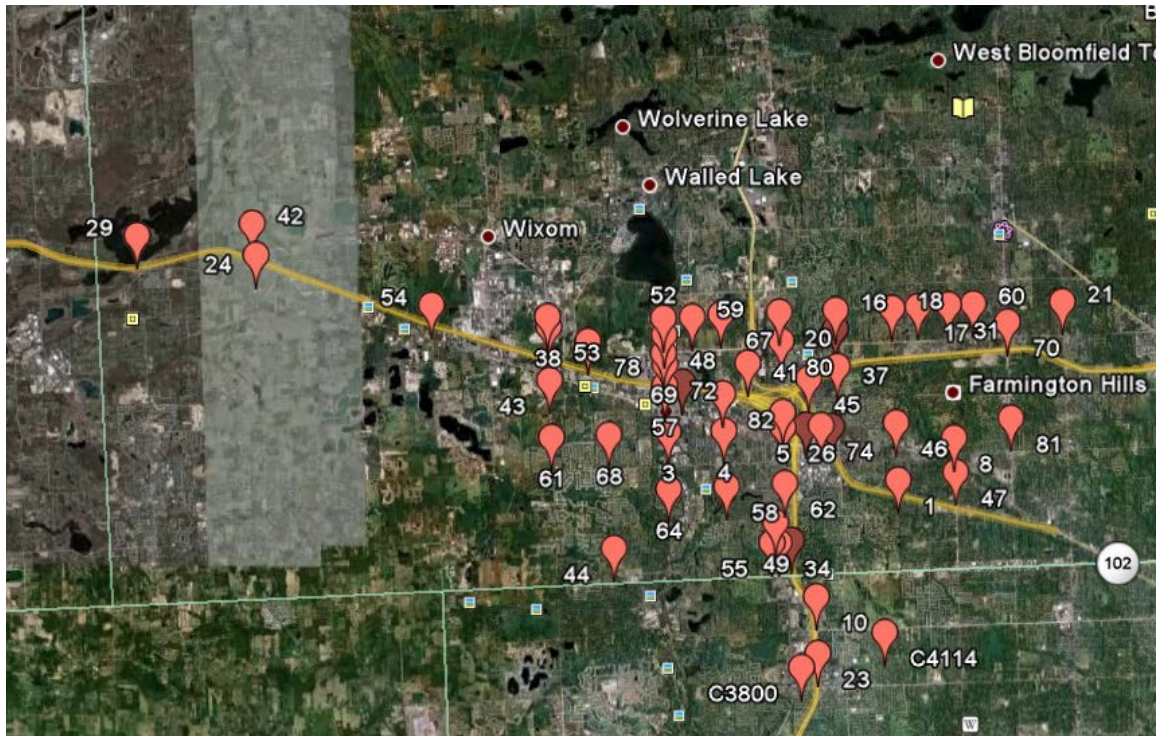


Figure 6-1. Location of RSEs and Environmental Sensor Stations (ESS) (Source: USDOT)

Standards

The probe message data follows the format specified in Version 17A of the SAE J2735 standard. J2735 messages are transmitted in Abstract Syntax Notation (ASN.1) format using Basic Encoding Rules (BER) to minimize the bandwidth required. However, BER files are not human readable and are not machine-readable without an expensive “translation” program. The original data collector has provided a direct “translation” of the BER files to XML format. To make the POC data more accessible to researchers, as part of the support to USDOT’s DCM Program, Noblis developed software to parse the XML files and to create comma-separated value (CSV) versions of the data, which are easier to use than the original XML version of the files. Each message header and each snapshot appears on one line, and individual values are separated by commas. There is one file for each date, containing all messages received by all RSEs.

Weather data also follows the SAE J2735 standard.

Metadata

Noblis has developed a metadata documentation that complies with the metadata standard for the DCM Research Data Exchange (RDE). It is included as an appendix in the document entitled, *Metadata Guidelines for Research Data Exchange* [54].

Storage

The POC test data set is stored on the DCM RDE and is available to the public for research [53].

Sponsor Agency

Capture, processing, formatting, and documenting of the POC test data set were sponsored by the USDOT.

Data Ownership and Intellectual Property Rights (IPR)

The USDOT owns the data set and all IPR associated with the data set.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.3 NCAR Data Set

Summary

The NCAR data sets include data from trials conducted at the Michigan Test Bed under the sponsorship of the National Center for Atmospheric Research (NCAR) to examine the accuracy of atmospheric data. These trials concentrated on collecting data during periods of rain or snow in April 2009 (NCAR 2009), and from late January through early April 2010 (NCAR 2010). The NCAR trials made use of fewer instrumented vehicles than used in the VII POC tests; the data collection and transmission procedures remained the same [58][59].

The NCAR 2009 trials were conducted to collect atmospheric data, in addition to driving and vehicle status data, and examine the accuracy of atmospheric data [58]. The NCAR 2009 trials featured approximately 12 OBE-equipped vehicles. The NCAR 2009 data set includes RSE and OBE data for the six days with the best data out of the nine days in April 2009 when the tests were conducted.

The NCAR 2010 trials were conducted to compare atmospheric data from vehicle mounted sensors to data from a nearby fixed weather observing station [59]. The NCAR 2010 trials made use of 10 OBE-equipped vehicles. The NCAR 2010 data set also includes six days with the best data.

Quality

Quality checks on the weather data were conducted by Meteorological Assimilation Data Ingest System (MADIS). These quality checks included: validity (within specified set of tolerance limits), internal consistency, temporal consistency, spatial consistency, and statistical spatial consistency [57].

Privacy

The NCAR test data sets do not include any PII.

Standards

The probe message data follows the format specified in Version 17A of the SAE J2735 standard. J2735 messages are transmitted in ASN.1 format using BER to minimize the bandwidth required. However, BER files are not human readable and are not machine-readable without an expensive “translation” program; hence a direct “translation” of the BER files to XML format was also provided. To make the XML data more accessible to researchers, as part of the support to USDOT’s DCM

Program, Noblis created CSV versions of the data. There is one file for each date, containing all messages received by all RSEs.

Weather data also follows the SAE J2735 standard.

Metadata

The metadata documentation that Noblis has developed for the VII POC test data set is also applicable for the NCAR data sets (6.1.1.2) [54].

Storage

The NCAR data sets are stored on the DCM RDE and are available to the public for research [53].

Sponsor Agency

Capture, and processing, of the NCAR data sets were sponsored by NCAR. Formatting, and documenting the data sets were sponsored by the USDOT.

Data Ownership and Intellectual Property Rights (IPR)

NCAR owns the data sets and all IPR associated with the data sets. However, the data sets are available to the USDOT for conducting research as well as for making them available on the DCM RDE for research.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.4 TFHRC Data Set

Summary

The TFHRC data set includes data generated at the TFHRC Test Bed (5.1.1.1.2). The TFHRC Test Bed has two OBE-equipped vehicles and two RSEs. The TFHRC data set includes probe data messages that are sent by the 2 vehicles to the RSEs which then send the messages to the SDN in Tennessee. Whenever messages are passed to the SDN, they get captured and archived in the DCM Prototype Data Environment using an automated routine built by Noblis for the DCM Program. The DCM Prototype Data Environment was developed by Noblis for the DCM Program to prototype the data environment concept, to provide access to VII POC test data sets, and to generate requirements for developing the DCM RDE. The automated routine will be revised in the near future to send the data to the DCM RDE.

Probe Data: Raw and processed probe data messages received by the two RSEs and passed through the SDN are available [60]. Probe data messages follow the SAE J2735 standard for probe messages.

Quality

The TFHRC data set has been verified for quality by Noblis for the DCM Program.

Privacy

The data set does not include any PII.

Standards

The probe message data follows the format specified in Version 17A of the SAE J2735 standard. To make the data accessible to researchers, Noblis has created CSV, XML, and KML versions of the data.

Metadata

The metadata documentation that Noblis has developed for the VII POC test data set is also applicable for the TFHRC data set (6.1.1.2).

Storage

The TFHRC data set is currently stored on the DCM Prototype Data Environment, and is available to the public for research.

Sponsor Agency

Capture, processing, formatting, and documenting the data set was sponsored by the USDOT.

Data Ownership and Intellectual Property Rights (IPR)

The USDOT owns the data set and all IPR associated with the data set.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.5 Integrated Mobile Observation (IMO) Data Set

Summary

The Integrated Mobile Observation (IMO) project was sponsored by the USDOT Road Weather Management Program (RWMP) to demonstrate how weather, road condition, and related vehicle data may be collected, transmitted, processed, and used for decision making. Another goal of the project was to provide data to NCAR to enable the enhancement of the Vehicle Data Translator (VDT), which meshes native (i.e., data intrinsic to the vehicle, such as data from the CAN bus) and non-native (i.e., data from external or add-on sensors, such as pavement temperature, relative humidity, plow up or down, etc.) weather-related vehicle observations with traditional weather data (e.g., radar, satellite, fixed weather stations); checks the quality of the observations; and generates road and/or atmospheric hazard products for a variety of end users. The IMO tests were conducted in Minnesota and Nevada in 2011 and 2012 in collaboration with the Minnesota and Nevada State Departments of Transportation (MnDOT and NDOT, respectively) as well as NCAR [61].

The Minnesota IMO data set comprises vehicle and environmental data collected from 160 to 180 snowplows and nine (9) light-duty maintenance trucks (Ford pick-up trucks) operated by MnDOT.

Data were collected from the vehicle CAN bus as well as external sensors. Data that were attempted to be captured from the CANbus include: atmospheric pressure, steering angle, anti-lock braking system, brake status, stability control system, traction control status, differential wheel speed, and emission data. Not all data were successfully collected due to the private nature of PID's (Parameter IDs). Data from the external sensors include: date, time, external air temperature, accelerometer, pavement temperature, rain (rain sensor), yaw rate, relative humidity, wiper status, headlight status, pavement wetness, sun (sun sensor), location, heading, velocity, elevation. The collected data were transmitted via cellular communications [62].

The Nevada IMO data set comprises vehicle and environmental data collected from 12 snowplows and eight light duty trucks operated by Nevada DOT (NDOT) on the I-80 corridor. Data are collected from the vehicle CAN bus as well as external sensors. Data include: date, time, location, bearing, speed, altitude, accuracy, road surface temperature, atmospheric pressure, atmospheric temperature, relative humidity, dew point, speed, brake status, engine intake air temperature and pressure, and spreader and plow status. Data are transmitted using NDOT's 800 MHz Enhanced Digital Access Communications System (EDACS) radio systems since Nevada has limited cellular network coverage [63].

Quality

The data sets were verified for accuracy by NCAR and processed using USDOT's Vehicle Data Translator (VDT).

Privacy

The IMO data sets do include PII. However, since data were generated from public sector fleets, there wasn't any specific concern about inclusion of PII.

Standards

It is unknown if the IMO data sets are formatted to comply with a specific ITS standard.

Metadata

USDOT will be sponsoring the development of metadata documentation in the near future. The metadata will be developed using the data dictionary to be supplied by NDOT/UNR, and will comply with the ASTM 2468-05 metadata standards.

Storage

The anonymized and cleaned data will be available for research through the DCM RDE.

Sponsor Agency

Capture, processing, formatting, and documenting of the IMO data sets were sponsored by the USDOT.

Data Ownership and Intellectual Property Rights (IPR)

Information on data ownership and IPR for the two IMO data sets is not clearly identified. However, both data sets are available to the USDOT for conducting research as well as for making them available through the DCM RDE for research.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.6 Florida Test Bed Data Set

Summary

The Florida Test Bed data set includes data collected during the demonstration at the 18th ITS World Congress in Orlando, Florida in October 2011 (5.1.1.1.4). The purpose of the data set is to test the capability of VADs to capture and store data in the form of the SAE J2735 Basic Safety Message as a prototype for larger scale tests such as the Safety Pilot Model Deployment. The USDOT is working with FDOT to establish a data sharing agreement to acquire data captured during the World Congress as well as data currently being generated at the Test Bed.

Probe Data: The VADs recorded vehicle data during the World Congress and continue to record data after the World Congress. The VADs are periodically removed from the vehicles to retrieve the data files. Data collected in September and October 2011 will be available on the DCM RDE. Basic safety messages and probe data messages that were received by the 29 RSEs, deployed along 40.2 kilometers (25 miles) of freeways and arterials around the Orlando Convention Center, and the data that continue to be recorded on the VADs since October 2011 are currently not available for posting on the DCM RDE.

Quality

The data have not been verified for quality. The data files are presented exactly as they were recorded on the VADs. No additional data checking or corrections were performed by FDOT. Moreover, FDOT does not make any claims regarding data completeness. There may be gaps in the data provided.

Privacy

It is unknown if the FDOT data set includes any PII.

Standards

The data elements were recorded on the VADs in pcap (packet capture) format. FDOT extracted the data files from the vehicles' VADs and provided them in their original pcap format. FDOT also converted the files from pcap format to CSV format for inclusion in the DCM RDE.

Metadata

Noblis has developed metadata documentation for the FDOT data set that complies with the ASTM 2468-05 metadata standards. The metadata documentation effort was funded by the DCM Program.

Storage

The anonymized and cleaned data will be available for research through the DCM RDE.

Sponsor Agency

Formatting and documenting of the Florida Test Bed data sets will be sponsored by the USDOT.

Data Ownership and Intellectual Property Rights (IPR)

FDOT owns the data set and all IPR associated with the data set. However, as part of the data sharing agreement with FDOT the data set will be available to the USDOT for conducting research as well as for making it available on the DCM RDE for research.

Cost

The data set will be available at no cost through the DCM RDE.

6.1.1.7 Mobile Millennium Data Set

Summary

The data were collected during the Mobile Century experiment run by UC Berkeley and Nokia, funded by Caltrans [64]. The project was run on February 8, 2008 between 10:00 AM and 6 PM (PST) on Interstate 880 (I-880), in San Francisco, CA. Over one hundred graduate students from UC Berkeley were employed to drive along Interstate 880 between Hayward and Fremont, California, for an entire day. This section of I-880, which is about 11.3 miles long, runs parallel to the southeastern shore of San Francisco Bay. The data set includes probe data from GPS-enabled cell phones, loop detector data from PeMS, and travel time data obtained through vehicle re-identifications using high resolution video data.

Virtual Trip Line Data: Virtual trip line data consists of two files, one for the Northbound direction and the other for the Southbound direction. The virtual trip lines are implemented by receiving a signal from a mobile device as it passes a virtual trip line location. There are 62 northbound and southbound trip line locations. Each file entry contains the ID and location of the virtual trip line, the time at which the measurement was taken, and the speed (mph) of the mobile device in the vehicle as it crossed the trip line.

Ground Truth Travel Time: There are two files containing Northbound travel times. The first file contains travel times on I-880 from Stevenson Boulevard to Decoto Road, and the second file contains travel times on I-880 from Decoto Road to Hinton Avenue. The location of these intersections is shown in Figure 6-2. Travel times were obtained through vehicle re-identification using high resolution video data. Each entry in the files contains only a departure time and the number of seconds taken. There is no vehicle identification information in the data file.

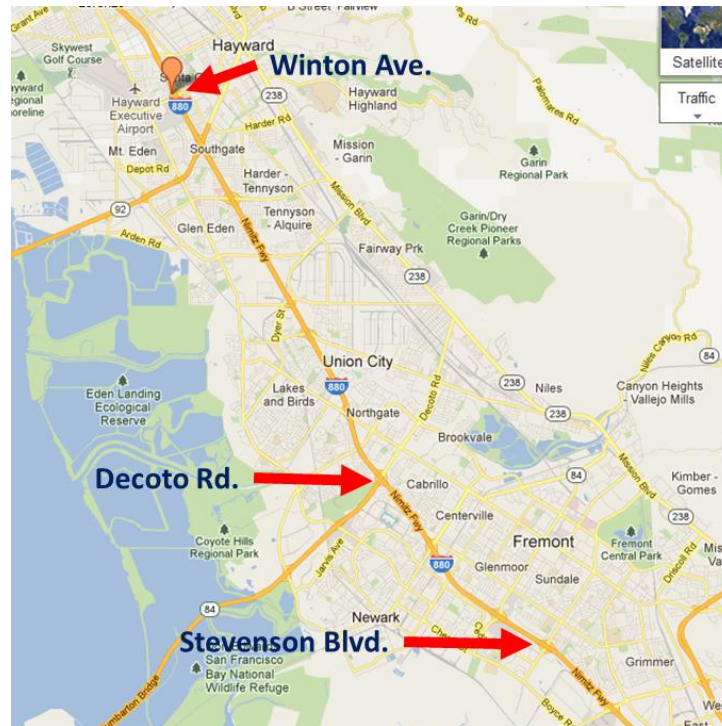


Figure 6-2. Intersection used for Ground Truth Travel Time Estimations (Source: University of California - Berkeley)

Vehicle Trajectory Data: Two types of vehicle trajectory data are provided. The first is the individual trip data, which includes individual trips in one direction. There are 1,388 northbound trips and 1,512 southbound trips. Each file contains the following: Unix time, latitude, longitude, post mile, and speed, recorded every 3 to 4 seconds. Parts of the data when a vehicle is not on the highway are excluded from the individual trip data. The second type of trajectory data that is provided is the individual phone log data, which includes the unprocessed location of the vehicles whose trips are in the individual trip data file. There are 77 log files from participating vehicles with Nokia N95 mobile devices. Each log file contains the following: Unix time, latitude, longitude, and speed. Speeds are estimated based on the GPS coordinates which are recorded every 3 to 4 seconds.

Loop Detector Data: Flow and occupancy data are reported every 30 seconds from 27 northbound loop detectors and 31 southbound detectors along I-880. The loop detector data were obtained from the Freeway Performance Measurement Systems (PeMS). The loop detector data include: detector ID, time, 30-second flow by lane, and 30-second occupancy by lane. A separate file provides the location (latitude, longitude, and milepost) of each loop detector.

Quality

The data set is verified for quality.

Privacy

The data set does not include any PII. All identifiers assigned to the cell phones were randomized to protect the participants in the experiment. The video data were also processed and a random number

was assigned to represent each vehicle. The loop detector data do not contain any PII. The speeds from virtual tripline locations record only location, time, and speed of a passing vehicle. An entry could come from any of the over 100 equipped vehicles. The travel times were based on re-identification of a vehicle, but the identifying information was discarded. Moreover, the identifying information is a random number assigned to represent each vehicle.

Standards

It is unknown if the Mobile Millennium data set is formatted to comply with a specific ITS standard.

Metadata

Data documentation is available for download from the Mobile Millennium web site [65].

Storage

The anonymized and cleaned data are available for research and analysis purpose only through the Mobile Millennium web site.

Sponsor Agency

Caltrans under a cooperative agreement with USDOT funded the joint UC Berkeley-Nokia project.

Data Ownership and Intellectual Property Rights (IPR)

According to the user agreement [65], the data may be used for research and analysis purposes only, but will not be redistributed. However, information on the data ownership and IPR associated with the data set is not publicly available. It is expected that Caltrans, UC Berkeley, and Nokia own the data, and that UC Berkeley and Nokia hold the IPR to the data processing.

Cost

The data set will be available at no cost for research and analysis purposes only from the Mobile Millennium web site.

6.1.2 Private sector probe data

In 2010, the Federal Highway Administration's (FHWA) Office of Operations sponsored a research project to examine the technical and institutional issues associated with the use of private sector travel time and speed data for public sector performance management. The effort led by Battelle and Texas Transportation Institute (TTI) produced a report [66] that examined issues associated with blended or fused traffic data, and concluded that what is most important is the accuracy of the end product (i.e., average travel times and speeds), which can be evaluated with several different quality assurance methods. The report also described a process to integrate private sector travel time data with public agency traffic volume data for a more comprehensive performance reporting system.

The report included a state-of-the-practice review of products and services offered by private sector data providers, and public sector agency uses of the private sector data products and services. Private sector data providers who were surveyed included: AirSage, American Trucking Research Institute (ATRI), INRIX, NAVTEQ, TomTom, and TrafficCast.

Data providers capture probe data from cell phones, Bluetooth systems, commercial GPS, and fleet GPS; process them; and make them available to public sector agencies and other data consumers. All surveyed data providers provide at a minimum, speed, travel time, and incident data. All six data providers provide discrete data, i.e., all individual data points that are captured on a segment within a timeframe are provided. When purchasing discrete data, a consumer would get all of the individual speeds or travel time points within a section; whereas when purchasing aggregate data they would only get one value for the section. All data providers verify the accuracy of their data, but almost none, with the exception of INRIX, indicate the level of accuracy when data are bought from them. Table 6-1 of the report summarizes the survey results [66]. Waze has been added to the table, but was not part of the survey.

