

Assessment Report of US-Japan- Europe Collaborative Research on Probe Data

International Probe Data Work Group Phase 2

www.its.dot.gov/index.htm

Final Report — January 2016

Publication Number: FHWA-JPO-16-356



U.S. Department of Transportation



MLIT

Ministry of Land, Infrastructure, Transport and Tourism

Produced by Noblis, Inc.
U.S. Department of Transportation
ITS Joint Program Office

Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.
The U.S. Government is not endorsing any manufacturers, products, or services cited herein and any trade name that may appear in the work has been included only because it is essential to the contents of the work.

Cover Photo Credit: USDOT (2012)

Technical Report Documentation Page

1. Report No. FHWA-JPO-16-356		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Assessment Report of US-Japan-Europe Collaborative Research on Probe Data International Probe Data Work Group Phase 2				5. Report Date January 2016	
				6. Performing Organization Code	
7. Author(s) Mike McGurrian, Meenakshy Vasudevan and Peiwei Wang (Noblis); Gene McHale and Dale Thompson (FHWA R&D); Koichi Sakai, Ryoichi Watanabe, Yoshihiro Tanaka, Hideyuki Kanoshima, Shingo Mawatari and Takahiro Tsukiji (MLIT/NILIM); Maxime Flament (ERTICO), Yvonne Barnard (ERTICO), Stephane Dreher (HERE) and Josep Maria Salanova (CERTH)				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 European Union's European Commission Directorate General for Communications Networks, Content & Technology (DG CONNECT)				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. DTFH61-11-D-00018	
12. Sponsoring Agency Name and Address ITS-Joint Program Office 1200 New Jersey Avenue, S.E. Washington, DC 20590				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code HOIT-1	
15. Supplementary Notes					
16. Abstract The United States Department of Transportation (USDOT), the Road Bureau of Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan, and the European Union's European Commission Directorate General for Communications Networks, Content & Technology (DG CONNECT) have a long history of sharing information on ITS (Intelligent Transportation Systems) activities. A US-Japan-Europe ITS Task Force was established specifically to facilitate the exchange of information and identify areas for collaborative research for the development and deployment of ITS in the three nations. 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 To continue the initial joint US-Japan work documented in the US-Japan Collaborative Research on Probe Data: Assessment Report [1], published in November 2013, this report documents the work conducted from the fall of 2013 through the fall of 2015 to: 1. Add probe system and probe data inputs from the European team; 2. Significantly expand on the initial assessment, providing an extensive expansion on assessing the three applications; 3. Discuss cross-cutting issues that affect all three applications; and 4. Introduce the next steps for future collaboration					
17. Key Words Probe data, probe systems, cooperative systems, connected vehicle, ITS Spot, ETC2.0, 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 172	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 (BTS), Brian Cronin (ITS JPO), and James Pol (FHWA R&D), for their review and comments.
- Marcia Pincus (ITS JPO), for a summary of AERIS applications, and review.
- Gabe Guevara (FHWA), for a review of the weather data and applications.
- Walt Fehr (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 (ITS JPO) and Brian Cronin (ITS JPO), for their support.
- Noblis: Karl Wunderlich for his review, JD Schneeberger for a summary of the AERIS applications, and Taylor Deurbrouck, 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.
- Ken Iwasaki (MLIT/NILIM) for his support.
- Mats Jonsson, Niels Agerholm, Hans Fiby, Paul Kompfner, Tobias Hess, Sandro Benrdt, Hans-Joachim Fischer, Tzanidaki Johanna, Eric-Mark Huitema, Jiří Novobilský, Kulmala Risto, Paul Spaanderman, Trond Hovland, and Vaa Torgeir for their review and contribution to this report.

Table of Contents

Executive Summary	7
1 Introduction	9
1.1 BACKGROUND	9
1.2 RESEARCH PURPOSE	9
1.3 RESEARCH OUTCOMES	10
2 Probe Data Definition and Scope of Research	11
3 Summary of Probe Systems	13
3.1 SUMMARY OF PROBE SYSTEMS IN THE US	13
3.1.1 Assessment of Research, Development, and Deployment of Connected Vehicle Systems in the US	13
3.1.2 Assessment of Research, Development, and Deployment of Probe Systems by the Private Sector in the US	32
3.2 SUMMARY OF PROBE SYSTEMS IN JAPAN	34
3.2.1 Status of Government R&D on Probe Systems	34
3.2.2 Summary of the Status of Probe System Research, Development and Deployment by the Private Sector in Japan	40
3.3 SUMMARY OF PROBE SYSTEMS IN EUROPE	43
3.3.1 Status of Probe Systems in Europe	43
3.3.2 European/Regional Activities	54
3.4 COMPARISON OF PROBE SYSTEMS	62
4 Summary of Probe Data	67
4.1 PROBE DATA IN THE US	67
4.1.1 Public sector probe data	67
4.1.2 Private sector probe data	77
4.1.3 Key Findings	80
4.2 PROBE DATA IN JAPAN	82
4.2.1 Probe data of Japanese Government	82
4.2.2 Private sector probe data	85
4.3 PROBE DATA IN EUROPE	85
4.3.1 European initiatives supporting open data in Europe	85
4.3.2 National initiatives	90
4.3.3 Example of private sector probe data: Tomtom	92
4.4 COMPARISON OF PROBE DATA	95
5 Candidate List of Probe Data Enabled Applications	100
5.1 CANDIDATE LIST PROPOSED BY USDOT	100
5.1.1 High-Priority Mobility Bundles Proposed by USDOT	100
5.1.2 Transformative Environmental Applications Proposed by USDOT	107
5.1.3 Road Weather Management Applications	110
5.2 CANDIDATE LIST PROPOSED BY MLIT	111

5.2.1	Level 1: Candidates that have Used Probe Data Up to Now in Road Administration	112
5.2.2	Candidate Applications Expected to Use Probe Data	117
5.2.3	Possibilities for the Future	121
5.3	CONSOLIDATED LIST OF CANDIDATE APPLICATIONS	122
6	Prioritized Probe Data-Enabled Applications	123
6.1	SEVEN TARGET AREAS OF HIGH PRIORITY APPLICATIONS.....	123
6.2	DEFINITION OF APPLICATIONS IN SEVEN TARGET AREAS	124
6.3	HIGH-PRIORITY APPLICATIONS OF INTEREST TO USDOT AND MLIT	129
7	Assessment of Three Priority Applications and Identification of Issues for Practical Implementation	130
7.1	TRAFFIC MANAGEMENT MEASURES ESTIMATION APPLICATION.....	130
7.1.1	Purpose	130
7.1.2	Application Summary	130
7.1.3	Expected Benefits.....	132
7.1.4	Relevant Examples in the US, Japan, and the EU	133
7.1.5	Application Specific Challenges	134
7.2	DYNAMIC SPEED HARMONIZATION APPLICATION.....	134
7.2.1	Purpose	134
7.2.2	Application Summary	134
7.2.3	Expected Benefits.....	137
7.2.4	Relevant Examples in the US, Japan and the EU	138
7.2.5	Application Specific Challenges	138
7.3	OPERATIONAL MAINTENANCE DECISION SUPPORT SYSTEM APPLICATION	139
7.3.1	Purpose	139
7.3.2	Application Summary	139
7.3.3	Expected Benefits.....	142
7.3.4	Relevant Examples in the US, Japan and the EU	143
7.3.5	Application-Specific Challenges.....	145
8	Cross-Cutting Issues	146
8.1	DATA USAGE.....	146
8.2	DATA PRIVACY	147
8.2.1	United States	147
8.2.2	Europe	149
8.2.3	Japanese Experience with ITS SPOT	152
8.3	SECURITY	153
8.4	STANDARDS.....	154
8.4.1	International Organization for Standardization (ISO).....	154
8.4.2	SAE International.....	155
8.4.3	Institute for Electrical and Electronic Engineering (IEEE).....	155
8.4.4	ETSI	155
8.4.5	ASTM.....	155
8.4.6	National Transportation Communications for Intelligent Transportation System (NTCIP)	156