Quality

Private sector data are typically verified for quality.

Privacy

Private sector data do not typically include any PII.

Standards

Information on the use of standards for formatting the data is not available.

Metadata

Information on the use of metadata standards for documenting the data is not available.

Storage

Private sector data that are not available to the USDOT for conducting research will not be stored and made available through the DCM RDE.

Sponsor Agency

In general, the private sector data provider is the sponsoring agency.

Data Ownership and Intellectual Property Rights (IPR)

In general, the private sector data provider owns the data set and all IPR associated with the data set.

Cost

There is cost associated with acquiring private sector data, although specific pricing information is not available. To procure data collected by the private sector, there are two options [26]:

- **Partnership with Private Entity:** The private sector provides a contracted service or commodity for a fee to the public sector; this could be to supplement what the public sector is already doing or to address a gap in public-sector coverage, capabilities, or technical resources. In addition, the private sector could be an “in kind” partner, who obtains access to data that are

- generated by the public sector (often at no charge to the private sector), and then uses that data to support the private business model and activities.
- **Buy Data:** The private sector provides a substantial operations or other role, for a fee, and is an essential partner in the development or delivery of a service. It should be noted that most often the information that is available for purchasing is not the “raw” probe data; rather it is the data or information derived from the raw probe data, such as link travel times, average speeds, etc.

Table 6-1. Summary of Private Sector Data Products and Services (Source: TTI)

	Airsage	ATRI	INRIX	NAVTEQ	TomTom	TrafficCast	Waze
Data Available ^[a]	S, TT, I, Q	S, TT, Q	S, TT, I, Q	S, TT, I, Q, V (portion of network)	S, TT, I, Q	S, TT, I, Q	S, TT, I
Services Available ^[b]	D, A, PM	D, A, PM	D, A	D, A	RD, A, PM	D, PM	D
Data Source ^[c, d]	Cell phone, 911, traffic counts	GPS on commercial truck-only fleets	State installed sensors, commercial fleets, consumer GPS	State installed sensors, commercial fleets, consumer GPS	Consumer GPS, Fleet GPS	State installed sensors, commercial fleets, consumer GPS, Bluetooth systems	GPS enabled cell phones
Aggregation Levels for Historical Usage	None, as captured	1 mile, 1 minute	15-60 minutes	15 minutes	1 hour	15 minutes	Unknown
Accuracy Checks Performed	Visual camera count, probe vehicles	Anomaly checking done, routines not disclosed	Independently verified in large-scale testing	Data checks prior to map matching. Comprehensive drive testing.	Data checks prior to map matching.	Simple-adjacent points compared, some clients doing accuracy checks.	Traveler verifies accuracy and reports anomalies with travel times and maps.
Documented Quality Levels	None provided. Stated they meet section 511 requirements.	None, burden is on receiver of data	Accuracy above 95% Availability above 99.9%	None provided.	None provided. Stated they meet section 511 requirements.	None provided. Stated they meet section 511 requirements.	None provided.

	Airsage	ATRI	INRIX	NAVTEQ	TomTom	TrafficCast	Waze
Pricing	Specific pricing information not provided.	Specific pricing information not provided. Not for profit.	Full use open licensing is \$800 per mile per year plus \$200 per mile one-time setup fee. 25% discount on other roads purchased in conjunction.	Specific pricing information not provided.	Specific pricing information not provided.	Specific pricing information not provided.	Free

Notes:

[a] Data Available: S = Speed, TT = Travel Time, Q = Quality, V= Volumes, I = Incidents, GPS= GPS fleet

[b] Services Available: D = Discrete Data (Individual data points), A = Aggregate Data, PM = Performance Measures

[c] National Coverage: Not listed in table. All providers indicated national coverage, except TrafficCast which is currently in urban areas

[d] Map Matching: Not listed in table. All providers except ATRI indicated a minimum use of TMC. ATRI uses mileposts. INRIX, NAVTEQ, and TomTom also use proprietary segmentation more detailed than TMC.

6.1.3 Key Findings

USDOT's DCM Program has adopted the tenet of "collect once, preserve, use many times," to support the development of the broadest possible collection of applications while fully leveraging federal research investment [67]. This tenet has become even more noteworthy as the USDOT gets ready to capture a substantial amount of probe data in the next two years to support connected vehicle research in the US. The USDOT-sponsored Safety Pilot that started in August 2012 will generate significant driver behavior and probe data that have previously not been available. In the next two years USDOT will also be embarking on the development and test of safety, mobility, environmental, and road-weather applications that will necessitate the development of relevant probe data environments. State and local agencies are keen on sponsoring (in some instances, jointly with USDOT) connected vehicle research to address safety and congestion issues on their transportation systems, by testing applications, equipment, communications, interfaces, etc., on local test beds (e.g., MCDOT Connected Vehicle Test Bed, Michigan V2V/V2I Test Bed, or one of the test beds). These tests will produce additional probe data that will be of value to the community engaged in connected vehicle research.

Data that are collected from diverse sources and for diverse purposes can be of lasting value to a broad range of researchers, private sector partners, and system operators, if the data: are available; are of sufficient quality and consistency required for the applications that are being developed; are anonymized to protect the privacy of individuals whose trips constitute the probe data; are formatted to comply with a standard to allow interoperability; have supporting metadata to facilitate use of the data; are easily accessible; and have clearly identified licensing and IPR to enable use of the data without violating any rights. Key findings include:

- **Quality Assurance:** The quality of policy and investment decisions is dependent on the quality of the data that informs the decision-making process. A review of the probe data sets reveals that data were verified for accuracy and consistency. However, none of the data sets identified the actual quality of the data. Agencies have their own internal procedures for performing quality control checks. Public sector data providers made their quality control procedures publicly available; while private sector data providers, with the exception of INRIX, publicized neither the processes nor the actual quality of their data sets. When assessing if the data are of sufficient quality for conducting research, it is important to determine how the data provider defines accurate or consistent data and what quality assurance processes are used. *A consistent definition of what constitutes accurate or consistent probe data needs to be established, and adopted by public and private sector data providers. Additionally, quality assurance processes need to be established.*
- **Privacy:** Federal and state laws recognize a certain degree of privacy with respect to driver information [66]. Probe data that are publicly available need to comply with the Fair Information Principle Practices (FIPPs) policy to protect PII. Data capture efforts that were reviewed revealed that data providers have established processes to remove PII from probe data. These ranged from eliminating the start and end segments of a trip, to assigning new IDs to a trip every day, to assigning temporary random IDs to a trip that only persisted for part of the trip. *A consistent approach to anonymizing probe data needs to be established, and adopted by public and private sector data providers.*
- **Standards:** Detailed standards for data and interface are critical for interoperability. Integrating data from multiple sources, especially in real time, requires the need for detailed guidelines and standards. As part of the Mobility Program, USDOT has sponsored an effort to examine existing standards and identify gaps [67]. This effort conducted a high-level assessment of

applications described later in 7.1 to identify gaps in standards and suggest an action plan to address the gaps. A key finding was that there are eight standards that address vehicle-to-vehicle and vehicle-to-infrastructure connected vehicle systems, but few ITS Standards for data exchange between travelers' portable devices and the infrastructure or vehicles (See Table 6-2). Another key finding was that Version 6.1 of the National ITS Architecture (NITSA) did not address wireless communications other than 5.9 GHz. Mobility and environmental applications will examine communications other than DSRC, such as cellular, Wi-Fi, for data exchange, and will heavily rely on data from travelers' portable devices in addition to data from vehicles and the infrastructure. *Standards need to be established to reflect the evolving needs of probe data research that capture a wide-range of communication technologies, and data sources.*

- **Metadata:** Metadata is critical to increasing the usability of the probe data. A review of the probe data sets revealed that data providers included data dictionaries and supporting documentation. However, there is no consistent approach to documenting the data. USDOT has adopted the ASTM 2468-05 metadata standards for data that are made available on the DCM RDE. However, the USDOT does not preclude use of other metadata standard. *One or more metadata standards for probe and supporting data need to be established and adopted by public and private sector data providers to increase usability of their data.*
- **Storage and Access:** To allow researchers easy access to probe data collected from various efforts, data needs to be readily and easily accessible. A review of the probe data efforts revealed that probe data collected through the sponsorship of USDOT would be either stored on or federated via the DCM RDE. For example, FDOT archives probe data generated at the Florida Test Bed in its SunGuide® system. To avoid duplication and prevent inconsistencies that develop from duplication, the DCM Program may choose to federate the FDOT probe data from the DCM RDE. When data are not archived by the data collector, the USDOT may choose to store the data and make it available on the DCM RDE. It is unknown if data that are not collected in partnership with USDOT are archived by the data provider. *Decentralized storage and selective federation are emerging data management practices to improve quality management and data integration without full centralization.*
- **Data Ownership and IPR:** To enable broad sharing of probe data it is critical to protect the IPR of entities that sponsor or conduct the data capture and management efforts. Having no clearly defined licensing agreement can cause ambiguity to data ownership and rights of use. Where data are observed to have value to a broad set of stakeholders this issue can become a serious and contentious issue [68]. Alternately, highly restrictive data sharing agreements can prevent broad utilization of data, even in federally-funded research programs [68]. A licensing agreement also provides a mechanism to indemnify the data provider from any liabilities. A review of the probe data efforts revealed that most efforts did not clearly identify data ownership and IPR for their data. For USDOT-sponsored efforts, USDOT has signed data sharing agreements with public sector agencies to allow use of anonymized data for research and to make them available on the DCM RDE. For example, data providers of the DCM test data sets agreed to make the data sets available for research under the Open Data Commons Attribution License. *Clear guidelines need to be established for identifying data ownership and licensing, including IPR, of probe data, supporting data, and processing tools.*

Table 6-2. Standards Relevant to Connected Vehicles

Standard	Description
SAE J2735	Standard for Dedicated Short Range Communications (DSRC)
ASTM E2213-03	Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems - 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications
IEEE 802.11p	Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part II: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification
IEEE 1609.4-2006	Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation
IEEE 1609.3	Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services
IEEE 1609.2-2006	Standard for Wireless Access in Vehicular Environments (WAVE) - Security Services for Applications and Management Messages
IEEE 1609.1-2006	Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager
IEEE P1609.0	Standard for Wireless Access in Vehicular Environments (WAVE) - Architecture

6.2 Probe Data in Japan

6.2.1 Probe data of Japanese Government

Configuration of Probe Data

The probe data collected by ITS Spots consists of basic information, travel record information, and behavior record information. Each of them is described below.

Basic information: The basic information consists of data on the ITS Spot-compatible car navigation systems (wireless unit information such as manufacturer and model number, and car navigation system information such as manufacturer and model number) and data about the vehicle. The vehicle data consists of a portion of the vehicle information provided by the user when setting up their ITS Spot-compatible car navigation systems. The vehicle identification number and a portion of the license plate information are excluded, making it impossible to identify the vehicle, the driver or the vehicle owner.

Travel record information: The travel record information includes time stamps, coordinates, and road categories (expressway, inner-urban expressway, arterial road, or other). This would be a great deal of data to store, if data was gathered and stored continually during travel. Therefore, travel record information is stored only at certain points: every 200 meters (660 feet) after a trip commences; or after changing orientation by at least 45 degrees from the previous data storage point (See Figure 6-3). The maximum storage capacity of an ITS Spot-compatible car navigation systems corresponds to approximately 80 km (50mi) of travel. Table 6-3 lists the data items that are collected.

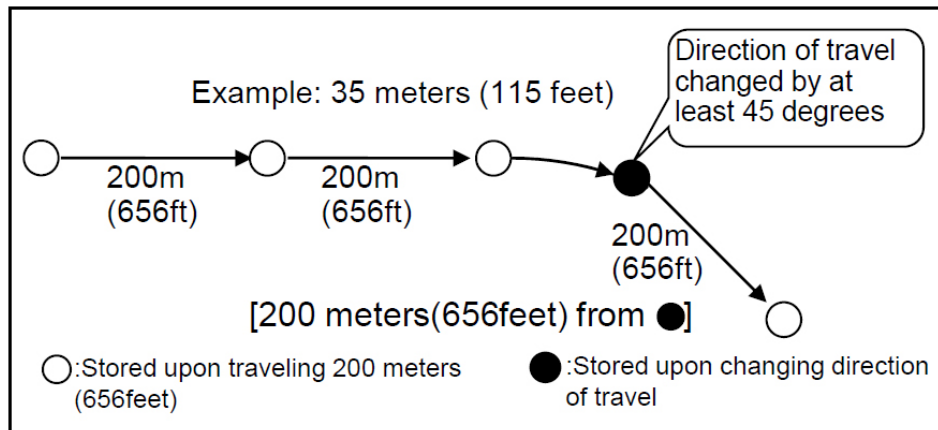


Figure 6-3. Timing of travel record data storage (Source: MLIT)

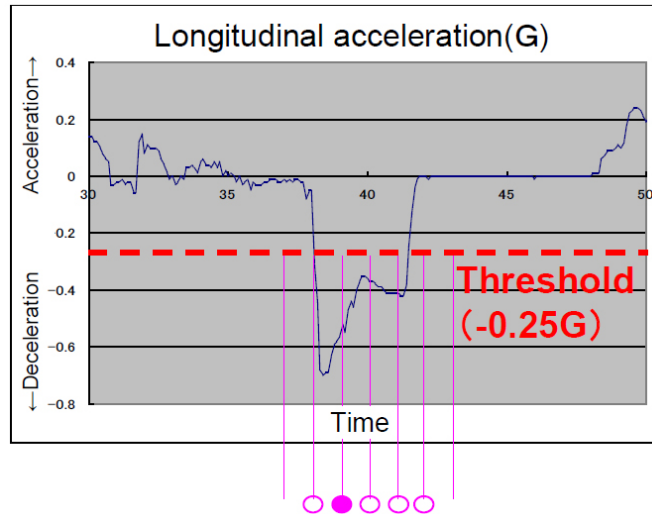
Table 6-3. Travel record data items (Source: MLIT)

Data item	Resolution
Time stamp	1 sec
Coordinates	10^{-5} degrees
Road categories	Expressway, inner-urban expressway, arterial road, or other
Velocity (option)	1km/h (0.621mi/h)
Altitude (option)	1 meter (3.28 feet)

Behavior record information: The behavior record information consists of time stamps, coordinates, direction, road category, longitudinal acceleration, lateral acceleration, and yaw angular velocity. In order to limit the amount of data accumulated, behavior record information is recorded only when a sudden braking or a sharp turn of the steering wheel occurs. This is done, because such events could occur at the time of an accident. Although an ITS Spot-compatible car navigation system monitors vehicle behavior data at fixed intervals, only the highest peak value of the data is stored whenever longitudinal acceleration, lateral acceleration, or yaw angular velocity exceeds predetermined thresholds (see Table 6-4 and Figure 6-4). Up to 31 events can be stored. Table 6-5 lists the items of data that are collected.

Table 6-4. Behavior record thresholds (Source: MLIT)

Data item	Resolution
Longitudinal acceleration	-0.25 G
Lateral acceleration	± 0.25 G
Yaw angular velocity	± 8.5 deg/sec



Sensing occurs at fixed intervals, and if a threshold is exceeded, only the highest peak value is selected and recorded. (The value indicated as ● in the figure above is recorded.)

Figure 6-4. Timing of behavior record data storage (Source MLIT)

Table 6-5. Behavior record data items (Source: MLIT)

Data item	Sensing Frequency	Resolution
Time stamp	1.0 sec	1 sec
Coordinates	1.0 sec	10 ⁻⁵ degrees
Direction	1.0 sec	16 points
Road categories	1.0 sec	Expressway, inner-urban expressway, arterial road, or other
Velocity (pulse)	0.3 sec or less	1 km/h (0.621mi/h)
Longitudinal acceleration	0.3 sec or less	0.01 G
Lateral acceleration	0.3 sec or less	0.01 G
Yaw angular velocity	0.3 sec or less	0.1 deg/sec

Retention of probe data

The probe server can retain collected raw probe data, including basic information, travel record information and behavior record information, and aggregated calculation data, including tables of travel times, travel time data per DRM link per 15-minute period, and travel time data of every hour per basic sections. This basic section information is used for the Road Traffic Survey conducted by MLIT every five years. The retention period of each type of data is indicated in Table 6-6.

Table 6-6. Probe data retention periods (Source: MLIT)

Category	Type of data	Retention period
Raw data	Basic information	90 days
	Travel record information	
	Behavior record information	
Aggregate calculation data	Travel time tables	60 days
	travel time data per DRM link per 15-minute period	3 years
	travel time data of every hour per basic section for the road traffic survey	3 years

Quality assurance of probe data

One of the probe server's functions is to eliminate abnormal data from among the data uplinked from ITS Spot-compatible car navigation systems through ITS Spots. This is to assure data quality. In addition, the server has a filter function for removing certain errors in the data, in the process of data aggregation. For example, if a vehicle speed on a specific road section calculated by collected data is significantly different than the average speed of all vehicles, the vehicle's data is removed.

6.2.2 Private sector probe data

There were no references that had been made available regarding the details of private sector probe data.

6.3 Comparison of Probe Data

This section compares the characteristics of probe data generated by connected vehicle systems in the US and ITS Spot in Japan. Table 6-7 specifically compares SAE J2735 BSM Part 1, elements of SAE J2735 Probe Data Message that are common to BSM Part 1, and ITS Spot probe data. SAE J2735 Probe Data Message also includes other data elements that are identical to elements of SAE J2735 BSM Part 2, but the focus of Table 6-7 is on those that are common with BSM Part 1. In addition to the data elements listed in the table, vehicles equipped with connected vehicle technology in the US are also capable of generating BSM Part 2 data elements, although these are optional and vary by manufacturer. The table shows that ITS Spot probe systems generate most of the data elements contained in BSM Part 1; the differences are in the message protocol, including data generation frequency, storage and transmission. Table 6-8 provides a summary comparison of the data elements included in BSM Part 1, Probe Data Message, and ITS Spot probe data.

Table 6-7. Comparison of Probe Data Generated by Connected Vehicle Systems and ITS Spot

Probe Data Elements	BSM 1 [a]- Data Generation Frequency	PDM [b] - Data Generation Frequency [c]	ITS Spot [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ITS Spot – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ITS Spot – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ITS Spot – Unit
Time Stamp	0.1 second	Only after 500 m (1,600 ft.) or 120 seconds, whichever occurs first, from origin. Generated periodically [f] OR event triggered [g] OR when vehicle starts [h] or stops [i].	Only after several hundred meters from origin; 1 second	No	30 snapshots Order of deletion: Periodic, Start/Stop, Event Order of deletion for periodic: 2 nd oldest, 4 th oldest, and so on.	Every 200 m (660 ft.) OR if direction changed by at least 45 degrees OR event triggered (and when longitudinal acceleration, lateral acceleration, or yaw rate exceed pre-determined thresholds); Data generated within several hundred meters of origin and destination are deleted.	Broadcast every 0.1 second	Once when in range of RSE. Order: Event, Start/Stop, Periodic	Once when in range of ITS Spot	Milliseconds from UTC time	Milliseconds from UTC time	Seconds
Roadway Type	Not available	Not available	See corresponding entry for " Time Stamp "	Not available	Not available	See corresponding entry for " Time Stamp "	Not available	Not available	See corresponding entry for " Time Stamp "	Not available	Not available	Expressway, inner-urban expressway, arterial road, or other
Longitude	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	No	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	See corresponding entry for " Time Stamp "	1/10 th Micro degree	1/10 th Micro degree	10 ⁻⁵ degrees

Probe Data Elements	BSM 1 [a]- Data Generation Frequency	PDM [b] - Data Generation Frequency [c]	ITS Spot [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ITS Spot – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ITS Spot – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ITS Spot – Unit
Latitude	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	1/10 th Micro degree	1/10 th Micro degree	10 ⁻⁵ degrees
Elevation	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	Optional	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	10 centimeters	10 centimeters	Meters
GPS Position Accuracy	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	Not available	No	See corresponding entry for “Time Stamp”	Not available	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	Not available	0.05 m	0.05 m	Not available
Speed [j]	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.3 seconds or less	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.02 meters/second	0.02 meters/second	km/h
Longitudinal acceleration	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.3 seconds or less	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.01 meters/second ²	0.01 meters/second ²	0.01 G
Lateral acceleration	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.3 seconds or less	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.01 meters/second ²	0.01 meters/second ²	0.01 G
Vehicle yaw rate	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.3 seconds or less	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	0.01 degrees/second	0.01 degrees/second	0.1 degrees/second
Heading/ Direction	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	1 second	No	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	1.5 degrees	1.5 degrees	16 points

Probe Data Elements	BSM 1 [a]- Data Generation Frequency	PDM [b] - Data Generation Frequency [c]	ITS Spot [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ITS Spot – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ITS Spot – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ITS Spot – Unit
Brake system status (Brake applied, traction control, stability control, ABS, brake boost, auxiliary brake)	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	No	See corresponding entry for “ Time Stamp ”	Not available	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	See note [k]	See note [k]	Not available
Vehicle length	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	No	See corresponding entry for “ Time Stamp ”	Not available	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	Centimeters	Centimeters	Not available
Vehicle width	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	No	See corresponding entry for “ Time Stamp ”	Not available	See corresponding entry for “ Time Stamp ”	See corresponding entry for “ Time Stamp ”	Not available	Centimeters	Centimeters	Not available

Notes:

[a] Connected Vehicle System - SAE J2735 Basic Safety Message Part 1 (US)

[b] Connected Vehicle System - SAE J2735 Probe Data Message (US)

[c]: New IDs are generated randomly by a vehicle every 120 seconds or 1 km (0.6 mi), whichever comes later for anonymity.