8.4.7	ITS Traffic Management Data Dictionary (TMDD).....	156
8.5	COMPLIANCE AND CERTIFICATION.....	156
8.6	MOBILE WIRELESS DATA COMMUNICATIONS OPTIONS.....	156
8.7	ACQUISITION, STORAGE, AND DISTRIBUTION OF DATA	158
8.8	PUBLIC AND PRIVATE SECTOR ROLES.....	158
8.9	QUALITY OF THE DATA AND META-DATA	158
8.9.1	Data Quality	158
8.9.2	Meta-Data	160
8.10	OTHER ISSUES	160
9	Recommended Next Steps	161
	References	162
APPENDIX A.	List of Acronyms	168
APPENDIX B.	Metric/English Conversion Factors	172

List of Tables

Table 3-1. Safety Pilot Vehicles and Devices (Source: UMTRI)	31
Table 3-2. Companies Offering ETC2.0-Compatible Car Navigation Systems/On-board Units (Source: Japan ITS Service Promotion Association).....	38
Table 3-3. Probe system ownership.....	39
Table 3-4. Status of research and development of three major private sector probe systems in Japan (Source: MLIT).....	41
Table 3-5. Comparison of Probe Systems in the US and Japan	63
Table 4-1. Summary of Private Sector Data Products and Services (Source: TTI)	79
Table 4-2. Standards Relevant to Connected Vehicles	82
Table 4-3. Travel record data items (Source: MLIT)	83
Table 4-4. Behavior record thresholds (Source: MLIT).....	83
Table 4-5. Behavior Record Data Items (Source: MLIT).....	84
Table 4-6. Probe Data Retention Periods (Source: MLIT).....	85
Table 4-7. Summary of Private Sector Data Products and Services in Europe	94
Table 4-8. Comparison of Probe Data Generated by Connected Vehicle Systems and ETC2.0	96
Table 4-9. Summary Comparison of Data Elements in J2735 BSM Part 1, J2735 Probe Data, and ETC2.0 Probe Data.....	99
Table 5-1. Candidates for Probe Data Use - Enabled Applications (Source: MLIT)	111
Table 5-2. Candidates for Probe Data-enabled Applications (Source: MLIT)	112
Table 5-3. Consolidated List of Applications	122
Table 7-1. Desired Probe Data Elements for Traffic Management Measures Estimation....	132
Table 7-2. Desired Probe Data Elements for Speed Harmonization	136
Table 7-3. Desired Probe Data Elements for Operational Maintenance Decision Support Systems.....	141
Table 8-1. Types of Personally Identifiable Information (PII)	147
Table 8-2. Applicability of Wireless Data Communications Technologies to the Three Applications	157

List of Figures

Figure 2-1. US-Japan Probe Data Scope (Source: USDOT).....	12
Figure 3-1. Core System Context Diagram (Source: USDOT).....	14
Figure 3-2. An Example Data Exchange in a Connected Vehicle System (Source: USDOT).....	15
Figure 3-3. Connected Vehicle Test Beds (Source: USDOT).....	16
Figure 3-4. Michigan 2010 V2V and V2I Test Bed (Source: USDOT).....	17
Figure 3-5. Michigan 2012 Connected Vehicle Test Bed (Source: USDOT).....	17
Figure 3-6. Michigan 2010 V2V and V2I Test Bed (Source: USDOT).....	19
Figure 3-7. Michigan 2012 Connected Vehicle Test Bed (Source: USDOT).....	20
Figure 3-8. TFHRC's Cooperative Vehicle Highway Test Bed (CVHT) Intelligent Intersection (Source: Turner-Fairbank Highway Research Center, FHWA)	22
Figure 3-9. Florida Test Bed RSE Coverage (Source: FDOT)	24
Figure 3-10. Maricopa County Connected Vehicle Test Bed (Source: MCDOT)	28
Figure 3-11. Safety Model Deployment Site (Source: MSDOT).....	31

Figure 3-12. Locations of ETC2.0 Roadside Units (Source: MLIT) [42].....	36
Figure 3-13. Collected probe data in downtown Sapporo City for the 3 months of June-August 2011 (Source: MLIT)	37
Figure 3-14. Conceptual Diagram of Probe System (Source: MLIT)	37
Figure 3-15. An ETC2.0-compatible car navigation system (left) and ETC2.0 roadside equipment (right) (Source: MLIT) [43].....	38
Figure 3-16. Types of Probe Data related Activities in Europe (Source: ERTICO)	44
Figure 4-1. Location of RSEs and Environmental Sensor Stations (ESS) (Source: USDOT).....	70
Figure 4-2. Intersection used for Ground Truth Travel Time Estimations (Source: University of California - Berkeley).....	76
Figure 4-3. Timing of travel record data storage (Source: MLIT)	83
Figure 4-4. Timing of behavior record data storage (Source MLIT)	84
Figure 4-5. Open Data Barometer (Source: barometer.opendataresearch.org).....	86
Figure 4-6. The Open Transport Data Manifesto (Source: www.epsiplatform.eu/transport)..	87
Figure 4-7. A snapshot of DLR Clearing House (Source: DLR)	92
Figure 4-8. Content in TomTom Traffic Database (Source: TomTom)	93
Figure 5-1. Comparison of average travel speed on major roads nationwide and in central Tokyo (Source: MLIT).....	113
Figure 5-2. Proportion of automobile use delay due to traffic congestion nationwide and in central Tokyo (Source: MLIT).....	113
Figure 5-3. Average travel time per time period between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT).....	114
Figure 5-4. Delay due to traffic congestion between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT).....	114
Figure 5-5. Comparison of average speed on secondary roads before and after social experiment of eliminating tolls on the Kyoto Tamba Expressway (Source: MLIT).....	115
Figure 5-6. Impact Analysis of a New Urban Expressway in Tokyo (Source: NILIM)	115
Figure 5-7. Sectors closed to traffic as a result of the Great East Japan Earthquake (Source: MLIT)	116
Figure 5-8. Map of information on roads usable by automobiles (Source: ITS Japan) [75] ..	117
Figure 5-9. Collection of behavior records (acceleration before and after) in central Osaka (Source: MLIT)	118
Figure 5-10. Field operational test for assisting distribution operations (Source: MLIT).....	119
Figure 5-11. Display of routes traveled (Source: MLIT)	119
Figure 5-12. Display of status of near-miss incidents and sudden acceleration (Source: MLIT)	120
Figure 5-13. 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).....	121
Figure 7-1. Traffic Management Measures Estimation Application Concept (Source: USDOT).....	131
Figure 7-2. Dynamic Speed Harmonization Application Concept (Source: USDOT)	135
Figure 7-3. Operational Maintenance Decision Support System Application Concept (Source: USDOT).....	140
Figure 8-1. Information Security Assessment Components (Source: USDOT)	153

Executive Summary

The United States Department of Transportation (USDOT), the Road Bureau of Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan, and the European Union's European Commission Directorate General for Communications Networks, Content & Technology (DG CONNECT) have a long history of sharing information on ITS (Intelligent Transportation Systems) activities. A US-Japan ITS Task Force was originally established specifically to facilitate the exchange of information and identify areas for collaborative research for the development and deployment of ITS in the US and Japan. The Task Force identified four high-priority areas for conducting collaborative research, including probe data. The initial joint US-Japan work was documented in the US-Japan Collaborative Research on Probe Data: Assessment Report [1], published in November 2013. The EU then became an active participant in this Task Force. This final report summarizes the work conducted from the fall of 2013 through the fall of 2015. In particular, it documents the analysis that has been conducted on the three high priority applications of probe data that were previously selected for joint study:

- Traffic Management Measures Estimation
- Dynamic Speed Harmonization, and
- Operational Maintenance Decision Support Systems

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
- Expanded probe data collaboration from a bi-lateral to a tri-lateral effort with European Union (EU) as the new partner
- Conducted research on the three high-priority applications identified jointly by US and Japan
- Identified and prioritized research gaps for future collaboration
- Addressed and refined 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)

Through the course of its work, the trilateral group identified several issues of mutual interest related to probe data as discussed in this report. The subset of topics that will be addressed collectively by the trilateral group is currently being determined. At this stage, the recommended next steps for future collaboration on probe data include:

- Conducting research on data accuracy and quality for the selected applications discussed in Section 7
- Using actual probe data as input in analysis to address the challenges on data accuracy, processing methods/algorithms, and aggregating/combining probe data with other data.
- Prioritizing and selecting a subset of the cross-cutting “horizontal” issues for more detailed investigation and discussions.