[d] ITS Spot (MLIT)

[e]: New IDs are generated whenever the engine is turned off.

[f]: Periodic snapshot is generated: every 4 seconds if speed ≤ 32.2 km/hour (20 mph), every 20 seconds if speed ≥ 96.6 km/hour (60 mph), linear interpolation between 4s and 20s if 32.2 km/hour < speed < 96.6 km/hour.

[g]: Event triggered snapshots are generated when change in vehicle status elements, either a state change (e.g., from off to on) or when a value exceeds a specific threshold or undergoes a transition (e.g., traction control is switched from off to on).

[h]: Start snapshot is generated when the vehicle speed exceeds 16.0934 km/hour (10 mph) after a stop.

[i]: Stop snapshot is generated when there is no movement for 5 seconds. Subsequent stop snapshots are generated only if vehicle is stopped for 15 seconds.

[j]: Instantaneous speed

[k]: Two bytes are reserved for Brake System Status. Each of the first four bits indicates whether brakes are active for a given wheel on the vehicle. A value of “1” indicates an active brake. The fifth bit is set to “1” to indicate when this data is unavailable. The sixth bit is reserved at this time (and set to zero). The next five 2-bit fields indicate the status respectively of the traction control system, the anti-lock brake system, the stability control system, the brake boost system, and the auxiliary brake system. A value of “0” (i.e., “00”) in the 2-bit fields implies the corresponding subsystem status is unavailable; “1” (i.e., “01”) implies it is off; “2” (i.e., “10”) implies it is on but not engaged; “3” (i.e., “11”) implies it is engaged.

Table 6-8. Summary Comparison of Data Elements in J2735 BSM Part 1, J2735 Probe Data, and ITS Spot Probe Data

Data Elements	US		Japan - ITS Spot
	J2735 BSM Part 1	J2735 Probe Data	
Position (Longitude, Latitude, Elevation)	✓	✓	✓
GPS Position Accuracy	✓	✓	
Speed	✓	✓	✓
Acceleration (Longitudinal, Lateral)	✓	✓	✓
Vehicle Yaw Rate	✓	✓	✓
Heading/Direction	✓	✓	✓
Vehicle Length, Width	✓	✓	
Roadway Type			✓
Time Stamp	✓	✓	✓
Vehicle Subsystem Status (brake, traction control, stability control, ABS, brake boost, auxiliary brake)	✓	✓	

7 Candidate List of Probe Data Enabled Applications

This chapter identifies a list of candidate applications that may be developed using probe data that have the potential to improve roadway operations, planning and maintenance; to provide better traveler information than what is currently available; and to mitigate negative environmental impacts.

7.1 Candidate list proposed by USDOT

This section summarizes six high-priority bundles of applications identified by USDOT's DMA Program, three transformative concepts identified by USDOT's AERIS Program, and four concepts proposed by USDOT's Road Weather Management Program.

7.1.1 High-Priority Mobility Bundles Proposed by USDOT

The DMA Program identified, with input from stakeholders, six high-priority bundles of applications [69] that have the potential to improve the nature, accuracy, precision and/or speed of dynamic decision making by both system managers and system users. Each bundle comprises two or more applications that make use of probe data. All proposed bundles are in the conceptual phase.

7.1.1.1 *Enable Advanced Travel Information System (Enable-ATIS)*

Enable Advanced Traveler Information System (Enable ATIS) seeks to provide a framework for multi-source, multimodal data to enable the development of new advanced traveler information applications and strategies. It is a transformative concept of the traveler information community that will:

- Improve transportation system mobility and safety by better informing agencies and individuals,
- Foster multi-source data integration and delivery, transforming the user experience,
- Advance research with new forms of data about traveler behavior and response to transportation operations, and
- Promote development of dynamic and transformative applications for real-time, multi-modal traveler information.

An Operational Concept has been developed for the bundle. Data and communication needs have not yet been defined. However, it is expected that the bundle will utilize real-time and historical probe data (as defined in Section 4), infrastructure data, transit-specific data (e.g., transit availability, routes, and schedules), road-weather data (e.g., pavement conditions, visibility, presence and impact of adverse weather), traveler choice data (e.g., origin, destination, and desired departure time, arrival time, mode, and route), parking data, and event data; process and aggregate the multi-source data; predict trip-specific travel times, and provide end-to-end planning information, including suggesting potential departure times, routes, modes (e.g., auto, transit, bicycle, walk), parking, etc. Planning

information may include approximate travel times, travel time reliability, and costs for each alternative. The end-to-end planning information may be disseminated via DSRC from the RSE to in-vehicle devices, or via cellular directly from a service provider to portable devices of travelers who have opted to receive the traveler information. The information may also be used by state and local agencies to manage their systems. The role of public versus private sector is still being explored.

Expected key benefits from this bundle include:

- Multi-modal end-to-end trip planning information (time of departure, cost, mode, route, parking) integrated with search results will be common;
- Corridor or regional transportation management systems utilizing systematically obtained traveler trip data will become a state-of-the practice; and
- Predictability and reliability of travel will increase.

This bundle has little potential to realize its full benefits if only probe data, as defined in Section 4, were used without supplementary data to provide comprehensive picture of the travel conditions.

7.1.1.2 Freight Advanced Traveler Information System (FRATIS)

Freight Advanced Traveler Information System (FRATIS) will provide freight-specific route guidance and optimizes drayage operations so that load movements are coordinated between freight facilities to reduce empty-load trips. The applications that compose FRATIS are:

- Freight-Specific Dynamic Travel Planning and Performance
 - Enhances traveler information systems to address specific freight needs
 - Integrates data on wait times at intermodal facilities (e.g. ports), incident alerts, road closures, work zones, routing restrictions (hazmat, oversize/overweight)
- Drayage Optimization (DR-OPT)
 - Optimizes truck/load movements between freight facilities, balancing early and late arrivals
 - Individual trucks are assigned time windows within which they will be expected to arrive at a pickup or drop-off location

The Freight-Specific Dynamic Travel Planning and Performance application will provide traveler information, dynamic routing, and enable performance monitoring by leveraging existing data in the public domain, as well as emerging private sector applications. The Intermodal Drayage Operations Optimization application will combine container load matching and freight information exchange systems to fully optimize drayage operations, thereby, minimizing bobtails/dry runs and wasted miles and spreading out truck arrivals at intermodal terminals throughout the day. These improvements would lead to corresponding benefits in terms of air quality and traffic congestion. To support these applications, the FRATIS system will need to integrate data from multiple sources:

- Connected vehicle data – Probe data (as defined in Section 4), road weather data, and infrastructure data. Queue lengths at intermodal terminals will need to be predicted;
- Regional ITS data – Such as truck parking locations and availability, and route restrictions;
- Truck movement data from third parties – Such as truck speeds and position data from GPS devices in trucks if trucks are not equipped with connected vehicle technology; and
- Intermodal terminal data – Such as container availability updates.

Expected key benefits from this bundle include:

- Reduction in terminal queue time,
- Reduction in travel time,
- Reduction in freight-involved incidents, and
- Reduction in weight-compliance infractions (i.e., percentage of vehicles over legal gross weight limit).

A Concept of Operations and System Requirements have already been developed, and a prototype will be developed in the next 12 to 18 months.

7.1.1.3 Integrated Dynamic Transit Operations (IDTO)

Integrated Dynamic Transit Operations (IDTO) will facilitate passenger connection protection, provide dynamic scheduling, dispatching, and routing of transit vehicles, and facilitate dynamic ridesharing. The applications that compose IDTO are:

- *Connection Protection (T-CONNECT)*, which enables coordination among public transportation providers and travelers to improve the probability of successful transit transfers;
- *Dynamic Transit Operations (T-DISP)*, which links available transportation service resources with travelers through dynamic transit vehicle scheduling, dispatching and routing capabilities; and
- *Dynamic Ridesharing (D-RIDE)*, which uses dynamic ridesharing technology, personal mobile devices, and voice activated on-board equipment to match riders and drivers.

The goal of T-CONNECT is to improve rider satisfaction and reduce expected trip time for multimodal travelers by increasing the probability of automatic intermodal or intra-modal connections. T-CONNECT will protect transfers between both transit (e.g., bus, subway and commuter rail) and non-transit (e.g., shared ride modes) modes, and will facilitate coordination between multiple agencies to accomplish the tasks. In certain situations, integration with other IDTO bundle applications (T-DISP and D-RIDE) may be required to coordinate connections between transit and non-transit modes. T-DISP seeks to expand transportation options by leveraging available services from multiple modes of transportation. Travelers would be able to request a trip via a handheld mobile device (or phone or personal computer) and have itineraries containing multiple transportation services (public transportation modes, private transportation services, shared-ride, walking and biking) sent to them via the same handheld device. T-DISP builds on existing technology systems such as computer-aided dispatch/automated vehicle location (CAD/AVL) systems and automated scheduling software. These systems will have to be expanded to incorporate business and organizational structures that aim to better coordinate transportation services in a region. A physical or virtual central system, such as a travel management coordination center (TMCC) would dynamically schedule and dispatch trips. T-DISP enhances communications with travelers to enable them to be presented with the broadest range of travel options when making a trip. The D-RIDE application is an approach to carpooling in which drivers and riders arrange trips within a relatively short time in advance of departure. Through the D-RIDE application, a person could arrange daily transportation to reach a variety of destinations, including those that are not serviced by transit. D-RIDE serves as a complement subsystem within the IDTO bundle by providing an alternative to transit when it is not a feasible mode of transport or unavailable within a certain geographic area. To support the three applications, the following are examples of data needed:

- Connected vehicle data – Probe data (as defined in Section 4), road weather data, and infrastructure data. Arrival time of transit vehicles at stops and schedule delays will need to be estimated using probe data.
- Transit-specific data – Such as transit vehicle capacity, transit schedules.
- Traveler data – Such as trip request, special request (medical/paratransit).

Expected key benefits from this bundle include:

- Increased percentage of successful connections involving fixed and flexible modes,
- Reduced time between making a request and receiving a trip confirmation, and
- Reduced passenger waiting times.

A Concept of Operations and System Requirements have already been developed, and a prototype will be developed in the next 12 to 18 months.

7.1.1.4 Intelligent Network Flow Optimization (INFLO)

The Intelligent Network Flow Optimization (INFLO) bundle will optimize network flow on freeway and arterials by informing motorists of existing and impending queues and bottlenecks; providing target speeds by location and lane; and allowing capability to form ad hoc platoons of uniform speed. The applications that compose INFLO are:

- *Dynamic Speed Harmonization (SPD-HARM)*, which aims to dynamically adjust and coordinate vehicle speeds in response to congestion, incidents, and road conditions to maximize throughput and reduce crashes.
- *Queue Warning (Q-WARN)*, which aims to provide drivers timely warnings and alerts of impending queue backup.
- *Cooperative Adaptive Cruise Control (CACC)*, which aims to dynamically adjust and coordinate cruise control speeds among platooning vehicles to improve traffic flow stability and increase throughput.

The bundle relies primarily on probe data (as defined in Section 4), road weather data, and infrastructure data. The SPD-HARM application will process the raw data to estimate target speeds by lane and broadcast the recommendations to affected vehicles. Information may be broadcast via DSRC from the RSE or transmitted via cellular from a traffic management center (TMC) to vehicles that have opted in to receive the speed recommendations or displayed on infrastructure-based signs. It is expected that target speeds recommendations will be made by an entity external to the vehicle, such as a traffic management center. The Q-WARN application will predict queues and broadcast the information using the same mechanism as used in the SPD-HARM application. In addition, whenever a vehicle determines that it is in a queued state it will broadcast its status to nearby upstream vehicles and to infrastructure-based central entities (such as the TMC) in order to minimize or prevent rear-end or other secondary collisions. The CACC application also uses the same types of data as the other two applications but differs from them in that the decisions are made within the vehicles themselves and supplemented by external information (for example, from a TMC providing reduced speed recommendations due to downstream congestion). This approach was taken because it was agreed that vehicle-based decision-making would be sufficient to organize and coordinate vehicles effectively within a local platoon, but that platoon-level speed recommendations should come from an external entity (such as a TMC) that has visibility into the conditions of the entire road network. Additionally,

vehicle to vehicle communication using DSRC-based communication is critical to the functioning of CACC unlike for the other two applications to allow vehicles to travel in a platoon.

To support the three applications, the following are examples of data needed:

- Connected vehicle data – Probe data (as defined in Section 4), vehicle type and size, road weather data (pavement conditions, visibility, snow, rain, etc.), and infrastructure data. Estimation of queues and bottlenecks will need to be predicted using probe data. Target speeds will need to be estimated by lane and zone. Gap settings will need to be estimated for platoons.

Expected key benefits from this bundle include:

- Increase in vehicle throughput,
- Reduction in number of primary and secondary crashes,
- Reduction in severity of crashes, and
- Increase in travel time reliability.

A Concept of Operations and System Requirements have already been developed, and a prototype will be developed in the near future.

7.1.1.5 Multi-Modal Intelligent Traffic Signal System (M-ISIG)

Multi-Modal Intelligent Traffic Signal System (M-ISIG) is a comprehensive traffic signal system for complex arterial networks including passenger vehicles, transit, pedestrians, freight, and emergency vehicles. The applications that compose M-ISIG are:

- *Intelligent Traffic Signal System (I-SIG)*, which is an overarching system optimization application accommodating signal priority, preemption and pedestrian movements;
- *Transit Signal Priority (TSP)*, which provides signal priority to transit at intersections and along arterial corridors;
- *Mobile Accessible Pedestrian Signal System (PED-SIG)*, which allows an automated pedestrian call to be sent to the traffic controller from the smart phone of registered users;
- *Freight Signal Priority (FSP)*, which provides signal priority to freight vehicles along an arterial corridor near a freight facility; and
- *Emergency Vehicle Preemption (PREEMPT)*, which provides signal preemption to emergency vehicles, and accommodates multiple emergency requests.

The ISIG plays the role of an over-arching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall arterial network performance. The TSP application provides a mechanism by which transit vehicles equipped with on-board equipment can communicate information such as passenger count data, service type, scheduled and actual arrival time, and heading information to roadside equipment via DSRC or some other communication capability to request priority. The PED-SIG application will facilitate pedestrian mobility at intersections for meeting pedestrians' special needs or for balanced utilization of the intersection by vehicles and pedestrians. This application will integrate traffic and pedestrian information from roadside or intersection detectors and new forms of data from wirelessly connected pedestrian-carried mobile devices (nomadic devices) to activate dynamic pedestrian signals or to inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time

SPaT information. The FSP application provides signal priority along an arterial corridor near a freight facility based upon current and projected freight movements into and out of the freight facility. The goal of the FSP application is to reduce delays and increase travel time reliability for freight traffic, and enhance safety at intersections around the freight facility. Another traffic signal system objective for freight is to reduce the number of stops, since stopping large commercial vehicles can reduce pavement life and can have negative air quality impacts. The PREEMPT application is a very high level of priority for emergency first responder vehicles. The goal of PREEMPT is to provide safe and efficient movement through intersections. As such, clearing queues and holding conflicting phases can facilitate EV movement. For congested conditions, it may take additional time to clear a standing queue, so the ability to provide information in a timely fashion is important.

To support the bundle, the following are examples of data needed:

- Connected vehicle data – Probe data (as defined in Section 4), road weather data, and infrastructure data. Arrival time of transit, freight, and emergency vehicles at intersection will need to be predicted using probe data. Queue lengths by lane will need to be estimated.
- Transit-specific data – Such as transit schedule delay, passenger count, heading for priority
- Freight-specific data – Such as freight schedule delay, load, route for priority
- Pedestrian data – Such as special needs (visually impaired, disabled).

Expected key benefits from this bundle include:

- Reduced overall vehicle delay,
- Increased throughput,
- Reduced queue length,
- Reduced average pedestrian wait time, and
- Reduced average transit delay, average commercial vehicle delay, and average emergency vehicle delay.

The bundle concept is still being finalized.

7.1.1.6 Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)

Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) is an advanced vehicle-to-vehicle safety messaging over DSRC to improve safety of emergency responders and travelers. The applications that compose R.E.S.C.U.M.E. are:

- *Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)*
 - Provides situational awareness to public safety responders while en route can help establish incident work zones that are safe for responders, travelers and crash victims alike
 - Input to responder vehicle routing, staging and secondary dispatch decisions
- *Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)*
 - Alerts drivers of lane closings and unsafe speeds for temporary work zones
 - Warns on-scene workers of vehicles with trajectories or speeds that pose a high risk to their safety
- *Advanced Automatic Crash Notification Relay (AACN-RELAY)*

- Allows vehicles to relay an emergency message (i.e., “AACN”) from other vehicles involved in an accident or other distress situation
- *Emergency Communications and Evacuation (EVAC)*
- Addresses needs of evacuees with and without their own transportation

The RESP-STG application will provide situational awareness to and coordination among emergency responders—upon dispatch and while en route— to establish incident scene work zones, upon initial arrival and staging of assets, and afterward if circumstances require additional dispatch and staging. It will provide valuable input to responder and dispatcher decisions and actions. There is a range of data that will be provided through mobile devices and other types of communication to help support emergency responder vehicle routing, staging, and secondary dispatch decision-making. These data will include staging plans, satellite imagery, geographic information system (GIS) map graphics, camera images, current weather data, sensor readings, and real-time modeling outputs.

The INC-ZONE concept is a communication approach that will improve protection of incident sites where there have been crashes, other accidents, or events impacting traffic such as stalled vehicles or vehicles pulled over for moving violations. Persons found in an incident zone could include accident victims, law enforcement, Emergency Medical Services (EMS), Fire and Rescue, HAZMAT Response Unit, Towing and Recovery assets, and roadway/infrastructure repair workers. One aspect of the INC-ZONE application is an in-vehicle messaging system that provides drivers with merging and speed guidance around an incident. Another aspect is providing in-vehicle incident scene alerts to drivers, both for the protection of the drivers as well as incident zone personnel. A third aspect is a warning system for on-scene workers when a vehicle approaching or in the incident zone is being operated outside of safe parameters for the conditions.

The AACN-RELAY refers to a capability that will allow vehicles to relay an emergency message (i.e., “AACN”) from other vehicles involved in an accident or other distress situation. An automatic crash notification feature transmits key data on the crash recorded by sensors mounted in the vehicle without the need for involvement of the driver or an occupant, in case they are incapacitated. For connected vehicle enabled vehicles, this will be initiated by two concurrent methods to get the crash message to an Emergency Communications Center (ECC, part of which is a public safety answering point, or PSAP) for action by emergency responders. These methods are (1) a call placed by a cell phone embedded as part of the car’s AACN system, and (2) the transmission of comparable information by a short-range wireless transmission to be relayed by other CV-enabled vehicles. The purpose of the AACN-RELAY application is to expand the population of AACN-RELAY capable vehicles and minimize the notification time to emergency responders. This reduces the time from the accident occurring to the first responders arriving on scene and delivering medical attention. AACN-RELAY also provides responders with key information regarding the characteristics of the incident that triggered transmission of the AACN message.

The EVAC concept will provide critical information such as dynamic route guidance information, current traffic and road conditions, location of available lodging, and location of fuel, food, water, cash machines, and other necessities. EVAC will also identify and locate people with special needs who are more likely to require guidance and assistance and will identify existing service providers and other available resources to them.

To support the bundle, the following are examples of data needed:

- Connected vehicle data – Probe data (as defined in Section 4), road weather data, and infrastructure data
- Incident data – Such as crash information recorded by vehicle sensors (for AACN-RELAY), camera images of incident (for RESP-STG)
- Traveler data – Such as special needs (medical) (for EVAC)
- Satellite imagery, geographic information system (GIS) map graphics

Expected key benefits from this bundle include:

- Responders to vehicle incidents will be provided with comprehensive information regarding the incident prior to dispatch (incident dynamics, condition of the victims, materials involved, etc.) reducing total response time;
- Equipment staging will impact travel conditions (e.g., throughput, delay) throughout the entire transportation system, and result in reduced congestion;
- En-route time for responders during congested conditions will be reduced;
- Secondary incidents will be reduced; and
- Ability to employ dynamic dispatching and routing of available resources (e.g., vehicles) across agencies during an evacuation will be widespread.

The bundle concept is still being finalized.

7.1.2 Transformative Environmental Applications Proposed by USDOT

The AERIS Program identified three transformative concepts [70] that have significant potential to decrease fuel consumption, greenhouse gases (GHGs), and criteria air pollutant emissions. These transformative concepts comprise two or more applications that make use of probe data.

7.1.2.1 *Eco-Signal Operations*

This transformative concept includes the use of connected vehicle technologies to decrease fuel consumption, greenhouse gases (GHGs), and criteria air pollutant emissions on arterials by reducing idling, reducing the number of stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections. The Eco-Signal Operations transformative concept features four applications: (1) Eco-Approach and Departure at Signalized Intersections, (2) Eco-Traffic Signal Timing, (3) Eco-Traffic Signal Priority, and (4) Connected Eco-Driving.

A foundational component of this concept uses wireless data communications among enabled vehicles and roadside infrastructure. This includes broadcasting signal phase and timing (SPaT) data to vehicles. Upon receiving this information, the *Eco-Approach and Departure at Signalized Intersections* application performs calculations to provide speed advice to the driver of the vehicle, allowing the driver to adapt the vehicle's speed to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner. This application also considers a vehicle's acceleration as it departs from a signalized intersection.

The *Eco-Traffic Signal Timing* application is similar to current adaptive traffic signal systems; however the application's objective would be to optimize traffic signals for the environment using connected vehicle data. These applications collect data from vehicles, such as vehicle location, speed, GHG and

other emissions data using connected vehicle technologies to determine the optimal operation of the traffic signal system based on the data.

Eco-Traffic Signal Priority application allows either transit or freight vehicles approaching a signalized intersection to request signal priority. This application considers the vehicle's location, speed, vehicle type (e.g., Alternative Fuel Vehicles) and associated GHG and other emissions to determine if priority should be granted. Other information, such as a transit vehicle's adherence to its schedule or number of passenger, may also be considered in granting priority.

Connected Eco-Driving application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions while driving on arterials. This advice includes recommended driving speeds, optimal acceleration, and optimal decelerations profiles based on prevailing traffic conditions and interactions with nearby vehicles. This application would also help optimize vehicle trajectories at non-signalized intersections such as stop signs and yield signs.

7.1.2.2 Dynamic Eco-lanes

This transformative concept includes dedicated lanes optimized for the environment using connected vehicle data. Drivers would be able to opt-in to these dedicated eco-lanes to take advantage of eco-friendly applications. The Dynamic Eco-Lanes transformative concept includes six applications: (1) Dynamic Eco-Lanes, (2) Eco-Speed Harmonization, (3) Eco-Cooperative Adaptive Cruise Control, (4) Eco-Ramp Metering, (5) Connected Eco-Driving, and (6) Multi-Modal Traveler Information.

Dynamic Eco-Lanes are similar to current high-occupancy vehicle (HOV) lanes; however they would be optimized for the environment and encourage use by low emission, high occupancy, freight, transit, and alternative fuel or regular vehicles operating in eco-friendly ways (i.e., eco-speed limits, vehicle platooning). The Eco-Lanes application supports the operation of Dynamic Eco-Lanes including establishing Eco-Lanes criteria and defining or geo-fencing the Eco-Lanes boundaries. Eco-Lanes criteria may include the types of vehicles allowed in the Eco-Lanes, emissions criteria for entering the Eco-Lanes, number of lanes, and the start and end of the Eco-Lanes. The application also conveys pre-trip and en-route traveler information about Dynamic Eco-Lanes to travelers. This includes information about criteria for vehicles to enter the Eco-Lanes, current and predictive traffic conditions in the Eco-Lanes, and geographic boundaries of the Eco-Lanes.

The *Eco-Speed Harmonization* application determines eco-speed limits for a roadway based traffic conditions, weather information, and GHG and criteria pollutant information collected from roadside equipment and vehicles using connected vehicle technologies. The purpose of speed harmonization is to dynamically change speed limits approaching areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that impact flow. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts and maintaining consistent speeds, thus reducing fuel consumption, GHGs, and other emissions on the roadway. Eco-speed limits may be broadcast and received by on-board equipment (OBE) units or displayed on variable speed limit (VSL) signs located along the roadway. This application is similar to current VSL applications; however the speed recommendations seek to minimize emissions and fuel consumption along the roadway.

The *Eco-Cooperative Adaptive Cruise Control* application automatically controls the speed of a vehicle leveraging connected vehicle technologies. The application uses vehicle-to-vehicle communications to transmit a vehicle's current speed and acceleration to a following vehicle. This allows the following vehicle to use adaptive cruise control (ACC) aimed at relieving a driver from manually adjusting their speed to maintain a constant speed and a safe distance from the lead vehicle. The Eco-Cooperative

Cruise Control would also incorporate other information such as road grade, roadway geometry, and road weather information to determine the most environmentally efficient trajectory for the following vehicle. In the long term, the application may also consider vehicle platoons where two or more vehicles travel with small gaps, reducing aerodynamic drag. Platooning relies on vehicle-to-vehicle (V2V) communication that allows vehicles to accelerate or break with minimal lag to maintain the platoon with the lead vehicle. The reduction of drag results in reduced fuel consumption, greater fuel efficiency, and less pollution for vehicles. This application is applicable to all vehicle classes.

The *Eco-Ramp Metering* application determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of automobiles entering the freeway. This application collects traffic and environmental data from vehicles and roadside equipment. This includes traffic and environmental conditions on the ramp, on the freeway upstream and downstream of the ramp. Using this information, the application determines a timing plan based for the ramp meter based on current and predictive traffic and environmental conditions. The objective for this application is to produce timing plans that reduce overall emissions. This includes reducing emissions from bottlenecks forming on the freeway as well as emissions from vehicles on the ramp.

The *Connected Eco-Driving* application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration, and optimal decelerations profiles based on prevailing traffic conditions and interactions with nearby vehicles. The application also provides feedback to drivers on their driving behavior to encourage drivers to drive in a more environmentally efficient manner. Finally, the application may also consider vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy (i.e., change gears, switch power sources, or reduce speed in an eco-friendly manner as the vehicle approaches a traffic signal).

The *Multi-Modal Traveler Information* application provides pre-trip and en-route multi-modal traveler information to encourage environmentally friendly transportation choices. The application collects traffic and environmental data from connected vehicles and other sources and uses this data to determine real-time or predictive traffic conditions which are then provided to travelers. Traffic conditions include information about roadway speeds and travel times and predicted traffic conditions. This information may be used by travelers to adjust their departure time or to select an alternate route. Another key component of this application is providing travelers with transit options to encourage mode shift. This includes information about transit schedules and real-time transit vehicle arrival and departure times.

7.1.2.3 Dynamic Low Emissions Zones

This transformative concept includes a geographically defined area which seeks to restrict or deter access by specific categories of high-polluting vehicles within the zone for the purpose of improving the air quality within the geographic area. This transformative concept also provides the capability for the Low Emissions Zone to be dynamic or allowing the operating entity to change the location or time of the Low Emissions Zone. For example, this would allow the Dynamic Low Emissions Zone to pop-up based on various criteria including atmospheric conditions, weather conditions, or special events. The Dynamic Low Emissions Zone transformative concept includes three applications: (1) Dynamic Emissions Pricing, (2) Connected Eco-Driving, and (3) Multi-Modal Traveler Information.

The *Dynamic Emissions Pricing* application leverages connected vehicle technologies to dynamically determine fees for vehicles entering the Low Emissions Zone. These fees may be based on the vehicle's engine emissions standard or emissions data collected directly from the vehicle using

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vehicle-to-infrastructure (V2I) communications. To encourage travelers entering the zone to use public transportation, policy could be in place to waive fees for transit vehicles entering the Low Emissions Zone.

The *Connected Eco-Driving* application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration, and optimal decelerations profiles based on prevailing traffic conditions and interactions with nearby vehicles. The application also provides feedback to drivers on their driving behavior to encourage drivers to drive in a more environmentally efficient manner. Finally, the application may also consider vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy (i.e., change gears, switch power sources, or reduce speed in an eco-friendly manner as the vehicle approaches a traffic signal). Once inside the Low Emissions Zone, if real-time data from the vehicle shows that it is being driven in a manner that reduces emissions (i.e., practicing eco-driving tactics), the driver could be given an economic reward.

The *Multi-Modal Traveler Information* application provides pre-trip and en-route multi-modal traveler information to encourage environmentally friendly transportation choices. The application collects traffic and environmental data from connected vehicles and other sources and uses this data to determine real-time or predictive traffic conditions which are then provided to travelers. Traffic conditions include information about roadway speeds and travel times and the forecasting of traffic conditions. This information may be used by travelers to adjust their departure time or to select an alternate route. Another key component of this application is providing travelers with transit options to encourage mode shift. This includes information about transit schedules and real-time transit vehicle arrival and departure times. Finally, the application includes information about criteria for vehicles to enter the Low Emissions Zone, expected fees and incentives for their trip, current and predictive traffic conditions, and the geographic boundaries of the Low Emissions Zone.

7.1.3 Road Weather Management Applications

The Road Weather Management Program has identified four applications that target four different users of the Vehicle Data Translator (VDT) software, which ingests, parses, processes, and quality checks mobile data observations (e.g., native and/or external) along with additional ancillary weather data (e.g., radar, satellite, fixed observations, and model data) [71].

7.1.3.1 VDT and Connected Vehicle Information for the Everyday Driver

Adverse weather is the cause of 25% of non-recurring traffic delays across the US. Approximately 24% of passenger vehicle crashes are weather-related [71]. Although the traveling public has access to traveler information that is focused primarily on accident and congestion information, few traveler information services provide the impact of weather information while on the road, making it difficult for travelers to make safe travel choices. The purpose of this application is to provide weather information to the traveling public. Road weather impact information generated by the VDT will be passed along to the traveling public through the various communications and telematics channels. The weather information (e.g., slickness, visibility, precipitation type/rate) will be specific to the road surface and will be directly pushed to communications' infrastructure such as 511 systems, in-vehicle communications devices, and smart phones. Content providers in the private sector can also use this information to develop applications tailored to the end-user, including applications that forecast traffic times, provide smart-routing, and forecast road impacts and/or hazards.

7.1.3.2 VDT and the Connected Vehicle Information for Freight-haulers and Truckers

Having near real-time access to connected-vehicle information through the VDT and/or commercial applications will be critical in the future to provide useful weather information to the freight-haulers on impending impacts to trucking routes. Smart-routing around areas that will be highly impacted by adverse weather is needed to allow for the safe and efficient transport of goods across the country. On a daily basis, freight companies and independent truckers have to make critical go/no-go and routing decisions due to weather conditions that are sometimes several states away. The purpose of this application is to provide weather and smart routing information to freight haulers and truckers. This application will provide smart routing information to freight companies and independent truckers by combining real-time mobile observations from passenger vehicles and freight-haulers, and the ancillary weather data from the VDT. With connected-vehicle information through the VDT, diagnostic information (such as segments with poor visibility or slick roads) would help support the critical decisions that freight companies and individual truckers must make. This information could be provided directly from the VDT to a communications portal for the truckers (such as 511) or to the private sector, which could tailor the information specifically to company or individual needs.

7.1.3.3 VDT and Connected Vehicle Information for Emergency Medical Services (EMS)

Emergency Medical personnel (First Responders) are highly impacted by adverse weather (e.g., hurricanes, snow, poor visibility) from both a tactical and strategic decision-making standpoint. Safety and response time are huge concerns for first responders. Twenty five percent of ambulance crashes occurred during poor weather and/or road conditions [71]. The decisions that are being made vary across geographic regions and urban/rural environments. The purpose of this application is to provide roadway status information and smart-routing to enable effective tactical and strategic decision-making.

Tactical decision-making application: During adverse weather conditions, a combination of a short-term pavement condition forecast, a diagnostic traffic product, and communications with the road agencies (e.g., which roads are plowed, which roads are closed) is required to provide smart-routing to EMS. VDT information from surrounding passenger vehicles and other ambulances will be used to provide tactical information for the first responders.

Strategic decision-making application: Accurate forecasts of adverse weather, such as hurricanes, blizzards and floods, are important because of the potential impact to staffing levels and pre-storm vehicle readiness. During major winter storms, decisions need to be made on proper timing for ambulance maintenance (e.g., snow chain installation) as well as necessary staff additions to make up for delayed call times. While the VDT and connected vehicle information will not provide direct information for strategic decision support, the assimilation of the observations (e.g., pavement temperature) into road impact models will indirectly benefit the forecast. The output from the VDT will be leveraged for a decision support system to provide more accurate road (and route) impact forecasts.

7.1.3.4 VDT and Connected Vehicle Information for Road Maintenance Community

Maintenance Decision Support System (MDSS) is a single-platform decision support system that provides relevant weather, road-weather, and treatment recommendations to various end-users that are in charge of maintaining the pavement during winter operations. The system was developed with funding from USDOT FHWA and it has been widely deployed over many snow-affected states and some foreign countries over the past ten years.

Many states also use Maintenance Management System (MMS), which provides a platform for agencies to manage and track resources, including personnel/labor, equipment, and material, used in snow-fighting. This application will make use of VDT output for each of these stand-alone systems, and also explore sharing of information between MDSS and MMS.

7.2 Candidate list proposed by MLIT

Various studies are underway by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) regarding the use of probe data in road administration (to make road management more sophisticated and efficient, etc.). In the fields shown in Table 7-1 and Table 7-2 probe data are being used in actual road administration, and practical research is also being promoted.

Table 7-1. Candidates for Probe Data Use - Enabled Applications (Source: MLIT)

Use Level	Applications	Specific Uses
Level 1 Candidates that have used probe data up to now in road administration	Advanced travel speed survey	Statistical comparison of the results of aggregate calculation of travel speed and delay in urban area and nationwide
	Determining road traffic conditions (zone travel time)	Determination of travel times per time period and sector in the Yamato sag section of the Tomei Expressway and results of aggregate calculation of delay
	Quantification of effects in post evaluation (reduction of travel time, etc.)	Change in travel speed before and after the social experiment of eliminating tolls on the Kyoto Tamba Expressway
	Support for confirming passability (impassable zones)	Efforts to assist the movement of victims of the Great East Japan Earthquake, etc. (e.g., identification of passable roads)
Level 2 In addition to Level 1, candidates that are expected to use probe data in the near future or for which research into use is being promoted	Identifying potential accident-prone locations	Efforts relating to the possibility of using behavior record information to identify locations at which hazardous incidents occur
	Determining route data (Origin-Destination data)	Identification of potential hazard locations based on behavior history information for specific distribution vehicles and study of travel time distribution in specific origin-destination sectors
	Determining detour routes	Example of use in assisting analysis of detours in the event of a disaster

Table 7-2. Candidates for Probe Data-enabled Applications (Source: MLIT)

Use Level	Candidates Applications
Level 3	Advanced congestion length survey
Possibilities for the future	Advanced origin-destination survey
	Identifying congestion-prone locations
	Determining traffic conditions on community roads
	Support for detection of obstacles or stopped vehicles on roads
	Support for monitoring passage of special vehicles and vehicles loaded with hazardous substances
	Determining vehicle passage during snowfall
	Determining road surface freezing
	Diagnosis of pavement deterioration, inspection of auxiliary structures, and investigation of road surface deterioration and subsidence, etc.
	More detailed congestion information

7.2.1 Level 1: Candidates that have Used Probe Data Up to Now in Road Administration

7.2.1.1 *Sophisticated Travel Speed Survey*

The long-term, wide-area collection of probe data will make it possible to use probe data in statistical studies. Figure 7-1 [72] and Figure 7-2 [73] show examples of a statistical comparison of aggregate calculations for traffic indicators (average speed and lost time (i.e., delay)) conducted by the Kanto Regional Development Bureau.

Figure 7-1 shows the results of a comparison of average travel time on major roads nationwide and in central Tokyo (Chiyoda Ward, Chuo Ward and Minato Ward). As the figure shows, the average speed on expressways in central Tokyo is 42 km per hour (26 mi per hour), while that on ordinary roads is 16 km per hour (10 mi per hour), about half the national average. In addition, Figure 7-2 shows that approximately 60% of driving time is spent in traffic jams and the like, and that the delay is 1.6 times longer than the national average.

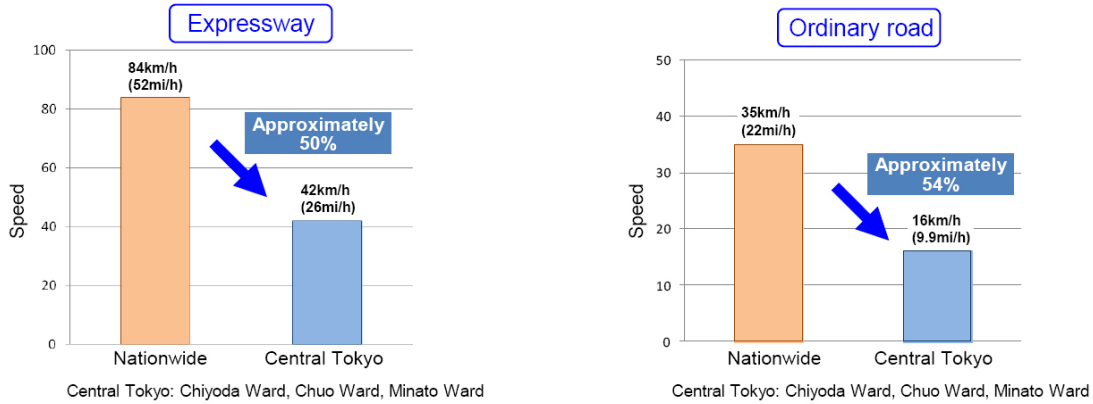
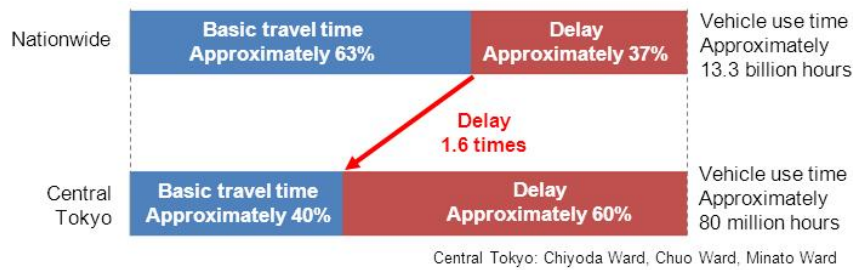


Figure 7-1. Comparison of average travel speed on major roads nationwide and in central Tokyo (Source: MLIT)



Conditions for calculation, etc.

- Target roads: Ordinary roads of prefectural road scale or greater (including major municipal roads in specified cities)
- Calculated based on traffic volume data from traffic counters between April 2009 and March 2010 (during 12-hour daylight period) and speed data collected by probe car systems
- The top 10% of annual speed results in each section are assumed to be free travel speeds with no traffic congestion, and basic travel times is calculated based on these results.
- * Travel speed and delay are calculations at this point in time and are subject to change due to the addition of data in the future, etc.