To support these or other collaborative research activities, the trilateral group may use tools beyond those discussed in this report. For example, the USDOT has developed a Trajectory Conversion Analysis (TCA) tool¹ to conduct studies to assess the impacts on traffic measures using probe message modeling. The TCA allows emulated vehicles to generate and transmit Probe Data Messages (PDMs), Basic Safety Messages (BSMs), the European Union’s Cooperative Awareness Messages (CAMs), Japan’s ITS SPOT messages and the prototype Basic Mobility Message (BMM) by either Dedicated Short Range Communication (DSRC) or via cellular and to evaluate. The USDOT is also developing tools to assist with Dynamic Interrogative Data Capture (DIDC), which uses dynamic adjustment of data collection in order to better manage the volume of data collected while meeting all application needs.

These next steps will be assessed and follow up activity determined via continued dialog within the trilateral group.

¹ <http://www.itsforge.net/index.php/community/explore-applications#/38/104>

1 Introduction

1.1 Background

The United States 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

The European Union's European Commission Directorate General for Communications Networks, Content & Technology (DG CONNECT) joined the task force in fall 2013, thus expanding the bi-lateral probe data collaboration group to a tri-lateral effort with the European Union (EU) as the new partner.

This document summarizes the collaborative research effort in the “probe data” high-priority area. The USDOT, MLIT and EU are promoting research and development (R&D) and deployment of cooperative systems. As part of this effort, the three partners 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.”

1.2 Research Purpose

As a part of the probe data collaborative research, the US-Japan-EU 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;
- Prioritized three applications of mutual interest for future collaboration;
- Conducted research on the three high-priority applications identified jointly;
- Identified and prioritized research gaps for future collaboration; and
- Addressed and refined 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).

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.

1.3 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 to enhance livability in the US. In EU, many probe data related research have been developed in different nations with different focuses. The US-Japan-EU ITS Task Force envisions significant benefits through the probe data collaborative research effort among the three partners. The expected research outcomes include:

- Promotion of probe data research and development in the U.S., Japan and EU 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 other two partners;
- Increased understanding and quantification of prospective benefits of deployments similar to Japan's ETC2.0 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.

2 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. For example, the USDOT J2735 Probe Data Message (PDM) contains vehicle position, motion, control, size and etc.

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 2-1 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.

2. Probe Data Definition and Scope of Research

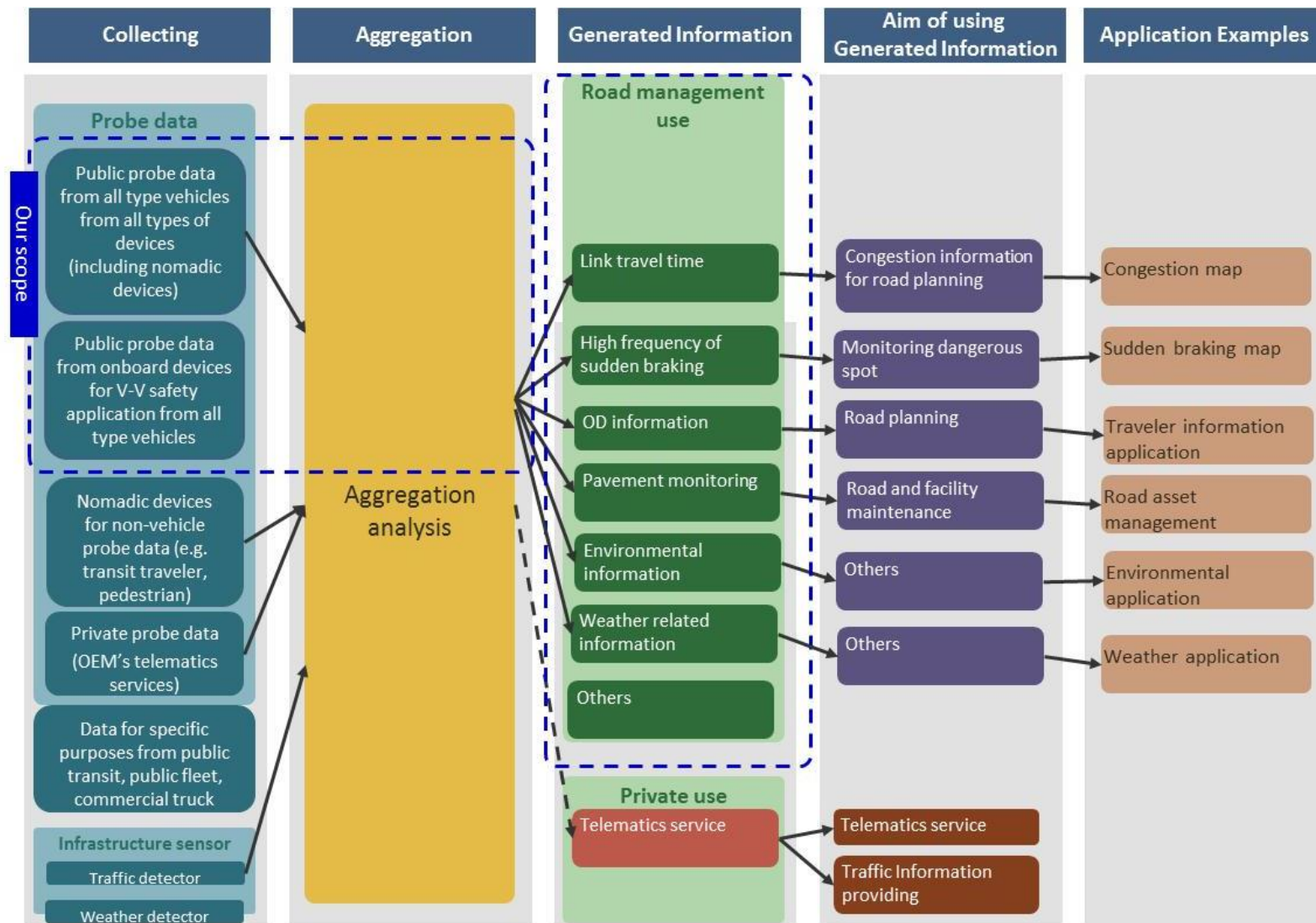


Figure 2-1. US-Japan Probe Data Scope (Source: USDOT)

3 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, Japan and EU.

3.1 Summary of Probe Systems in the US

3.1.1 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 is deployed and managed regionally, but follows national standards to ensure that they are compatible and interoperable. Figure 3-1 [3] 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.

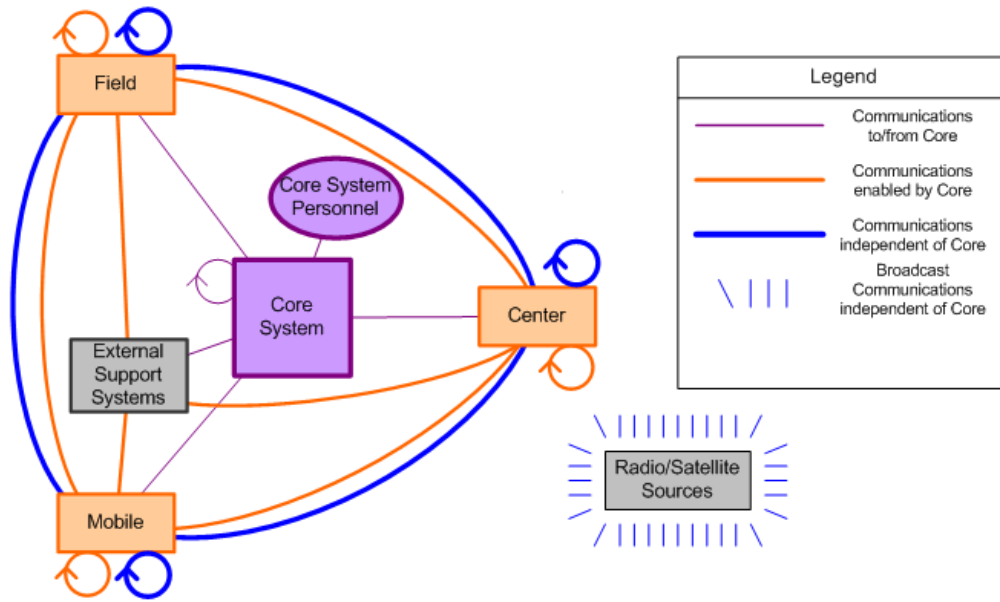


Figure 3-1. Core System Context Diagram (Source: USDOT)

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 overloads the bandwidth, and is unnecessary. Moreover, due to the large number of RSEs that needs 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 3-2 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.