Source :Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
http://www.ktr.mlit.go.jp/honkyoku/road/3kanjo/whats/traffic_jam.htm

Figure 7-2. Proportion of automobile use delay due to traffic congestion nationwide and in central Tokyo (Source: MLIT)

7.2.1.2 Determining Road Traffic Conditions (Zone Travel Time)

Aggregate calculation of probe data for individual time periods and individual sectors makes it possible to use probe data for assessment of the service level of the target road.

Figure 7-3 shows average travel times per time period on the Tomei Expressway during the Golden Week vacation period (April 29-May 5). A decrease in speed can be seen when traveling toward Tokyo in the early evening between the Atsugi IC and the area near the Yokohama Machida IC, and a decrease in speed can be seen when traveling away from Tokyo from morning until early afternoon in the sector between the Atsugi IC and the Tomei Kawasaki IC. Figure 7-4 shows a 3D map of delay

due to traffic congestion, created based on these data. This map determined the difference between the average speed for the 12-hour daylight period for road probe data (7:00 a.m.-7:00 p.m.) and the regulated speed limit (100 km/h (62 mi/h)); the traffic volume was multiplied by the average number of persons per vehicle (1.3 persons) to determine the delay per DRM link. The greater the amount of blue in the bands that extend from top to bottom, the greater the amount of time that is lost to traffic congestion.

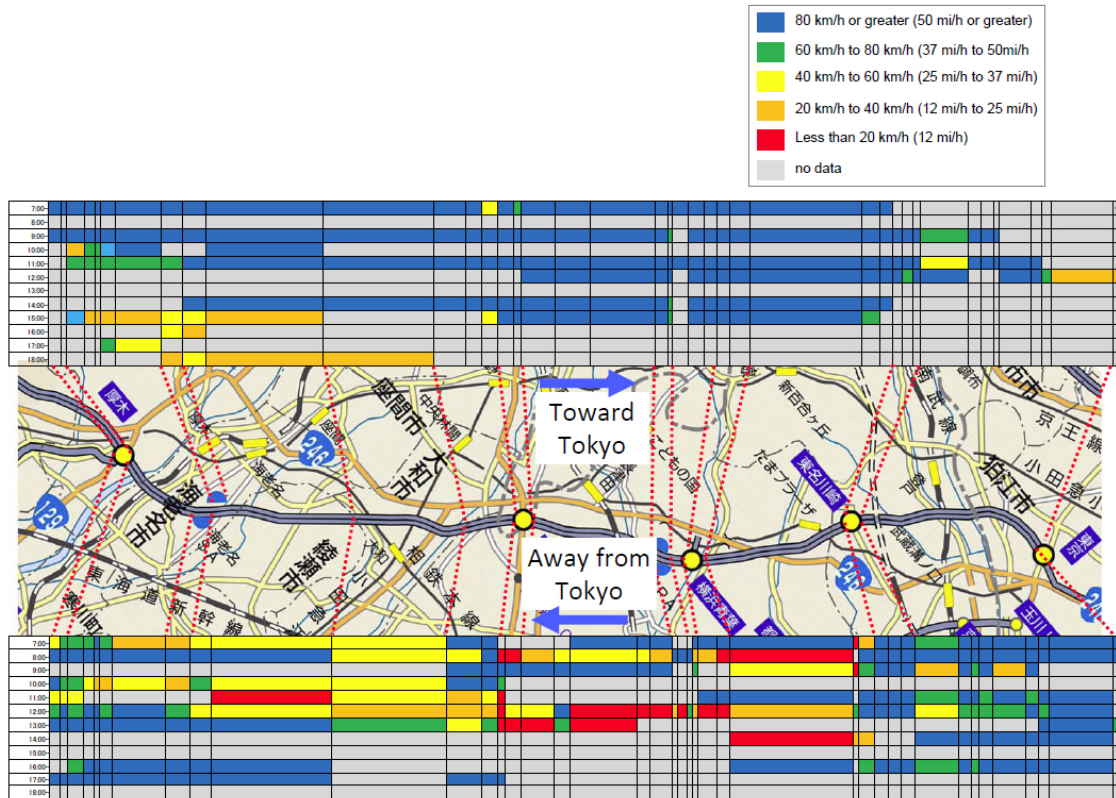


Figure 7-3. Average travel time per time period between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT)

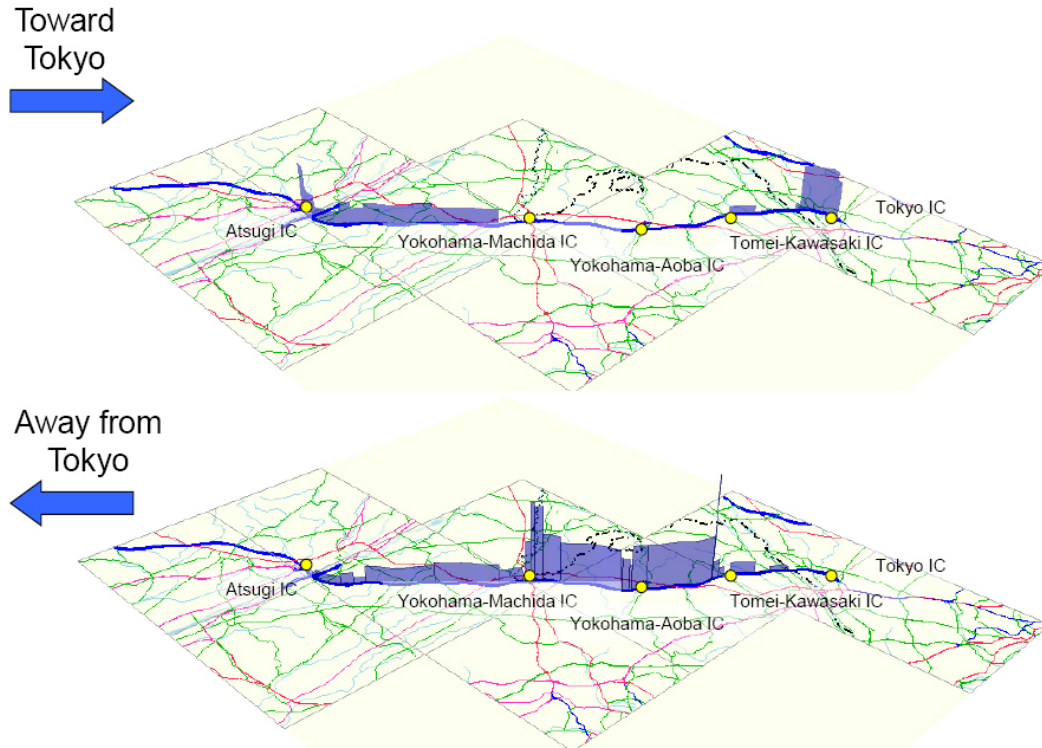


Figure 7-4. Delay due to traffic congestion between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT)

7.2.1.3 Quantification of Effects in Post-Evaluation

Using probe data to determine the traffic conditions (speed, etc.) in the area around the project locations and comparing the results make it possible to assess the effect of reducing travel time, etc. at those project locations.

Figure 7-5 [74] shows the average speed on secondary roads before and after the social experiment of eliminating tolls on the Kyoto Tamba Expressway. The social experiment of eliminating tolls on the expressway encourages full use of the expressway, reduces distribution costs and the cost of goods, and stimulates the local economy, so as a rule it was decided to eliminate expressway tolls. From June 28, 2010 (Monday) through June 19, 2011 (Sunday), the social experiment of eliminating tolls was conducted on approximately 20% of all expressways nationwide (a total length of 1,652 km (1,026 mi)) and the economic effect on the local community and the impact on traffic congestion and the environment was determined. The social experiment of eliminating tolls on the Kyoto Tamba Expressway was conducted with the goal of alleviating traffic congestion on the parallel National Road No. 9 and reducing travel time. Before the social experiment, there were many links in which the speed was less than 40 km/h (25 mi/h), but after the social experiment there were many links in which the speed was 50 km/h (31 mi/h).

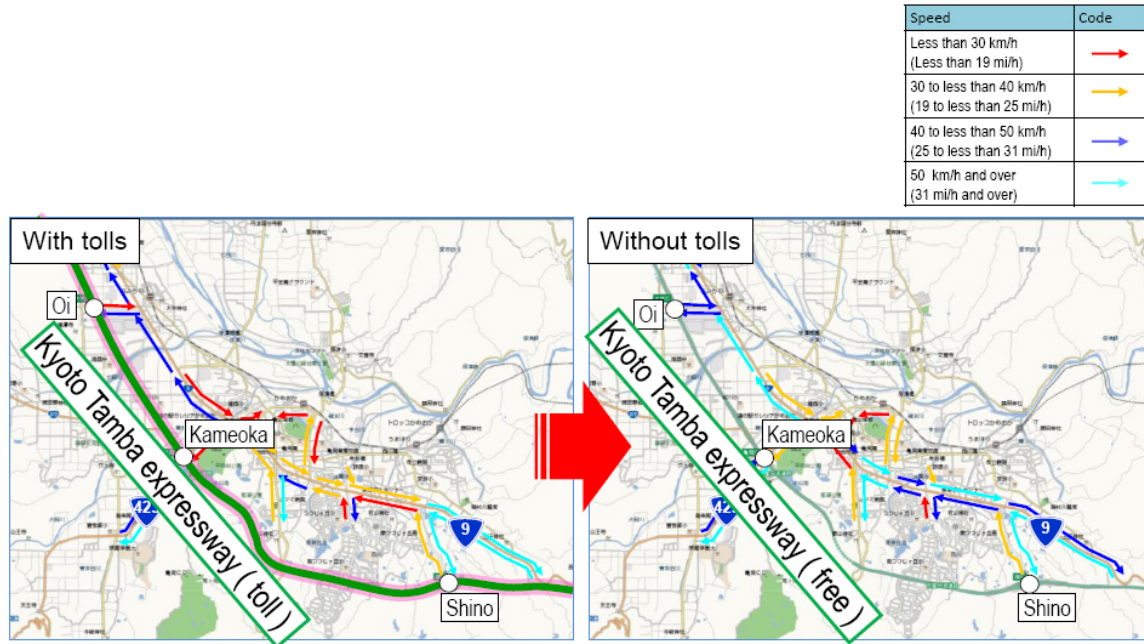


Figure 7-5. Comparison of average speed on secondary roads before and after social experiment of eliminating tolls on the Kyoto Tamba Expressway (Source: MLIT)

7.2.1.4 Support for Confirming Passability (Impassible Zones)

Probe data can be used to help confirm whether or not roads are usable in the event of a disaster. In the Great East Japan Earthquake and subsequent tsunami that occurred on March 11, 2011, roads were cut off over an extremely wide area extending from the Tohoku region to the Kanto region (approximately 700 km (440 mi) north to south) (Figure 7-6) [75].

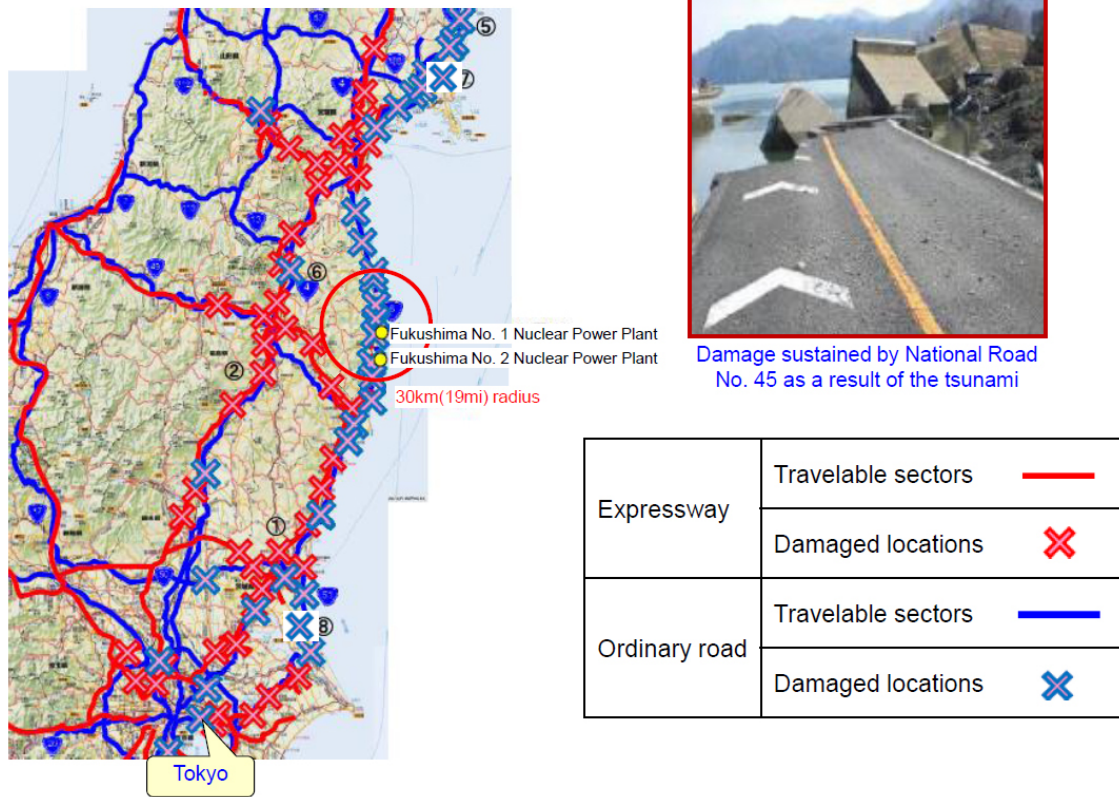


Figure 7-6. Sectors closed to traffic as a result of the Great East Japan Earthquake (Source: MLIT)

As there were some roads that were still usable, information was needed on which roads were still usable in order to ensure delivery of aid and dispatch of rescue personnel to the disaster-afflicted areas. Accordingly, a mere eight days after the disaster, ITS Japan and the Geographical Survey Institute released a “Map of roads usable by automobiles” on the Internet with the aim of assisting the delivery of goods to the Tohoku region. In the map shown in Figure 7-7, the blue lines indicate information on roads on which vehicles had been able to travel, while the red lines and the X's indicate information provided by road administrators on the location of road closures [76].

The information provided by ITS Japan represented the integration of information on confirmed usable roads collected by Honda, Pioneer, Toyota, and Nissan. In addition to maps of information on roads usable by automobiles, ITS is also studying the deployment of various other services relating to the integration and use of private sector data.



Figure 7-7. Map of information on roads usable by automobiles (Source: ITS Japan) [75]

7.2.2 Candidate Applications Expected to Use Probe Data

In addition to Level 1 applications, Level 2 contains candidate applications that are expected to use probe data in the near future or for which research into use is being promoted.

7.2.2.1 Identifying Potential Accident Prone Locations

Of the data collected as road probe data, the behavior record information is information on driver behavior in terms of longitudinal acceleration, lateral acceleration and yaw angular velocity (rotation on a vertical axis) that is generated from the vehicle. The mechanism is such that only the results that exceed a set threshold in response to sudden braking and sudden turning of the steering wheel are recorded. For this reason, the locations at which many items of behavior record information are recorded are identified as locations at which hazardous incidents occur, and it is anticipated that statistical analysis will enable this information to contribute to future traffic safety measures.

Figure 7-8 shows the status of the collection of behavior records (acceleration before and after) by road probe units in central Osaka from June 2011 through March 2012. The blue arrows indicate the locations at which acceleration before or after of -0.25 G through -0.30 G occurred. The redder the notations, the greater the acceleration that was produced. At present, most acceleration is produced on expressways, but as ITS Spot-compatible car navigation systems become more and more popular, it is anticipated that such locations will be collected on ordinary roads as well.

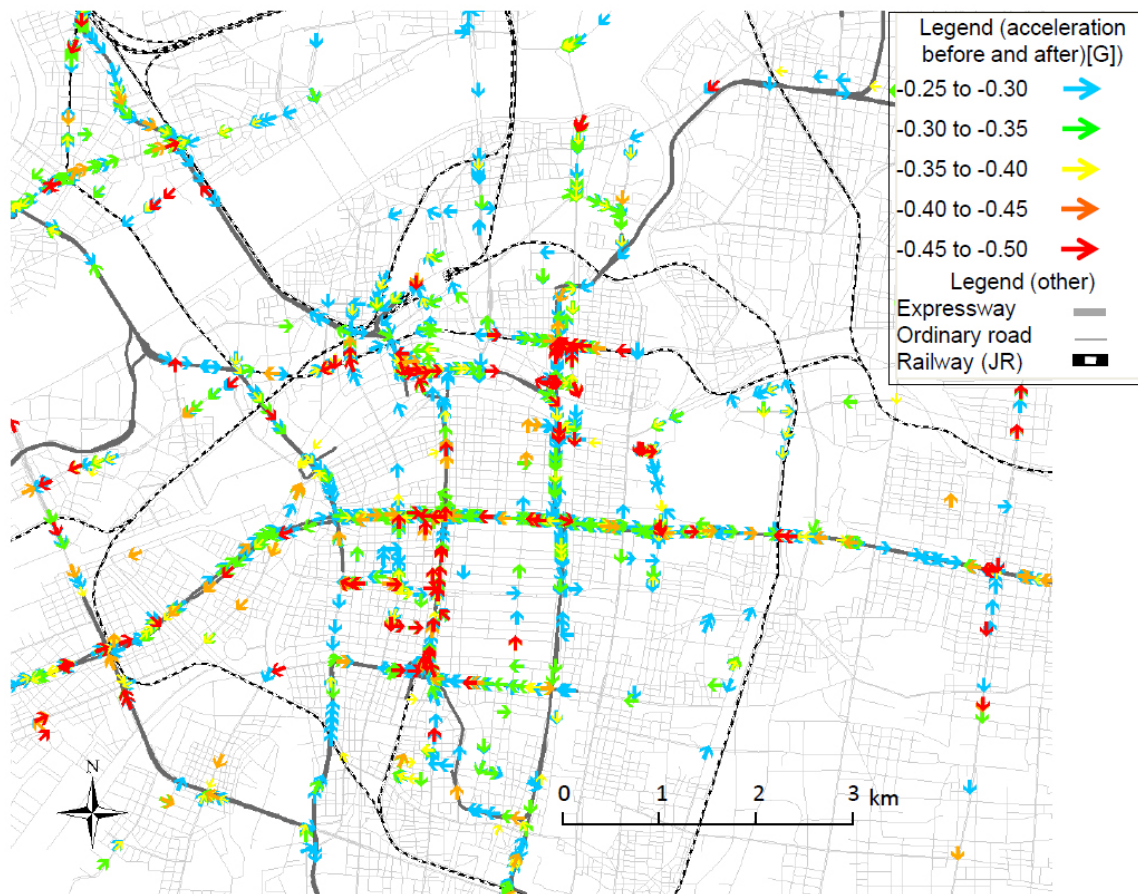


Figure 7-8. Collection of behavior records (acceleration before and after) in central Osaka (Source: MLIT)

7.2.2.2 Determining Route Data (Origin-Destination data)

Field Operational Test of ITS Spot Service designed to assist distribution operations

This test was conducted for probe information (information on travel locations, etc.) for a distribution company's vehicles traveling from the distribution center at the Port of Hakata to household appliance superstores in various parts of Kyushu. In this test, the information was collected by ITS Spots (communication antennas) installed on Kyushu expressways and provided in real time to the Hakata Island Next-Generation Distribution Research Council ("Distribution Research Council") via a probe processing unit (see Figure 7-9) [77]. In September 2010, the Distribution Research Council had initiated the test, centering on three household appliance superstores, 18 electronic appliance manufacturers, and 2 distribution companies, with the aim of increasing the efficiency of household appliance distribution for products entering and leaving the distribution center at the Port of Hakata, and to reduce environmental load. As of 2012, the Distribution Research Council has achieved joint delivery on the part of eight companies.

Normally it is not possible to identify the vehicle from which the probe information came. For this test, however, the test vehicles were provided with information enabling individual vehicles to be identified,

and test vehicles were identified based on this information. The Distribution Research Workshop is using this information to manage vehicle operations and manage the distribution of goods. Road administrators are also expected to be able to use the same probe information as an aid in traffic analysis.