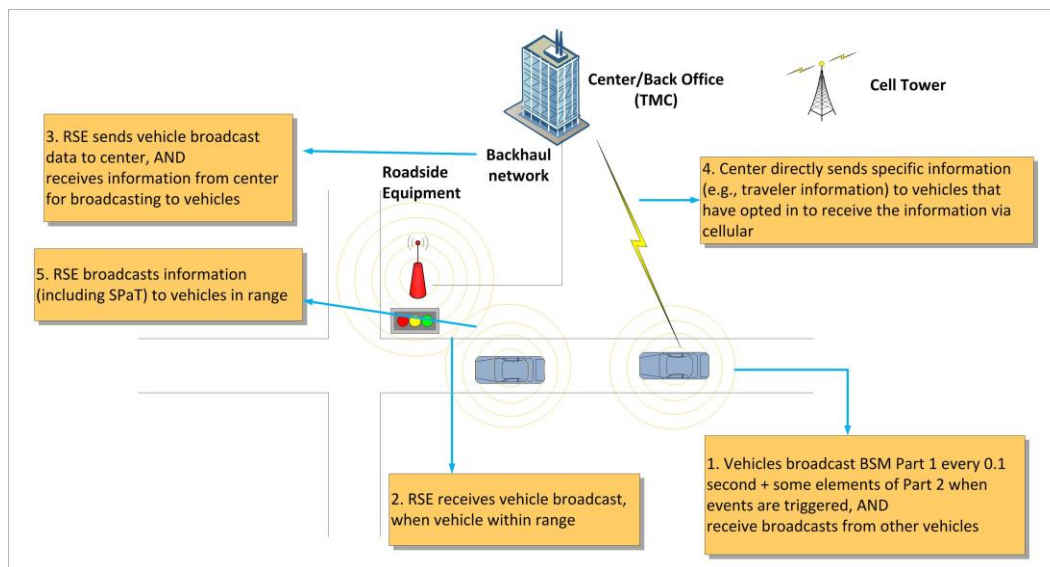


Figure 3-2. An Example Data Exchange in a Connected Vehicle System (Source: USDOT)

3.1.1.1 Connected Vehicle Test Beds

The Connected Vehicle Test Beds in Michigan, in Virginia at the Turner-Fairbank Highway Research Centers (TFHRC), California, Florida, New York, Minnesota, and Maricopa County 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 3-3, [3]). 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 also serve as precursors or foundations for state and local deployments using connected vehicle technologies.



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

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 [3].

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) [4][5]. 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 3-4).

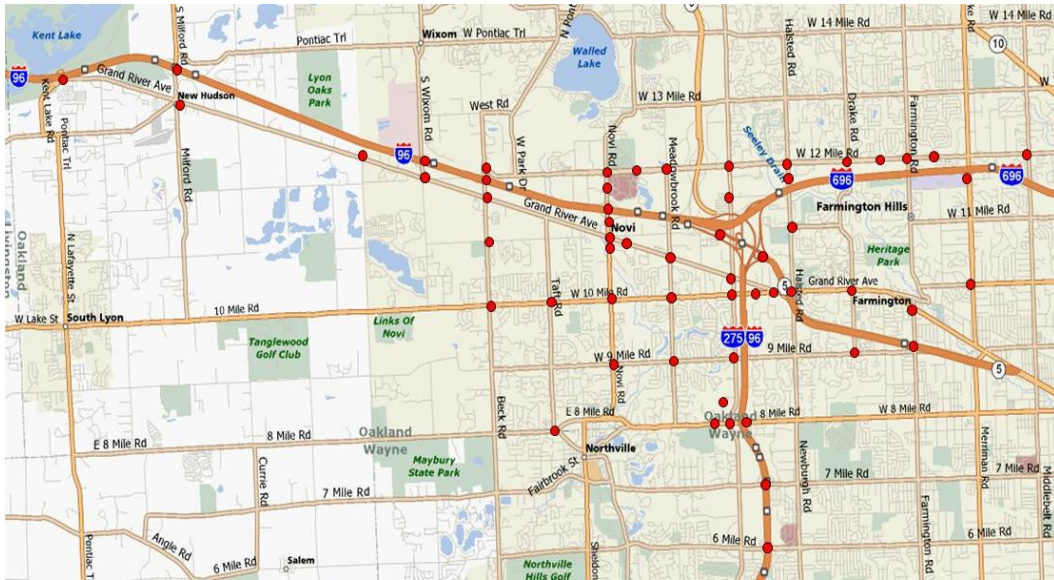


Figure 3-4. Michigan 2010 V2V and V2I Test Bed (Source: USDOT)

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 3-5). The Test Bed includes three key subsystems [3]:

- 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 3-5. 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 [3]:

- **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 USDOT Research Data Exchange (RDE).

Sponsor Agency

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

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.

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 is 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.

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 [3].

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) [4][5]. 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 3-6).

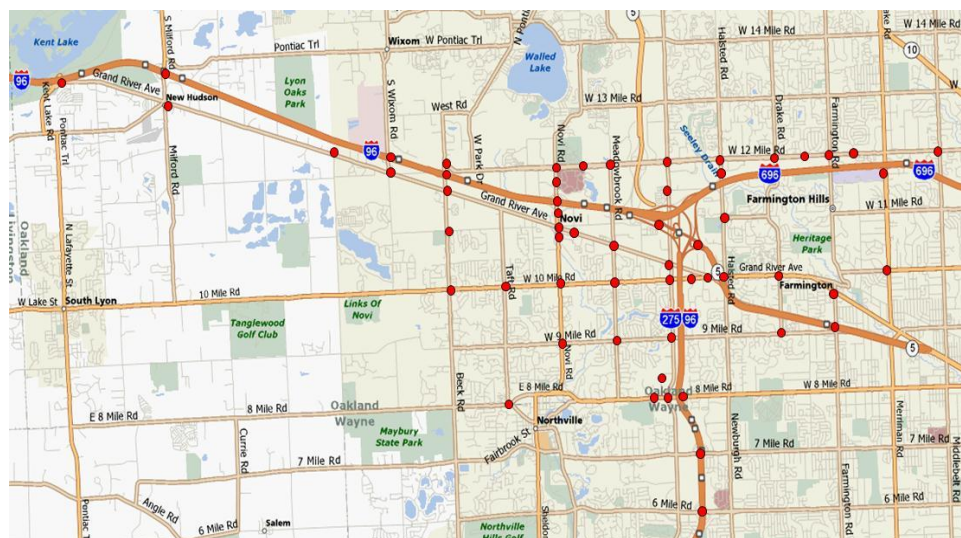


Figure 3-6. Michigan 2010 V2V and V2I Test Bed (Source: USDOT)

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

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 3-7). The Test Bed includes three key subsystems [3]:

- 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 3-7. 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 USDOT 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.

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 is 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.

TFHRC Connected Vehicle Test Bed

Purpose

The TFHRC Test Bed enables 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 [6].

Summary

The Cooperative Vehicle-Highway Test Bed (Figure 3-8), 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 3-8. 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.

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 USDOT 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.

Cost

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

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 [7].

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 [8]. 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 [9]. 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 [7].

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[10]. 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 3-9). 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 [11]. 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 [12]. 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 [13].

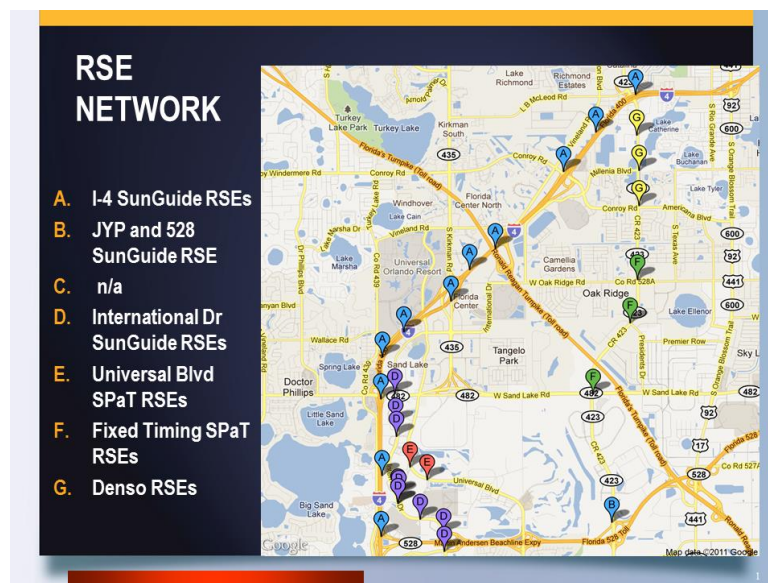


Figure 3-9. Florida Test Bed RSE Coverage (Source: FDOT)

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 USDOT 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.

Cost

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

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 [14].

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.

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 [15].

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 [16].

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 [17]. Driver type clinics were held for the demonstration.

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.

Sponsor Agency

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.

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 [18].

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 is expanded to include a total of nine intersections that form a loop so that equipped test vehicles can circulate more easily around the network (Figure 3-10), [19].

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 [20].

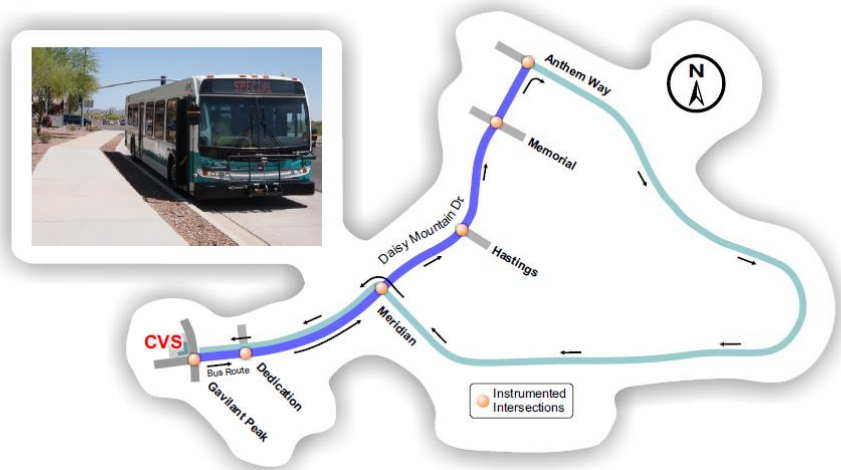


Figure 3-10. Maricopa County Connected Vehicle Test Bed (Source: MCDOT)

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 USDOT 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.

Cost

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

Safety Pilot

Purpose

The Safety Pilot has been 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 [21]. Findings from the Safety Pilot informed the National Highway Traffic Safety Administration (NHTSA) on how to proceed with connected vehicle technology, which ranges 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 has been 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 [22]. 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 [23]. Driver clinics was not held for transit drivers since transit drivers are already highly trained in advanced equipment and data on human factors already exist [22].

The Safety Pilot Model Deployment was 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 took place from August 2012 to late 2013 and tested 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 3-11), [24]. 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 [25][26]. 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.

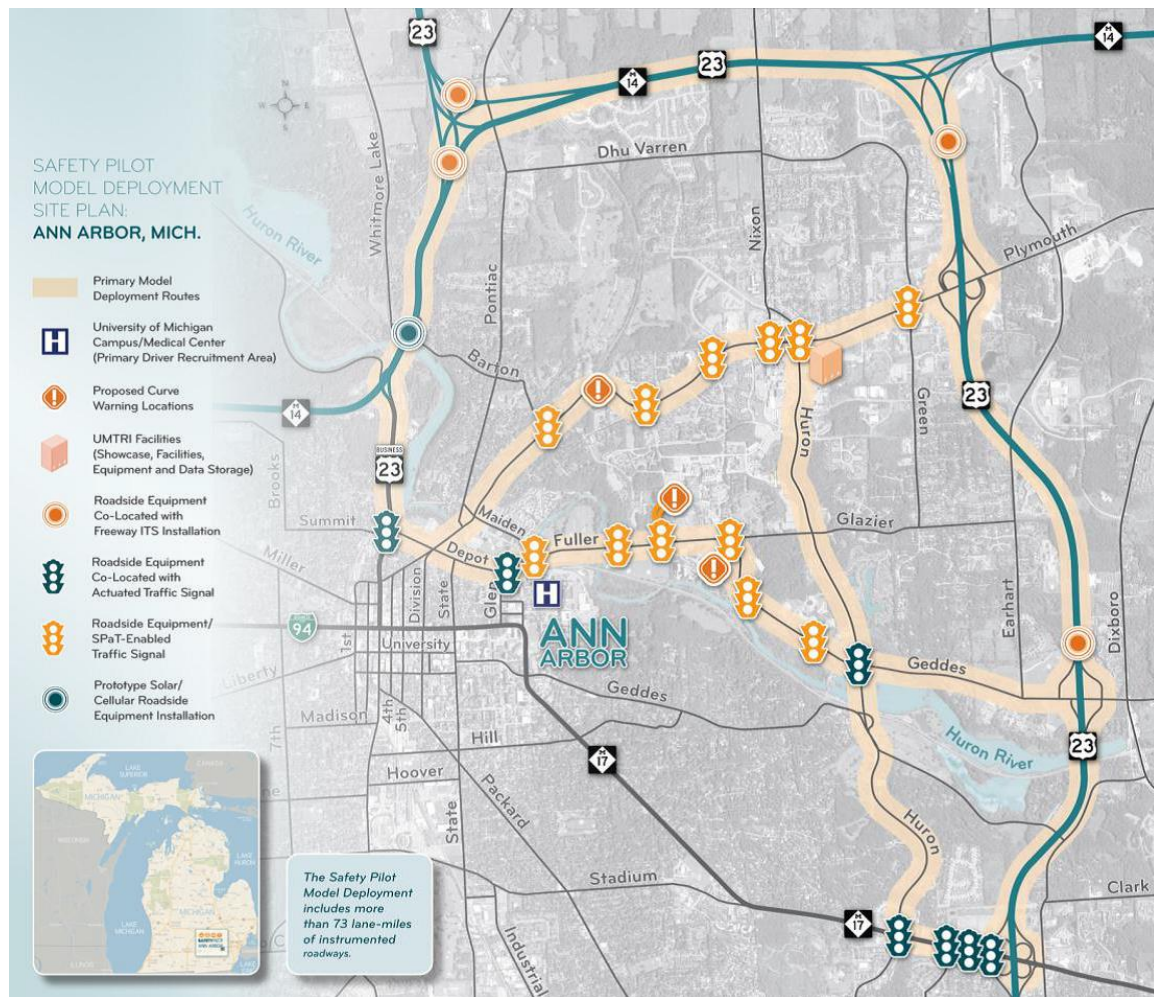


Figure 3-11. Safety Model Deployment Site (Source: MSDOT)

Table 3-1 Safety Pilot Vehicles and Devices (Source: UMTRI) shows the number and types of devices and vehicles available for the Safety Pilot [25].

Table 3-1. 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 is archived by UMTRI and USDOT's Volpe Center. As part of the data sharing agreement, all data is available to USDOT in support of NHTSA's rule-making decision. A subset of data that are anonymized is available after the conclusion of the NHTSA analysis to the DCM (Data Capture and Management) Program for making it available for research on the USDOT 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.

Cost

Information on the cost associated with using the Safety Pilot for additional connected vehicle research and testing is not publicly available.