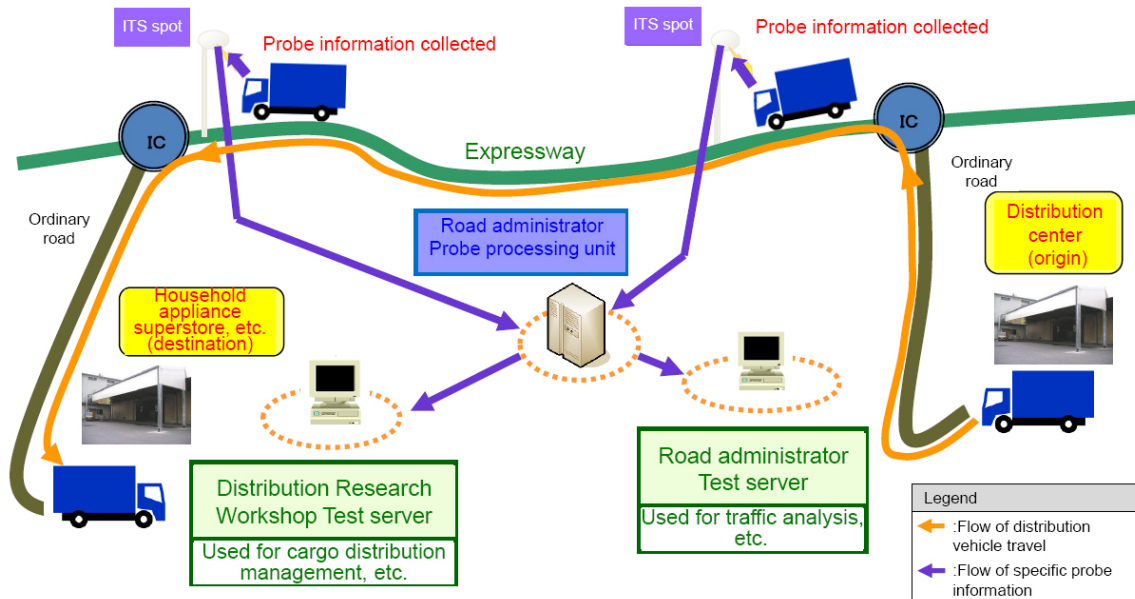


Figure 7-9. Field operational test for assisting distribution operations (Source: MLIT)

Anticipated Effect

1. **Increased efficiency and sophistication of product delivery:** Real-time location data for the vehicle can be used to calculate the estimated arrival time at the delivery destination. Sending this information to the delivery destination as needed will increase the efficiency of product delivery in terms of securing cargo receiving space at the delivery destination (household appliance superstore), staff deployment planning and so on, in addition to improving the service level of product delivery by distribution companies (Figure 7-10).

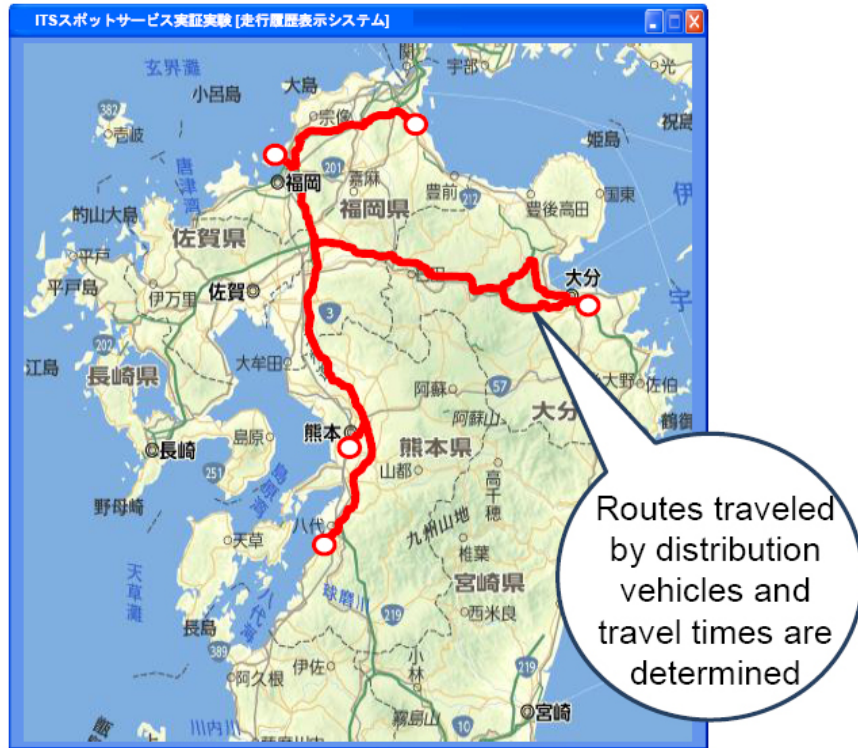


Figure 7-10. Display of routes traveled (Source: MLIT)

2. **Increased sophistication for management of safe and reliable cargo transport operations:** There is a need to ensure safe and reliable driving by drivers who are transporting goods, and to prevent accidents involving transport vehicles. The vehicle driving record and records of sudden braking and other behaviors can be used to determine uneven speeds and sudden braking, sudden turning of the steering wheel and other indicators of the status of vehicle operation by individual drivers, and can be used to provide cautionary advice to drivers (Figure 7-11). This is expected to ensure driving safety and reduce CO₂ emissions.

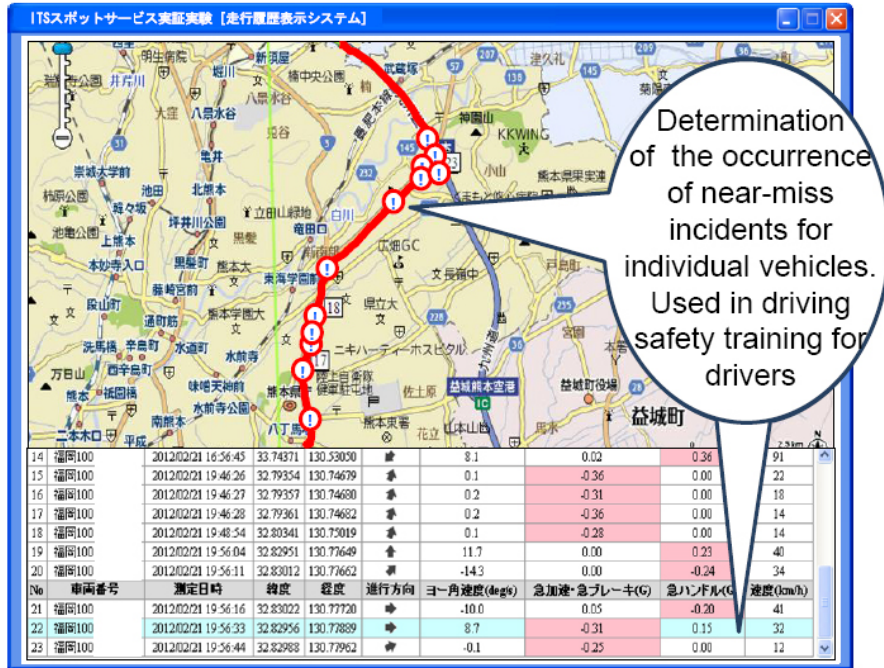


Figure 7-11. Display of status of near-miss incidents and sudden acceleration (Source: MLIT)

7.2.2.3 Determining detour routes

The use of probe data enables the traffic status of detours in the event of a disaster to be determined. Probe data are expected to be used to plan detours as well as for analysis of detours. Figure 7-12 [78] shows the status of traffic on major roads on the Japan Sea side that functioned as detours at the time of the Great East Japan Earthquake. Along with the increase in traffic volume on these roads, travel times decreased greatly in certain sectors. Past data are currently being used to determine the traffic status of detours. In addition, studies are being promoted with the aim of acquiring data in real time for determining the traffic status on detours in the future.

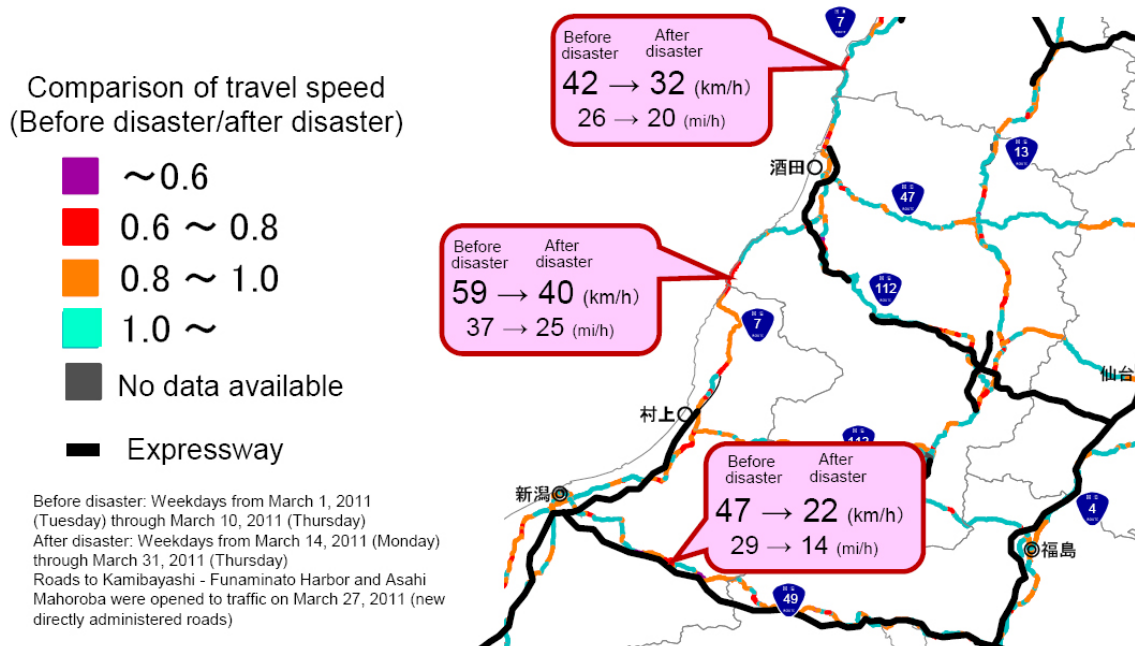


Figure 7-12. Status of traffic on major roads on the Japan Sea side that functioned as detours at the time of the Great East Japan Earthquake (Source: MLIT)

7.2.3 Possibilities for the Future

In addition to the Level 1 and Level 2 applications that Japan is either actively pursuing or interested in pursuing in the near future, they have also classified some longer-term potential uses of probe data, which are classified as Level 3. Some examples of Level 3 applications are:

- Advanced congestion length survey - This service will determine the end of a traffic congestion based on vehicle position and speed information. Advanced origin-destination survey- This service will alternate video observation and human observation with position and speed information of specified vehicles.
- Identifying congestion-prone locations - This service will support extraction of congestion-prone locations based on vehicle position and speed information.
- Determining traffic conditions on community roads - This service will detect potential hazard zone and sudden changes in vehicle action based on vehicle location and speed information and acceleration information in all around. Support for detection of obstacles or stopped vehicles on roads - This service will estimate obstacles or stopped vehicles on roads by detecting sudden changes in vehicle action of traffic conditions.
- Support for monitoring passage of special vehicles and vehicles loaded with hazardous substances - This service will monitor the status of compliance of permitted roads based on position and speed information of specified vehicles.
- Determining vehicle passage during snowfall - This service will detect vehicle passage during snowfall based on vehicle position and speed information.
- Determining road surface freezing - This service will detect road surface freezing by acquiring information of sensor from vehicles.

- Diagnosis of pavement deterioration, inspection of auxiliary structures, and investigation of road surface deterioration and subsidence, etc. - This service will detect road surface deterioration based on information of sensor from vehicles.
- More detailed congestion information - This service will detect more detailed congestion conditions.

7.3 Consolidated list of candidate applications

Table 7-3 shows a consolidated list of applications that are currently of interest to USDOT and MLIT, and are potential candidate applications for future collaboration.

Table 7-3. Consolidated List of Applications

ID	Application	US	Japan
1	Estimate traffic management measures (e.g., travel time, speed, delay)	✓	✓
2	Identify bottleneck locations	✓	✓
3	Identify accident-prone locations		✓
4	Identify road closures		✓
5	Detect stopped vehicles or obstacles on the roads	✓	✓
6	Identify duration of congestion	✓	✓
7	Determine pavement traction conditions	✓	✓
8	Identify HazMat vehicles		✓
9	Incident management/Emergency response	✓	
10	Route guidance	✓	
11	Traveler information	✓	
12	Intelligent signal systems	✓	
13	Freight operations	✓	✓
14	Transit operations	✓	
15	Intelligent network (freeway/arterial) flow optimization	✓	
16	Eco-Signal Operations	✓	
17	Eco-Lanes	✓	
18	Dynamic Low Emissions Zone	✓	
19	Road and infrastructure deterioration diagnosis		✓

8 Prioritized Probe Data-Enabled Applications

This chapter prioritizes the 19 applications identified in Section 7.3, and identifies three applications for future collaboration on further research and development or deployment.

8.1 Seven Target Areas of High Priority Applications

As a first step, the US-Japan ITS Task Force removed applications that were redundant from the list of 19 applications. Next, the Task Force developed the following prioritization criteria:

- Uses Probe Data
- Near-Term Deployment Readiness (i.e., algorithms are already in place or research will be ready for prototyping in 18 months to 2 years)
- Promotes international standards harmonization
- Public sector application
- Expressway/Freeway application (NOTE: MLIT's primary focus is on freeway or expressway applications.)

After removing applications that had limited potential for future collaboration due to low US and MLIT priorities, the Task Force combined applications that targeted a common problem into a specific target area. Seven such target areas were identified for potential collaboration on further research or deployment. Given below are the seven target areas and their component applications:

1. Traffic Management Measures Estimation and Traveler Information Applications
 - 1-1. Traffic Management Measures Estimation Application
 - 1-2. Traveler Information Application
2. Safety Applications
 - 2-1. Queue Warning Application
 - 2-2. Determination of Accident Prone Location Application
3. Freight Operations Applications
 - 3-1. Freight-Specific Dynamic Travel Planning and Performance Application
 - 3-2. Detection of Pavement Deterioration due to Heavy Vehicles and Determination of Travel Routes of Heavy Vehicle Application
 - 3-3. Intermodal Drayage Operations Optimization Application
4. Freeway-Based Dynamic Speed Harmonization Application
 - 4-1. Dynamic Speed Harmonization Application
5. Non-Signal Related Environmental Applications
 - 5-1. Determination of Road Environment Application
 - 5-2. Eco-Driving Promotion Application
 - 5-3. Eco-Lanes Application
 - 5-4. Dynamic Low Emission Zone Application
6. Road and Infrastructure Deterioration Diagnosis Applications
 - 6-1. Road and Infrastructure Deterioration Diagnosis Application

7. Road Weather Management Applications
 - 7-1. Enhanced Maintenance Decision Support System Application
 - 7-2. Weather-Responsive Traffic Management Application
 - 7-3. Road Weather Advisories and Warnings for Motorists and Freight Carriers Application
 - 7-4. Information and Routing Support for Emergency Responders Application

8.2 Definition of Applications in Seven Target Areas

This section presents a high-level definition of the component applications in each target area developed jointly by US and MLIT.

1. Traffic Management Measures Estimation and Traveler Information Applications

1-1. Traffic Management Measures Estimation Application

Traffic management measures estimation application uses probe data to estimate key measures of interest for traffic management including travel times (origin-destination specific, facility-specific), speed profiles, flows (origin-destination specific, facility-specific), and queues (including location and length). This application:

- Collects speed, location, and time stamp from vehicle;
- Scrubs data to remove personally identifiable information (PII);
- Stores vehicle's travel history at a center;
- Matches scrubbed data against digital road maps to calculate vehicle's travel time;
- Calculates travel times of multiple vehicles using above steps;
- Calculates a travel time for the roadway section;
- Analyzes road sections that have lower speed or higher congestion, and identifies the frequency and characteristics of occurrence; and
- Provides basic information for use in highway administration for analysis of road network performance and development of road improvement plans.

1-2. Traveler Information Application

Traveler information application uses real-time and historical probe data, and other supplementary data (including tolling, parking availability, etc.) to recommend trip departure time, mode, route, travel cost, and approximate trip time, via vehicle-to-infrastructure (V2I) and infrastructure-to-mobile (I2M) communications. Speed, location, and time stamp are collected from vehicles in real-time, scrubbed to remove PII, and stored at a center. Scrubbed data are matched against digital road maps to calculate the travel time for a road section. The required travel time and state of congestion are determined for each section, and this information is provided to drivers and others. This application:

- Collects speed, location, and time stamp from vehicle;
- Scrubs data to remove PII;
- Stores vehicle's travel history at a center;
- Matches scrubbed data against digital road maps to calculate vehicle's travel time;
- Calculates travel times of multiple vehicles using above steps;
- Calculates travel time and congestion for the roadway section; and
- Provides information to drivers and others.

2. Safety Applications

2-1. Queue Warning Application

Queue warning application aims to minimize or prevent impacts of rear-end or secondary collisions by utilizing V2I and V2V communications to detect existing queues and/or predict impending queues; and communicate advisory queue warning messages to drivers upstream of roadway segments with existing or developing vehicle queues. This application:

- Collects speed, transverse and lateral acceleration, location, and time stamp from vehicles in real-time,
- Scrubs data to remove PII;
- Stores data at a center;
- Matches scrubbed data against digital road maps to estimate current locations of tail-ends of congestion, and detect presence of stopped vehicles or obstacles on the road; and
- Provides information to drivers and others.

2-2. Determination of Accident Prone Location Application

Determination of accident prone location application uses historical and real-time probe data and incident data logs, to detect and/or predict locations that are accident prone, and communicate the information to vehicles via V2I communications. This application:

- Collects speed, transverse and lateral acceleration, location, and time stamp from vehicles;
- Scrubs data to remove PII;
- Stores data at a center;
- Matches scrubbed data against digital road maps to identify potential accident hotspots and locations;
- Provides information to highway managers who use it to identify strategies to prevent accident and congestion; and
- Provides information to drivers.

3. Freight Operations Applications

3-1. Freight-Specific Dynamic Travel Planning and Performance Application

The *Freight-Specific Dynamic Travel Planning and Performance application* provides traveler information, and dynamic routing, and enables performance monitoring by leveraging existing data in the public domain, as well as emerging private sector applications. This application:

- Collects state of travel of a logistics vehicle, including speed, location, and time stamp;
- Stores data at a center; and
- Provides data to logistics companies that manage and operate logistics.

3-2. Detection of Pavement Deterioration due to Heavy Vehicles and Determination of Travel Routes of Heavy Vehicle Application

Detection of Pavement Deterioration due to Heavy Vehicles and Determination of Travel Routes of Heavy Vehicle application aims to help highway managers in identifying routes where road pavement should be inspected for deterioration and determining travel routes of heavy vehicles. This application:

- Collects location and time stamp data from heavy vehicles;
- Stores data at a center;
- Matches data against digital road maps to calculate routes that were taken by heavy vehicles; and
- Provides archives to highway managers in identifying routes where road pavement should be inspected for deterioration and determining travel routes of heavy vehicles.

3-3. Intermodal Drayage Operations Optimization Application

The *Intermodal Drayage Operations Optimization application* combines container load matching and freight information exchange systems to fully optimize drayage operations, thereby, minimizing bobtails/dry runs and wasted miles and spreading out truck arrivals at intermodal terminals throughout the day.

4. Freeway-Based Dynamic Speed Harmonization Application

4-1. Dynamic Speed Harmonization Application

Dynamic Speed Harmonization application aims to maximize throughput and reduce crashes by utilizing V2I and vehicle-to-vehicle (V2V) communications to detect impending congestion that might necessitate speed harmonization; generating appropriate target speed recommendations for upstream traffic; and communicating the recommendations to the affected vehicles using either I2V or V2V communication. This application:

- Collects speed, acceleration/deceleration, location, time stamp, status of ABS and brakes, etc. in real time from vehicles;
- Scrubs data to remove PII;
- Stores data in a center;
- Determine traffic conditions (such as reductions in traffic flow rates and occurrence of congestion) using real-time and historical data;
- Develops target speed recommendations by lane; and
- Provides target speed recommendations to drivers.