3.1.2 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 [27]. 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 [27].

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 [28]. 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 [28]. Data providers have started to crowdsource data from travelers' mobile

devices to gather traffic information [29]. Private sector sources are progressively being used and trusted by public sector organizations [30].

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 [28]. 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 [28]. 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 [31]. 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 [28]. 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 [32]. 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 [33]. 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 [34] [35]. Waze, which is a free and open source traffic and navigation application, uses a novel way of using data from GPS-enabled smartphones [36]. 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 [28]. 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 [37].

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" [28]. 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 [38].

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 [39]. 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 [40].

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 [27]:

- SiriusXM displays navigation information from XM NavTraffic in 130 metropolitan markets [41].
- 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 [42].

3.2 Summary of Probe Systems in Japan

3.2.1 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 ETC2.0, which is a high-speed, large-capacity road-to-vehicle communication system.

In Japan, "ETC2.0 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. In addition, "ETC2.0 Service" replaced "ITS Spot Service" with some new sub-services in 2014.

ETC2.0 Service 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. ETC2.0 Services are provided by ETC2.0 roadside units installed on the roadside and an ETC2.0-compatible car navigation system installed in vehicles. ETC2.0 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. ETC2.0 is a system developed as a platform for various ITS services.

One of the main characteristics of ETC2.0 is the quick and mutual transmission of large amounts of data between ETC2.0 roadside units installed on the roadside and ETC2.0-compatible car navigation systems installed in vehicles. ETC2.0 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 ETC2.0 to function as a probe system.

MLIT has been conducting research and development on utilizing this ETC2.0 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 ETC2.0 and a National Police Agency’s system. This report covers only the ETC2.0 system.

Outline of the system of Road Traffic Probe Data

ETC2.0 uses DSRC in the 5.8 GHz band, which is the same frequency bandwidth used for ETC. ETC2.0 is capable of two-way communications between a roadside unit and an on board unit on this 5.8 GHz band. ETC2.0-compatible car navigation systems can upload its accumulated probe data when a car equipped with it passes under an ETC2.0 roadside units.

Scope and roads covered

Approximately 1,600 ETC2.0 roadside units have been deployed nationwide, primarily on expressways (see Figure 3-12). 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 ETC2.0 roadside units approximately every 10-15 km (6.2-9.3mi), and inner-urban expressways have ETC2.0 roadside units every 4 km (2.5mi). In addition, about 50 ETC2.0 roadside units are installed in service-areas along expressways and Michi-no-eki (parking and rest areas) along general roads. Also, 20 ETC2.0 roadside units have been recently deployed in general road areas mainly in rural areas.

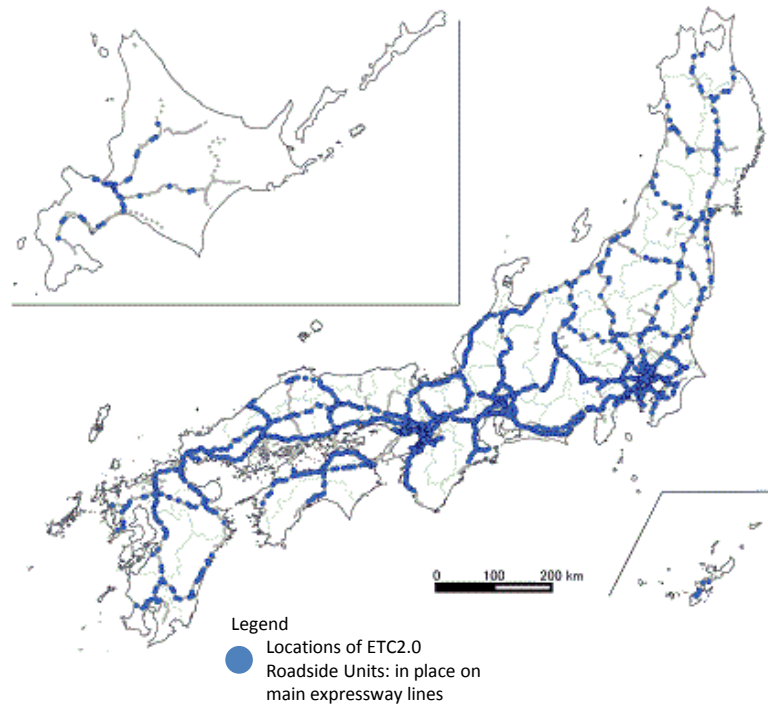


Figure 3-12. Locations of ETC2.0 Roadside Units (Source: MLIT) [43]

ETC2.0-compatible car navigation systems have the capacity of storing and uploading probe information accumulated over approximately 80 km (50mi). While almost half of ETC2.0 roadside units are deployed mainly on expressways, data uplinked to ETC2.0 roadside units 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 3-13 describes vehicle speed data collected by the ETC2.0 probe system in downtown Sapporo City. Red and white circles in these figures indicate locations of ETC2.0 roadside units. Although ETC2.0 roadside units are installed only on the expressways, vehicle speed data collected by ETC2.0 roadside units 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).

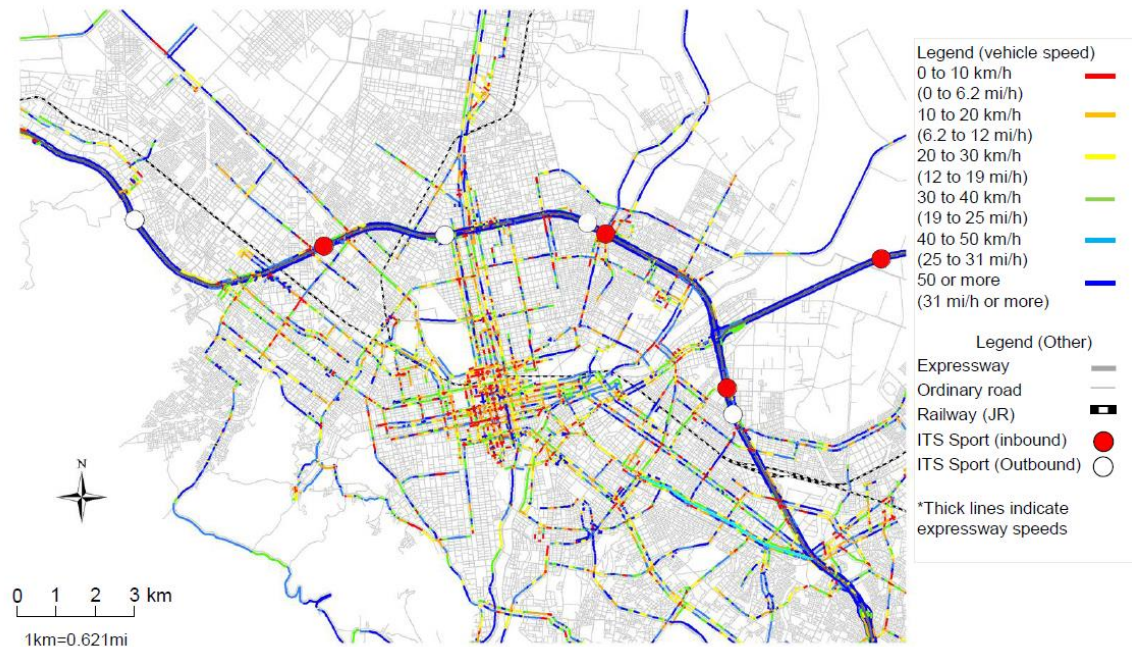


Figure 3-13. Collected probe data in downtown Sapporo City for the 3 months of June-August 2011 (Source: MLIT)

Conceptual diagram of the probe system

The probe system consists of: ETC2.0-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 3-14). An example of ETC2.0-compatible car navigation system and ETC2.0 roadside units are as shown (Figure 3-15).

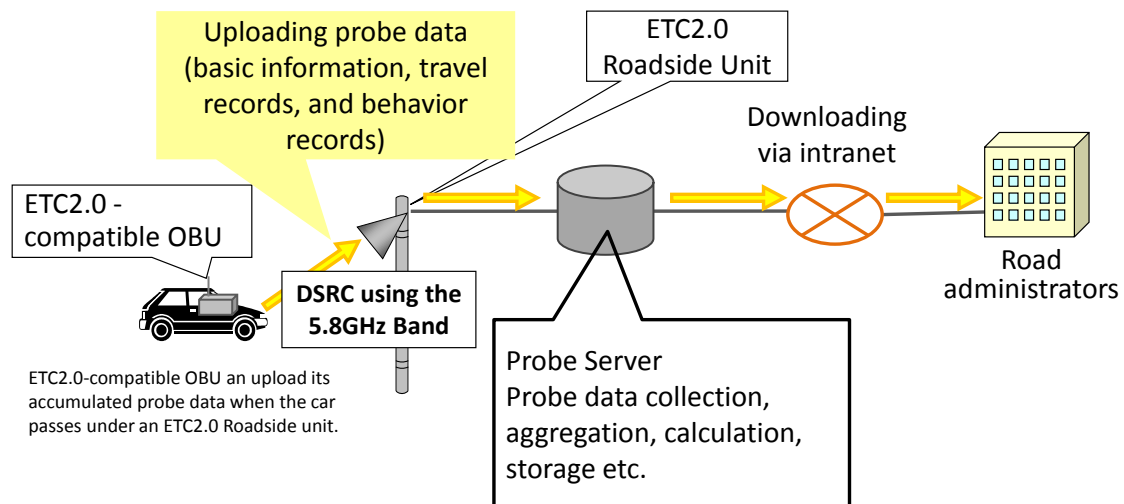


Figure 3-14. Conceptual Diagram of Probe System (Source: MLIT)



Figure 3-15. An ETC2.0-compatible car navigation system (left) and ETC2.0 roadside equipment (right) (Source: MLIT) [44]

Components of the probe system (summary)

ETC2.0-compatible car navigation systems: ETC2.0-compatible car navigation systems are devices capable of collecting and accumulating probe data and then transmitting that stored data to an ETC2.0 roadside unit. 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 ETC2.0-compatible car navigation system is retained even when a car is not being operated. When accumulated data is uplinked to an ETC2.0 roadside unit, the data is erased from the ETC2.0-compatible car navigation system at the same time, creating space for new data.

ETC2.0-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 3-2) [45]. By July 2014, a cumulative total of over 350,000 units had been installed in vehicles.

Table 3-2. Companies Offering ETC2.0-Compatible Car Navigation Systems/On-board Units (Source: Japan ITS Service Promotion Association)

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

ETC2.0 Roadside Unit: ETC2.0 roadside units are devices that collect the probe data uploaded from ETC2.0-compatible car navigation systems and transmit it to a probe server.

As stated in the previous section, approximately 1,600 ETC2.0 roadside units have been installed mainly on expressways. When a vehicle equipped with an ETC2.0-compatible car navigation system passes through a communication area of an ETC2.0 roadside unit (around 20m in length), accumulated probe data is uplinked to the ETC2.0 roadside unit.

The on board storage capacity is limited to 80 km (50mi) of driving. If a vehicle travels less than 80 km (50mi) between ETC2.0 roadside units, all the data will be uplinked. If a vehicle travels more than 80 km (50mi) without passing under an ETC2.0 roadside unit 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 ETC2.0 roadside units 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 ETC2.0-compatible car navigation systems, ETC2.0 roadside units, and probe servers. The ownership of each component is as indicated in Table 3-3. 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 ETC2.0 roadside units and ETC2.0-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 3-3. Probe system ownership

Component	Owner
ETC2.0-compatible Car Navigation Systems	Purchasers of ETC2.0-compatible car navigation systems
ETC2.0 Roadside Units	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 ETC2.0-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, ETC2.0-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 ETC2.0 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

ETC2.0 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.

ETC2.0 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).

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

Table 3-4 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.

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.

Table 3-4. 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
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	G-BOOK mX: No basic charge but customer must pay communications charges G-BOOK mXpro: No fee for first year, ¥12,000/year (\$120/year) for second and subsequent years * Exchange rate \$1=¥100	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 Normally ¥5,250/year (\$53/year)(including operator service fee; excluding electric vehicles), clerical fee not included, communication charges not included No charge for special program only (electric vehicles) Normally ¥15,750/year (\$158/year) (including operator service fee; electric vehicles), clerical fee not included, communications charges included, additional fees for companies. * Exchange rate \$1=¥100	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)

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.

3.3 Summary of Probe Systems in Europe

3.3.1 Status of Probe Systems in Europe

Road transport Data collection systems set up and maintained by Public Authorities in Europe for the generation of transport statistics and traffic flow information are generally based on static sensor data only. A few Public Authorities have started collecting and using Probe Data either to complement static sensor data or as a sole mean to generate transport statistics or to support transport network monitoring activities. These authorities however remain exceptions today as the majority of Probe Data systems in Europe is mainly driven by industry, including fleet operators, service providers or car manufactures, and is based essentially on GPS tracking with nomadic devices. In addition, most activities generating Probe Data in Europe are not focusing on Probe Data use but in the provision of cooperative mobility and traveler services which generate this kind of data.

Several types of initiatives supported and sponsored by governments or Public Authorities involving Probe Data Systems have appeared in Europe during the last decade with the main objective to support the deployment of cooperative ITS systems and encourage the cooperation between the automotive/service provider sectors and road operators/authorities: large-scale Field Operational Tests (FOT), pilot projects for systems that are near deployment, test-beds and Cooperative ITS testing and deployment corridors. A significant amount of Probe Data is generated during the execution of these activities, but the use of these Probe Data sets for providing added value services to the citizens and the public authorities is low and most of the times service providers driven which ends to lower societal impacts.

The execution of government sponsored national and EU-wide Field Operational Tests (FOT) for cooperative systems has led to the implementation of systems and methodologies for the acquisition, management and analysis of data stemming from connected vehicles, creating a basis and framework for the deployment of probe data collection systems in Europe. C-ITS Test Beds constitute the next stage to prepare the introduction of C-ITS from 2015 in Europe.

In 2013, the FOT-Net and iMobility Support projects, on request of the European Commission, commissioned a literature study on the State of the Art of Probe Data Systems in Europe in order to provide input for this report. The study was performed in 2013 by S. Sandford and T. Paulin from FTW Telecommunications Research Center in Vienna, and is available at: <http://fot-net.eu/literature-study-on-the-state-of-the-art-of-probe-data-systems-in-europe/>. A large part of the information in this chapter is taken from this report.

As shown in Figure 3-16, there are several types of project and studies collecting probe data:

- Field operational tests (FOT): both European and national projects, testing different kinds of ITS. In the last years the focus has been on cooperative systems in which vehicles and infrastructure communicate with each other. The purpose of these FOTs is to test systems in the real world environment and the way in which drivers behave with the systems.

- Pilot projects are field test that are near deployment, where systems are tried out in the real world with the purpose to pave the way for large scale deployment.
- Test-beds: 14 test-beds within the SATIE-project, focussing on an integrated approach to services in mostly an urban or corridor setting. There is also a variety in local and regional activities in Europe.
- C-ITS corridors. Following the developments of several national initiatives like the Dutch Integrated Testsite for Cooperative Mobility (DITCM) in The Netherlands and Testfeld Telematik in Austria, a first step has been made in the creation of a cross-border implementation with the European Cooperative ITS Corridor between Rotterdam and Vienna.

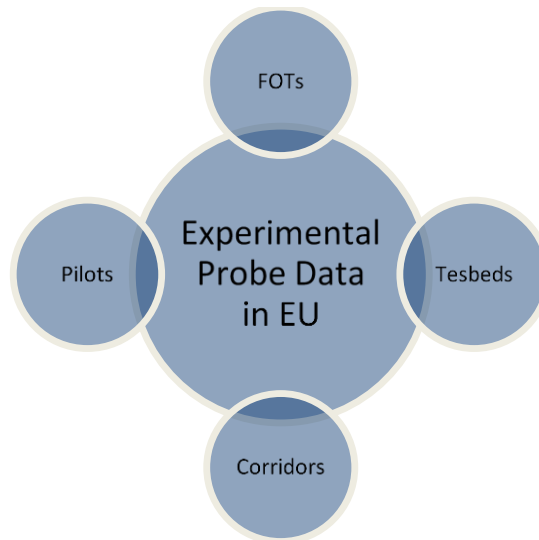


Figure 3-16. Types of Probe Data related Activities in Europe (Source: ERTICO)

3.3.1.1 FESTA and FOT-Net for Field Operational Tests

In 2007, the European Commission has started including Field Operational Tests of Cooperative Systems in their funding programme. Previous framework programmes had supported R&D within consortia projects which has led to the development of mature cooperative and Intelligent Transportation systems technologies and application (GST, PreVENT, CVIS, SafeSpot, COOPERS...).