5. Non-Signal Related Environmental Applications

5-1. Determination of Road Environment Application

Determination of Road Environment Application uses probe data to provide basic information for use in highway administration, including determination of environmental problems and development of countermeasures. This application:

- Collects speed, acceleration/deceleration, location, time stamp, vehicle type, and other data from vehicles;
- Stores data in a center;

- Matches data against digital road maps to estimate carbon dioxide emissions and noise, etc., based on speed and acceleration/deceleration data; and
- Analyzes data to determine frequency of worsened environmental conditions and characteristics of occurrence.

5-2. Eco-Driving Promotion Application

Eco-driving Promotion Applications aims to provide drivers with information such as sections with poor fuel efficiency per unit distance. Speed, location, time stamp, and vehicle type are collected in real-time from vehicles.

5-3. Eco-Lanes Application

Eco-lanes application (or concept) seeks to encourage the use of dedicated freeway lanes by vehicles operating in eco-friendly ways, such as ECO-speed harmonization, ECO-CACC (eco-Cooperative Adaptive Cruise Control), and wireless charging of electric vehicles moving at freeway speeds.

5-4. Dynamic Low Emission Zone Application

Dynamic Low Emissions Zone application (or concept) seeks to incentivize “green transportation choices” or restrict access to specific categories of high-polluting vehicles within a geographically defined area or zone for the purpose of improving the air quality within the zone.

6. Road and Infrastructure Deterioration Diagnosis Applications

6-1. Road and Infrastructure Deterioration Diagnosis Application

Road and Infrastructure Deterioration Diagnosis application makes use of probe data to detect deterioration of road surfaces, including presence of potential potholes and rough road surface locations, and provides recommendations of road locations needing maintenance to maintenance managers and vehicle operators. This application:

- Collects speed, location, time stamp, and other CAN bus data, vertical acceleration from onboard units and smart phones, and camera images, etc. from vehicles;
- Scrubs data to remove PII;
- Stores data in a center;
- Matches data against digital road maps to estimate locations of deteriorated pavement and uneven surfaces; and
- Provides information to road management operators, which is used to improve the efficiency of road management operations, including identifying locations where road pavement should be inspected.

7. Road Weather Management Applications

7-1. Enhanced Maintenance Decision Support System Application

Enhanced Maintenance Decision Support System application aims to acquire road-weather data from connected vehicles, including snow plows, maintenance vehicles, and other

general public vehicles to recommend treatment plans and weather response plans to snow plow operators, and drivers of maintenance vehicles. This application:

- Collects speed, location, time stamp, wiper status, fog light status, headlight status, ABS status, traction control status, etc. from CAN bus, and camera images, pavement temperatures, etc., from an external add-on sensor on vehicles;
- Scrubs data to remove PII;
- Stores data in a center;
- Matches data against digital road maps to estimate meteorological conditions such as rain, snow, freezing road surfaces, and fog in each road section;
- Analyzes relationships of effects on road facilities in natural disasters such as landslides, and relationships of frequent traffic accident conditions to locally heavy rains, etc. ; and
- Provides information to road management operators to improve the efficiency of road management operations via:
 - Information on outside temperatures and ABS actuation to support decisions on locations for application of deicing agents
 - Estimated rainfall conditions based on the use of windshield wipers to support decisions on closure of sections with traffic restrictions.

7-2. Weather-Responsive Traffic Management Application

Weather-Responsive Traffic Management application aims to use connected vehicle data and communications systems to enhance the operation of variable speed limit systems and improve work zone safety during severe weather events.

7-3. Road Weather Advisories and Warnings for Motorists and Freight Carriers Application

Road Weather Advisories and Warnings for Motorists and Freight Carriers application aims to use road-weather data from connected vehicles to provide information to travelers on deteriorating road and weather conditions on specific roadway segments. This application:

- Collects speed, location, time stamp, wiper status, fog light status, headlight status, ABS status, traction control status, etc. from CAN bus, and camera images, pavement temperatures, etc., from an external add-on sensor on vehicles;
- Scrubs data to remove PII;
- Stores data in a center;
- Matches data against digital road maps to estimate meteorological conditions such as rain, snow, freezing road surfaces, and fog in each road section;
- Provides information to motorists; and
- Provides information to freight shippers and truck drivers on deteriorating road and weather conditions on specific roadway segments.

7-4. Information and Routing Support for Emergency Responders Application

Information and Routing Support for Emergency Responders application aims to use road-weather data from connected vehicles and data from other surface weather observation systems, to provide information to emergency responders on weather-impacted travel routes (e.g., road or lane closures due to snow, flooding, wind-blown debris), response routes,

calculate response times, and influence decisions to hand-off an emergency call from one responder to another responder in a different location.

8.3 High-Priority Applications of Interest to USDOT and MLIT

Individual prioritizations were sought from internal stakeholders within USDOT and MLIT to generate the list of applications identified in Section 8.2. Prioritizations were done using the criteria specified in Section 8.1:

- Probe Data usage
- Near-Term Deployment Readiness (i.e., algorithms are already in place or research will be ready for prototyping in 18 months to 2 years)
- Promotion of international standards harmonization
- Public sector application
- Expressway/Freeway application relevance (NOTE: MLIT's primary focus is on freeway or expressway applications.)

The following three applications were then jointly selected for further collaborative research by the Task Force during face-to-face discussions:

- 1-1. Traffic Management Measures Estimation Application,
- 4-1. Dynamic Speed Harmonization Application, and
- 7-1. Enhanced Maintenance Decision Support System Application.

9 Assessment of Technical Feasibility of Applications and Identification of Issues for Practical Implementation

This chapter documents an assessment of the three high-priority applications identified in Chapter 8.

9.1 Traffic Management Measures Estimation Application

9.1.1 Purpose

The purpose of the traffic management measures estimation application that makes use of probe data is to provide comprehensive, accurate, and precise information rapidly for improving decision-making.

9.1.2 Application Summary

Figure 9-1 provides a graphical illustration of the application concept.

The center system collects data from vehicles, including vehicle length/width, speed, location, time stamp, location, and heading/direction.

Travel data from all vehicles that drive through a road section are aggregated for the section at the center system to estimate measures. Fundamental measures include, section travel time, speed, and delay (congestion level). In addition, queues at known bottlenecks (e.g., at a lane drop) as well as variable locations (e.g., at an incident) and shockwaves may also be estimated.

The system also aggregates individual origin and destination data to generate data for planning purposes.

For additional information, please refer to Section 8.2.

9.1.2.1 Data Needs

Data needs, shown graphically in Figure 9-1, include: vehicle type, time stamp, location, speed, and heading/direction. The frequency with which probe data generation occurs might be:

- Periodic – these occur at regular intervals based on vehicle movement
- Event Triggered - these occur when the state of certain vehicle status elements change

Periodic probe data generation may occur every 10th of second to 2 minutes, or when the vehicle covers a pre-specified spatial distance (e.g., 200 m). Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., either a state change (e.g., from off to on) or when a value exceeds a specific threshold (e.g., heading/direction changes by more than 45 degrees) or undergoes a transition (e.g., vehicle starts after a stop). Examples of event-triggers are: vehicle heading/direction changes; vehicle starts and stops; hard braking occurs; light and windshield wiper

status change; ABS, traction control system, and hazard lights are active; airbag is deployed, vehicle is disabled, etc. In addition, a digital map database is also needed.

9.1.2.2 Communication Needs

Probe data may be collected from vehicles either via short range communication (DSRC) or long range communication (e.g., cellular) media.

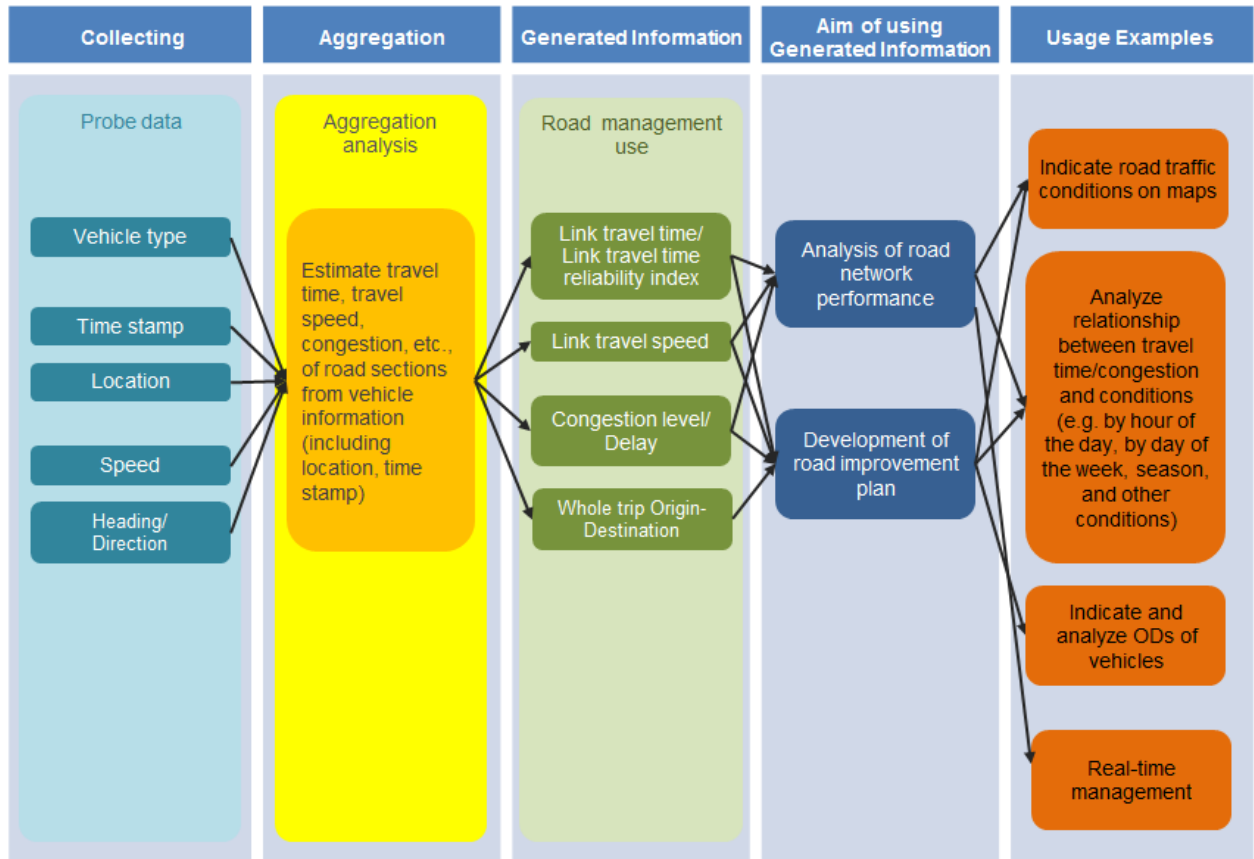


Figure 9-1. Traffic Management Measures Estimation Application Concept

9.1.3 Expected Benefits

This section presents the expected benefits of the application that makes use of probe data. Traffic Management Measures Estimation application will:

- *Improve traffic awareness*, due to increases in coverage, accuracy, and precision that are possible through use of probe data. Relying only on infrastructure sensors is limiting due to lack of broad or comprehensive deployment, especially on sub-urban and rural roads;
- *Enable real-time or active management*, due to increased speed with which the state of the traffic is available to decision makers, including the identification of traffic jams;
- *Increase capability to predict and forecast traffic*, due to availability of comprehensive, accurate, and precise information on traffic state, allowing for the development of countermeasures for traffic congestion at particular road sections or intersections; and

- *Improve planning and evaluation models*, due to increased capability to more accurately estimate origin-destination and traffic demand.

9.1.4 Current Status in US and Japan

In Japan, ITS Spot probe data has been collected, aggregated and shown as congestion level or travel time according to each section and each hours by MLIT in order to utilize road administration such as road planning.

Specifically, the calculated average travel speed according to specified route section and hour are output in tabular form and displayed in congestion level as a time-space diagram. Envisaged uses are project effect evaluation such as determining current travel and comparing speed travel speed before and after a project; traffic safety measures such as determining travel speed either or after implementing safety measures to reduce speeds; and disaster countermeasures such as monitoring the status of occurrence of congestion on routes affected by a disaster and detour routes in real time when a disaster occurs.

In US, private and public sector probe data have been used to estimate measures such as travel times and delays (Chapter 6). The private sector continues to be active in collecting probe data on US roadways to estimate key measures (e.g., INRIX [31], Waze [35], and ALK Technologies [30]).

In addition, the USDOT has recently initiated an effort (BSM Data Emulator) that will develop a tool for simulating mobile wireless messaging protocols, and estimate key transportation measures, including travel time, shockwaves, queues, delays, etc., using data generated from this tool.

9.1.5 Challenges

This section presents some illustrative examples of technical, operational, and institutional challenges faced by the deployment of the Traffic Management Measures Estimation application.

- *Measurement Accuracy*: Accuracy of measures estimation will be low in the near term due to limited probe data, especially for measures such as shockwaves and queues, if supplementary data are not used. It is currently unknown what minimum level of market penetration is required for accuracy or if there is an upper level of market penetration, where the probe data need only be sampled.
- *Data Processing*: Measures estimation will become challenging for a region in the long term due to vast amounts of probe data generated with increased market adoption of probe systems, necessitating Big Data solutions to data processing.
- *Data Integration*: Data agreements that clearly define data ownership need to be developed to avoid issues with integrating probe data collected by various public sector agencies. One or more metadata standards could aid this effort.
- *Data Fusion*: Effective data fusion will be challenging as data gathered from probe data are combined with data gathered through static, infrastructure-based sensors.

9.2 Dynamic Speed Harmonization Application

9.2.1 Purpose

The purpose of the dynamic speed harmonization application is to maximize roadway throughput, reduce crashes, and reduce fuel consumption by harmonizing speeds within and across lanes, using probe data.

9.2.2 Application Summary

Figure 9-2 provides a graphical illustration of the application concept.

The application concept reflects an operational environment in which speed recommendation decisions are made at the center, and then communicated to the affected traffic. In such an environment, the speed harmonization application resides within the center or the infrastructure-based entity and is external to the vehicle. Such an approach was taken since using V2V communication is not well suited to providing a comprehensive view of the roadway traffic conditions, which is fundamental to effective speed harmonization. Communication of target speed recommendations to the affected vehicles will always give priority to crash avoidance/mitigation safety applications when such applications determine that a safety alert is necessary.

Data processing and estimation of target speeds are done at a center, and are external to the vehicle. This is because V2V communication is not well suited to providing a comprehensive view of the traffic conditions, which is fundamental to effective speed harmonization. The center collects data (see Figure 9-2) in real-time from vehicles.

Data are used to estimate road segment-specific and network-specific travel times, delays, and throughput. These are used to monitor the performance of the roadway and to improve the application.

Data are also used to detect shockwaves and queues (location, lanes, length, propagation speed, time of occurrence, etc.). Historical and real-time data are used to predict future shockwaves and queues.

Data are used to estimate target speeds to harmonize or reduce speed variation within and across lanes. Target speeds are developed by segment, by lane, by vehicle type, and by road surface/weather/visibility conditions.

Target speed recommendations are provided to drivers. In addition, motives for speed harmonization (e.g., presence of shockwave, wet pavement, poor visibility, work zones) are also provided to improve compliance.

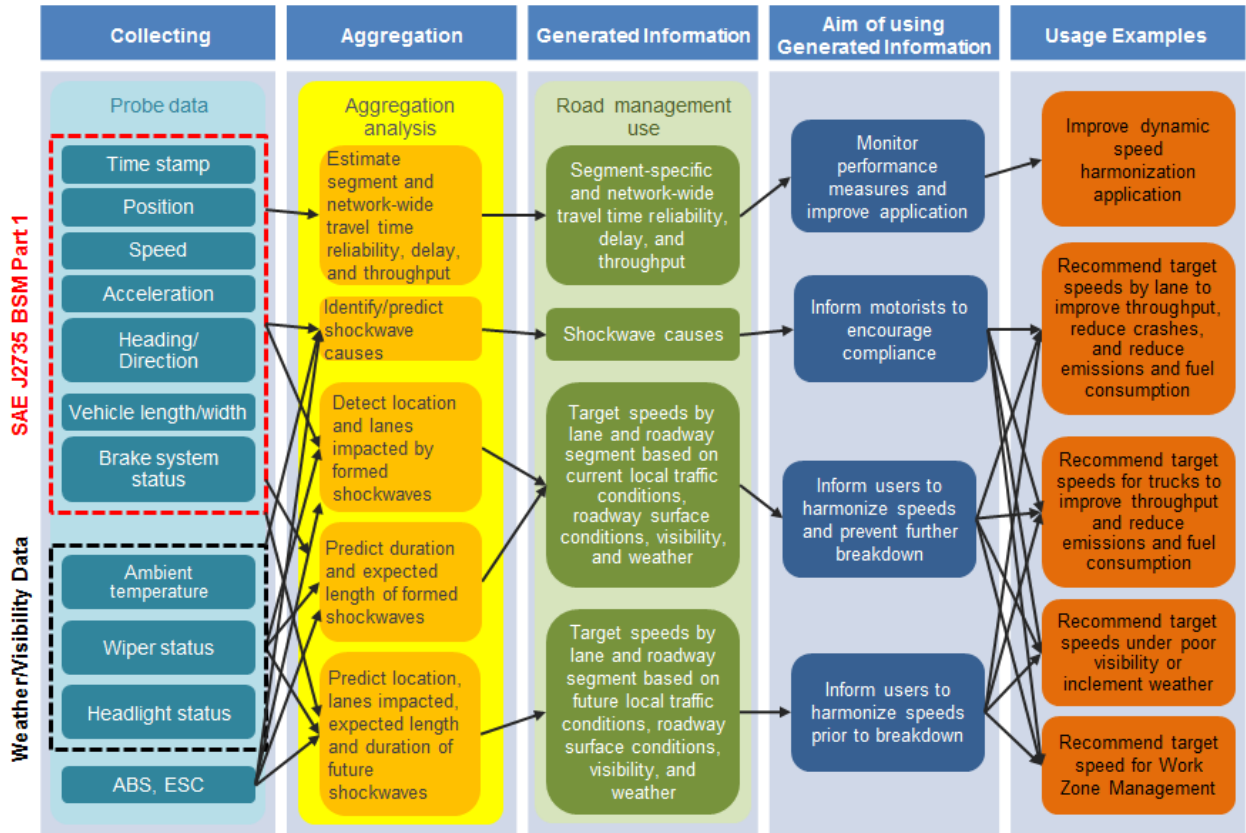


Figure 9-2. Dynamic Speed Harmonization Application Concept

9.2.2.1 Data Needs

Data needs, shown graphically in Figure 9-2, include: vehicle length/width, location, speed, time stamp, heading/direction, brake status, ambient temperature, wiper status, headlight status, fog light status, ABS status, etc. The frequency with which probe data generation occurs might be:

- Periodic – these occur at regular intervals based on vehicle movement
- Event Triggered - these occur when the state of certain vehicle status elements change

Periodic probe data generation may occur every 10th of second to 2 minutes, or when the vehicle covers a pre-specified spatial distance (e.g., 200 m). Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., either a state change (e.g., from off to on) or when a value exceeds a specific threshold (e.g., heading/direction changes by more than 45 degrees) or undergoes a transition (e.g., vehicle starts after a stop). Examples of event-triggers are: vehicle heading/direction changes; vehicle starts and stops; hard braking occurs; light and windshield wiper status change; ABS, traction control system, and hazard lights are active; airbag is deployed, vehicle is disabled, etc. In addition, a digital map database is also needed.

9.2.2.2 Communication Needs

Probe data may be collected from vehicles either via short range communication (DSRC) or long range communication (e.g., cellular) media. Information will be sent using both point-to-point as well as broadcast communication.

9.2.3 Expected Benefits

This section presents the expected benefits of dynamic speed harmonization application that makes use of probe data. The application is expected to have the following benefits:

- *Improved mobility* by increasing throughput, improving travel time reliability, and decreasing delays;
- *Improved safety* by decreasing the number and severity of crashes; and
- *Reduced negative environmental impacts* due to reductions in fuel consumption and emissions.

These benefits are achievable though decrease in speed variation within and across lanes and can be observed on:

- Freeway segments that experience recurring congestion,
- Segments before and at work zones,
- Truck-specific lanes or segments with high truck demand, and
- Freeway segments under inclement weather, poor visibility or low pavement friction conditions.

9.2.4 Current Status in US and Japan

In Japan, MLIT has researched and developed a system that roadside equipment such as ITS Spot will provide appropriate time gap or travel speed to vehicles such as ACC-equipped vehicles in accordance with the traffic situation detected by roadside sensors for realizing smooth traffic on expressways including sag sections. However probe data is not utilized in this system so far, there is a possibility for roadside sensor to be replaced with probe data in the future.

In the US, speed harmonization has been implemented over the past 30 years as variable speed limits, predominantly for improving safety. These systems have been implemented on freeways to reduce congestion, and truck-related crashes, and on rural roads as part of weather advisories. However, speed harmonization that makes use of probe data has not yet been implemented.

The USDOT has recently initiated couple of efforts to prototype speed harmonization, one in combination with queue warning using aftermarket devices, and another in combination with cooperative adaptive cruise control using vehicle-integrated devices.

9.2.5 Challenges

This section presents some illustrative examples of technical, operational, and institutional challenges that are likely when deploying a speed harmonization application. Challenges identified in Section 9.1.5 are also relevant to speed harmonization. In addition, the following challenges are identified for implementation of speed harmonization:

- *Electromagnetic Interference and Electromagnetic Compatibility:* Communication reliability and consistency is critical to the operation of the application, necessitating investigation of approaches to reduce potential communication disturbances or data degradation.
- *Driver Compliance:* Compliance is crucial to the effectiveness of speed harmonization in the absence of automation as the application relies on manual throttle adjustments by drivers and adherence to posted/broadcasted speeds.
- *Co-deployment with Other Traffic Management Applications:* Co-deploying the application with other applications, while reducing implementation and operational costs, can increase the complexity of system integration.
- *Operations and Maintenance Costs:* As adoption and integration of probe data systems will be gradual and uneven, traffic management centers will have to support both legacy systems (for non-enabled vehicles) and probe systems, resulting in high personnel training costs and operations and maintenance costs in the near term.
- *CAN Bus Data Interface:* The CAN bus needs to be connected to the on-board unit, so that the vehicle data that indicates road surface conditions can be processed by the onboard unit.

9.3 Enhanced Maintenance Decision Support System Application

9.3.1 Purpose

The purpose of the Enhanced Maintenance Decision Support System (E-MDSS) application is to generate and send improved road-surface treatment plans to snow plow operators and drivers of maintenance vehicles by using road-weather data from maintenance and other probe vehicles.

9.3.2 Application Summary

Figure 9-3 provides a graphical illustration of the application concept.

The center collects data (see Figure 9-3) in real-time from probe vehicles as well as snow plows and other road-maintenance vehicles.

Data are processed to estimate, predict and forecast road-surface conditions, and snowfall. The hazard algorithm performs road hazard assessments of road weather data for three road weather hazard conditions: precipitation, road condition, and visibility. These are used to generate treatment plans and sent to snow plow operators and other maintenance vehicles.

In addition, probe vehicles will continue to capture road surface data after treatment plans have been implemented. These data are collected at the center and continuously assessed to monitor the outcome of the initial treatment.

Data are also used to estimate and predict visibility, rainfall, wind, etc. These are used to support decisions on road closures.

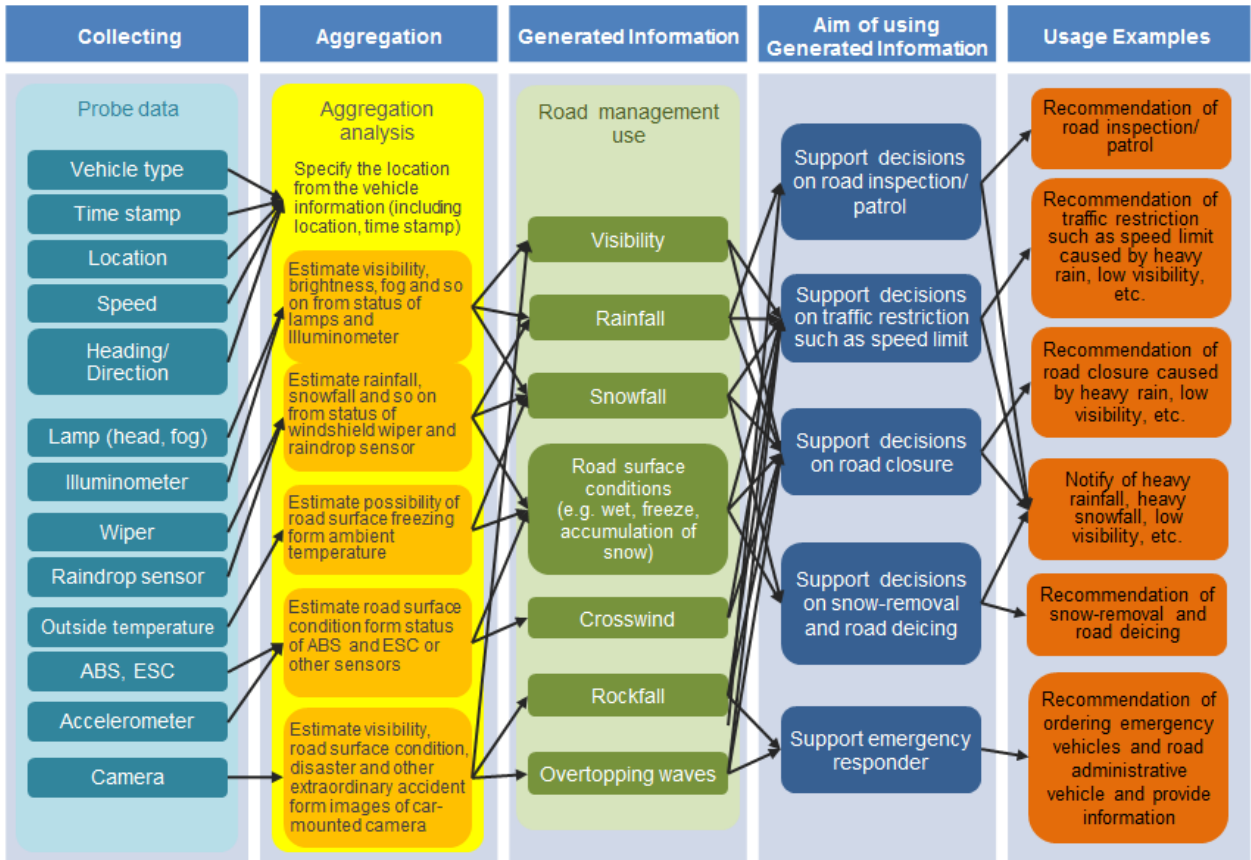


Figure 9-3. Enhanced Maintenance Decision Support System Application Concept

9.3.2.1 Data Needs

Data needs, shown graphically in Figure 9-3, include: vehicle length/width, location, speed, time stamp, heading/direction, brake status, ambient temperature, wiper status, headlight status, fog light status, ABS status, camera images, etc. The frequency with which probe data generation occurs might be:

- Periodic – these occur at regular intervals based on vehicle movement
- Event Triggered - these occur when the state of certain vehicle status elements change

Periodic probe data generation may occur every 10th of second to 2 minutes, or when the vehicle covers a pre-specified spatial distance (e.g., 200 m). Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., either a state change (e.g., from off to on) or when a value exceeds a specific threshold (e.g., heading/direction changes by more than 45 degrees) or undergoes a transition (e.g., vehicle starts after a stop). Examples of event-triggers are: vehicle heading/direction changes; vehicle starts and stops; hard braking occurs; light and windshield wiper status change; ABS, traction control system, and hazard lights are active; airbag is deployed, vehicle is disabled, etc. In addition, a digital map database is also needed.

9.3.2.2 Communication Needs

Probe data may be collected from vehicles either via short range communication (DSRC) or long range communication (e.g., cellular) media.

9.3.3 Expected Benefits

This section presents the expected benefits of the application that makes use of probe data. Enhanced Maintenance Decision Support System application that makes use of probe data will generate improved information that will allow agencies to:

- Make better decisions about asset and resource availability, equipment maintenance, and equipment and materials purchasing or procurement;
- Provide more timely and proactive treatment (snow removal, de-icing) of road surfaces under inclement weather; and
- Provide prompt closure of roads due to low visibility or heavy rainfall or snowfall.

It is expected that targeting the three areas listed above will result in the following benefits:

- *Improved mobility* by increasing throughput, improving travel time reliability, decreasing delays, and providing better traveler information on closed roads;
- *Improved safety* by decreasing crashes, fatalities, injuries, and property damage; and
- *Improved agency efficiency* by improved resource management.

9.3.4 Current Status in US and Japan

The application is still in the conceptual stage in Japan, requiring further research and development, but there is a strong interest in pursuing this area due to the frequency of extreme weather events (e.g., typhoons, tsunamis, heavy snow) throughout the country.

In the US, the application is an enhancement of the Maintenance Decision Support System (MDSS), which is a decision support tool that maintenance managers have been using to develop treatment and response plans to winter storms and other winter weather events. However, MDSS acquires data from fixed and remote sensors.

The USDOT has partnered with Michigan, Minnesota, and Nevada departments of transportation to prototype and test E-MDSS, which is expected to be completed in Fall 2014.

9.3.5 Challenges

This section presents some illustrative examples of technical, operational, and institutional challenges that are likely when deploying an E-MDSS application. Challenges identified in Section 9.1.5 are also relevant to E-MDSS. In addition, the following challenges are identified for implementation of E-MDSS:

- *Shorter Term Detection of Road Surface Conditions:* Accuracy is limited when road-surface conditions are uneven across lanes, or under complex road conditions (e.g., patchy ice, mixed precipitation, pavement temperature hovering around 0°C), especially when forecasts are to be made in the shorter term (1 to 2 hours).
- *Hazard Algorithm Accuracy and Prediction Capability:* The hazard algorithm has not been tested using robust data, possibly leading to lower confidence among users (maintenance managers) about its accuracy of current and predicted conditions.

- *Electromagnetic Interference and Electromagnetic Compatibility:* Communication reliability and consistency is critical to the operation of the application, necessitating investigation of approaches to reduce potential communication disturbances or data degradation.
- *Image Processing Capabilities:* The accuracy and reliability of image processing capabilities to identify the roadway conditions captured by the onboard cameras is currently unknown.
- *CAN Bus Data:* The CAN bus needs to be connected to the on-board unit, so that the vehicle data that indicates road surface conditions can be processed by the onboard unit.

9.4 Cross-Cutting Issues

This section identifies cross-cutting issues common to all three applications.

9.4.1 Security

All three applications have the following security needs:

- Threat 1: Malicious entity might masquerade as an authorized device and manipulate data to deliver unauthorized data.
 - Security Measure 1: Authentication of the message
 - Security Measure 2: Encryption or authentication of data
 - Security Measure 3: Improvement of tamper resistance of devices*Risk without Security:* Decline in reliability of services; confusion among drivers due to false information; decline in accuracy of probe data; decline in application effectiveness; loss in confidence in probe system technology
- Threat 2: Malicious entity might intercept or eavesdrop on infrastructure to vehicle communication to acquire private information (e.g., credit card number)
 - Security Measure 1: Encryption of data*Risk without Security:* Illegal use of personal information (e.g., credit card); loss of privacy; loss in confidence in probe system technology

9.4.2 Standards

The US has identified the following US standards [64]: NTCIP 2306, ITE TMDD, IEEE 1512-2006, IEEE 1512.1, IEEE 1512.2, IEEE 1512.3, ASTM E2665-08, SAE J2354, SAE J2395, and SAE J2735.

Japan has also identified the following standards: ISO 22837, ISO24100, and ISO TS25114.

The US and Japan are working together on the harmonization of international standards and future standardization needs for the deployment of cooperative vehicle and ITS systems.

9.4.3 Policy and Probe Data

- *Quality Assurance:* A consistent definition of what constitutes accurate or consistent probe data needs to be established, and adopted by public and private sector data providers. Secondly, quality assurance processes need to be established.
- *Privacy:* A consistent approach to anonymizing probe data needs to be established, and adopted by public and private sector data providers.

- *Metadata:* One or more metadata standards for probe and supporting data need to be established and adopted by public and private sector data providers to increase usability of their data.
- *Storage and Access:* Decentralized storage and selective federation are emerging data management practices to improve quality management and data integration without full centralization.
- *Data Ownership and IPR:* Clear guidelines need to be established for identifying data ownership and licensing, including IPR, of probe data, supporting data, and processing tools.

10 Recommended Next Steps

The next steps for future collaboration on probe data include:

- Expand probe data collaboration from a bi-lateral to a tri-lateral effort with European Union (EU) as the new partner
- Conduct research on the three high-priority applications identified jointly by US and Japan
- Identify and prioritize research gaps for future collaboration
- Address and refine cross-cutting issues related to probe data such as standards, security, privacy, quality assurance, metadata, storage and access, and data ownership and IPR

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APPENDIX A. List of Acronyms

Acronym	Meaning
AACN	Advanced Automatic Crash Notification
AACN-RELAY	Advanced Automatic Crash Notification Relay
ABS	Antilock Braking System
ACC	Adaptive Cruise Control
ADOT	Arizona Department of Transportation
AERIS	Applications for the Environment: Real-Time Information Synthesis
ALPR	Automated License Plate Reader
ARIB	Association of Radio Industries and Businesses
ASD	Aftermarket Safety Devices
ASN.1	Abstract Syntax Notation One
ASTM	American Society for Testing and Materials
ATIS	Advanced Traveler Information Systems
ATM	Advanced Traffic Management
ATRI	American Transportation Research Institute
AVL	Automatic Vehicle Location
BSM	Basic Safety Message
BTS	Berkeley Transportation Systems
CACC	Cooperative Adaptive Cruise Control
CAD/AVL	Computer-aided Dispatch/Automated Vehicle Location
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CHP	Community Health Plan
CICAS	Cooperative Intersection Collision Avoidance Systems
CICAS-SSA	Cooperative Intersection Collision Avoidance Systems – Stop Sign Assist
CO2	Carbon Dioxide
CSV	Comma-Separated Value
CTS PFS	Cooperative Transportation System Pooled Fund Study
CVHT	Cooperative Vehicle Highway Test Bed
CVII	Commercial Vehicle Infrastructure Integration
DCM	Data Capture and Management
DMA	Dynamic Mobility Applications
DOT	Department of Transportation
D-RIDE	Dynamic Ridesharing
DRM	Digital Road Maps
DR-OPT	Drayage Optimization
DSRC	Dedicated Short Range Communications
DSRC-SPF	Digital Short-Range Communications Security Platform
ECC	Elliptic Curve Cryptography
ECO-CACC	Eco-Cooperative Adaptive Cruise Control
EDACS	Enhanced Digital Access Communications System
E-MDSS	Enhanced Maintenance Decision Support System
EMS	Emergency Medical Services
ESS	Environmental Sensor Stations

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Acronym	Meaning
ETC	Electronic Toll Collection
EVAC	Emergency Communications and Evacuation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRATIS	Freight Advanced Traveler Information Systems
FSP	Freight Signal Priority
GHG	Greenhouse Gas
GID	Geographic Information Description
GIS	Geographical Information System
GPS	Global Positioning System
HAZMAT	Hazardous material
HOV	High-Occupancy Vehicle
I2M	Infrastructure-to-Mobile
I2V	Infrastructure-to-Vehicle
IC	Interchange
IDTO	Integrated Dynamic Transit Operations
IEEE	Institute of Electrical and Electronics Engineers
IMO	Integrated Mobile Observation
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
INFLO	Intelligent Network Flow Optimization
IPR	Intellectual Property Rights
I-SIG	Intelligent Traffic Signal System
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
KML	Keyhole Markup Language
LAN	Local Area Network
MAC	Medium Access Control
MADIS	Meteorological Assimilation Data Ingest System
MBUF	Mileage-Based User Fees
MCDOT	Maricopa County Department of Transportation
MDOT	Maryland Department of Transportation
MDSS	Maintenance Decision Support System
M-ISIG	Multi-Modal Intelligent Traffic Signal System
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MMS	Maintenance Management System
MSDOT	Michigan Department of Transportation
MTC	Metropolitan Transportation Commission
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NDOT	Nevada State Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NITSA	National ITS Architecture
NOAA	National Oceanic and Atmospheric Administration

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Acronym	Meaning
NSP	Northern State Parkway
NTCIP	National Transportation Communications for ITS Protocol
NYS	New York State
NYS DOT	New York State Department of Transportation
OBE	On-Board Equipment
OD	Origin-Destination
PATH	Partners for Advanced Transit and Highways
PED-SIG	Mobile Accessible Pedestrian Signal System
PFS	Pooled-Fund Study
PHY	Physical Layer
PII	Personally Identifiable Information
POC	Proof of Concept
PREEMPT	Emergency Vehicle Preemption
PSAP	Public Safety Answering Point
PST	Pacific Standard Time
Q-WARN	Queue Warning
RCOC	Road Commission of Oakland County
RDE	Research Data Exchange
RESP-STG	Incident Scene Pre-Arrival Staging and Guidance for Emergency Responders
RITA	Research and Innovative Technology Administration
RITA/BTS	Research and Innovative Technology Administration/Bureau of Transportation Statistics
RITA/ITS JPO	Research and Innovative Technology Administration/Intelligent Transportation Systems Joint Program Office
RSE	Roadside Equipment
RWMP	Road Weather Management Program
SAD	System Architecture Document
SAE	Society of Automotive Engineers
SAIC	Science Applications International Corporation
SCMS	Security Certificate Credential Management
SDN	Service Delivery Node
SPD-HARM	Dynamic Speed Harmonization
SSP	Southern State Parkway
T-CONNECT	Connection Protection
T-DISP	Dynamic Transit Operations
TFHRC	Turner-Fairbank Highway Research Centers
TMC	Transportation Management Center
TMCC	Travel Management Coordination Center
TSP	Transit Signal Priority
TTI	Texas Transportation Institute
UMTRI	University of Michigan Transportation Research Institute
USDOT	U.S. Department of Transportation
UTC	Coordinated Universal Time
V2I	Vehicle-to-Infrastructure

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Acronym	Meaning
V2V	Vehicle-to-Vehicle
VAD	Vehicle Awareness Device
VDT	Vehicle Data Translator
VICS	Vehicle Information and Communication System
VII	Vehicle Infrastructure Integration
VMS	Variable Message Sign
VSL	Variable Speed Limit
WAVE	Wireless Access in Vehicular Environments
WSDOT	Washington State Department of Transportation
XML	Extensible Markup Language

APPENDIX B. Metric/English Conversion Factors

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		LENGTH (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft.)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd.)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft.)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd.)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		AREA (APPROXIMATE)	
1 square inch (sq. in, in ²)	= 6.5 square centimeters (cm ²)	1 square centimeter (cm ²)	= 0.16 square inch (sq. in, in ²)
1 square foot (sq. ft., ft ²)	= 0.09 square meter (m ²)	1 square meter (m ²)	= 1.2 square yards (sq. yd., yd ²)
1 square yard (sq. yd., yd ²)	= 0.8 square meter (m ²)	1 square kilometer (km ²)	= 0.4 square mile (sq. mi, mi ²)
1 square mile (sq. mi, mi ²)	= 2.6 square kilometers (km ²)	10,000 square meters (m ²)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m ²)		
MASS - WEIGHT (APPROXIMATE)		MASS - WEIGHT (APPROXIMATE)	
1 ounce (oz.)	= 28 grams (gm.)	1 gram (gm.)	= 0.036 ounce (oz.)
1 pound (lb.)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb.)
1 short ton = 2,000 pounds (lb.)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)		VOLUME (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz.)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz.)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft., ft ³)	= 0.03 cubic meter (m ³)	1 cubic meter (m ³)	= 36 cubic feet (cu ft., ft ³)
1 cubic yard (cu yd., yd ³)	= 0.76 cubic meter (m ³)	1 cubic meter (m ³)	= 1.3 cubic yards (cu yd., yd ³)
TEMPERATURE (EXACT)		TEMPERATURE (EXACT)	
$[(x-32)(5/9)]$ °F	= y °C	$[(9/5)y + 32]$ °C	= x °F

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price \$2.50 SD Catalog No. C13 102

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