The objective of Field Operation Tests was to carry out large scale tests of these technologies as a first step towards their EU-wide deployment. A selection of major Field Operational Tests which have resulted from the EC and national funding programmes is presented in this section. EU-wide FOTs have used the methodology developed by the FESTA Project from 2007 to 2008 for the implementation of the tests, experimental procedures and data analysis.

The FESTA handbook has been updated subsequently by FOT-Net. The last version dates from 28 February 2014 and can be found at: http://wiki.fot-net.eu/index.php?title=FESTA_handbook. FESTA provides recommendations for conducting Field Operational Test and is as such not concerned with the collection of real-time probe data. The term probe data (or floating car data) is not used in the handbook. In data collection most of the focus is on data collected from vehicles that are instrumented with data acquisition equipment. However, also other data sources such as nomadic devices like smart phones are discussed. FESTA is focussed on research and evaluation activities, but much of the knowledge and experiences laid down in this handbook are of interest for the deployment of probe

data that are gathered for other reasons. Recommendations for gathering, storing and analysing data are equally useful in the probe data domain. While for most FOTs, data has been collected offline by data loggers, they have contributed in identifying fundamental parameters for probe data collection frameworks such as the type, format and sampling frequency for the data to be collected and the necessary contextual information for cooperative applications.

The FESTA methodology is maintained by the FOT-Net support actions, funded by the European Commission. FOT-Net has built a community over the years of projects and experts involved in performing Field Operational Tests and Naturalistic Driving Studies, exchanging experiences and building a knowledge base. The first support action started in 2008, the second in 2011. A third support action, FOT-Net Data (a more elaborate description is given below), started in 2014 and is specifically concerned with the sharing and re-using of data-sets from FOTs.

Next to knowledge and experiences from FOTs, FOT data are also important for deployment of ITS. In many cases probe data are collected and used in real-time or within a short time-frame and not stored for a longer period. FOT data are usually stored and may be made available for further research. This means that these data can be used as a baseline for traffic modelling, predictions, simulations, driver behaviour modelling etc.

FOT-Net has developed a FOT wiki in which information about European, national and international FOTs is gathered (wiki.fot-net.eu). In this wiki FOTs provide information about their own projects, including contact details. A large part of this chapter made use of the information gathered in the wiki. The FOT-Net wiki is currently taking the next step, providing information about data-sets that are available and that can be re-used, under certain conditions, by other projects and researchers.

3.3.1.2 Past European data projects in road transport

In this section we discuss some of the older projects and initiatives, that form the basis for the more recent and ongoing work. These projects often formed the background for the work that is now being performed, and were sometimes the first in a series of projects. First two large-scale FOTs are described, next some projects that dealt explicitly with probe data.

Information about European projects can be found at the website from the European Commission: http://cordis.europa.eu/projects/home_en.html and at the FOT-Net [wiki: wiki.fot-net.eu](http://wiki.fot-net.eu).

Two large pan-European FOTs were conducted (co-funded by the EC) from 2008 to 2012, using the FESTA methodology: euroFOT and TeleFOT.

- **euroFOT** (www.eurofot-ip.eu) – In euroFOT for over twelve months, one thousand cars and trucks equipped with advanced driver assistance systems travelled European roads. Their movements were tracked and parameters such as acceleration and lane changes recorded. The FOT focused on eight distinct vehicle functions that assisted drivers in detecting hazards and avoiding accidents: Adaptive Cruise Control (ACC), Forward Collision Warning (FCW), Speed Regulation System (SRS), Blind Spot Information System (BLIS), Lane Departure Warning (LDW), Curve Speed Warning (CSW), safe human/machine interface, and Fuel Efficiency Advisor (FEA). More than one hundred terabytes of data were collected and analysed.
- **TeleFOT** (www.telefot.eu) – The TeleFOT project evaluated in-vehicle aftermarket and nomadic devices. Almost 3,000 drivers covering a combined distance of more than 10 million kilometres in eight European countries participated. Different functions were tested, covering two main areas: safe driving, and economic and fuel-efficient driving. The services tested included Static and Dynamic Navigation Support, Green Driving Support, Speed Limit Information, and Traffic Information. TeleFOT not only collected a huge amount of data

through in-vehicle data loggers but also subjective data such as participant questionnaires. The data was further enriched by map matching and metadata which provided specific contextual details.

Several legacy projects dealing with probe data are listed below:

- **In-time** – In-Time3 (Intelligent and efficient travel management for European cities) was a FP7 Project (2009-2012) that has the objective to reduce traffic congestion, pollution and energy consumption in transport in cities. For this purpose, a system was developed and demonstrated in 4 pilot cities, including a regional data/service server for the distribution of interoperable intermodal real-time Traffic and Travel Data to a European Traffic Information Service Provider (TISP). The project brought together all the stakeholders necessary for the development of pre- and in-trip multimodal information services for the users: road operators, public transport operators, urban transport management centers. The collection of traffic data, partly using vehicle probes, was also addressed in the project.
- **ROADIDEA** – The EU ROADIDEA project (2008-2010) studied the European transport service system and tried to analyse all available information sources, ranging from FCD, in-road sensor over to weather information, and identifies how these can be merged and used for various applications. With regard to data, standardisation and architectures, ROADIDEA identifies four trends; islands of technology, data pool models, vertical integration and finally decentralised networked world. Islands of technology represent the current state of ITSs where each provider has its own, mostly closed and undocumented solution. The data pool model consists of a well-defined storage of data, most probably founded publicly or by a non-profit organization. This model however requires close collaboration between the data creator and the entity which store the data on the data format. Implementation can be centralized, distributed. Access can be free as well as licence based. Vertical integration is similar to the data pool approach, with the main difference being that the operator also uses the data for providing services using the data, resulting in a potential risk for conflict of interests. Decentralised networked world allows for exchange of ITS data without a centralized entity. The project raised the point where users must opt-in before location data is allowed to be collected about them and that an option must be provided which makes it possible to disable the feature on the go, but also points out that an increasing amount of users already provide social networking companies with their location information voluntarily. On the other hand, employees should have the same options as private persons, but there are some services which require tracking, such as fleet management and similar.
- **VIAJEO** (www.viajeo.eu) – The Project Viajeo (2009-2012), "International Demonstrations of Platform for Transport Planning and Travel Information" integrated the open platform with local components and demonstrates its applications in four cities: Athens, Beijing, Shanghai and Sao Paulo. The project (was co-funded by the EC DG Research for Specific International Cooperation Actions (SIGA). Among the services in Athens were taxi fleet management and traffic information (alerts), modal trip planning and information for the end user, information for authorities and traffic planners. The traffic data collection in the cities (Athens) used a combination of fixed and vehicle sources, the latter being the classical Taxi fleet.
- **FREILOT** – FREILOT was an EU pilot project (2009-2012) with 4 pilot sites: Bilbao, Helmond, Krakow and Lyon. The FREILOT service aimed to demonstrate that reduction up to 25% of fuel consumption is feasible on specific urban areas or corridors. It aimed to increase the involvement of fleet operators, cities and other stakeholders in the scheme. Smooth driving behavior, optimized planning and routing combine with smooth heavy vehicle targeted traffic control can contribute to achieve higher fuel efficiency, less pollution, higher driver comfort and more efficient use of infrastructure. The project evaluated the following services:

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

- Energy Efficient Intersection Control (EEIC) supporting the traffic manager
- Eco-Driving Support (EDS) supporting the driver
- Acceleration and Speed Limiters (ASL and AL) optimising vehicle performance
- Delivery Space Booking (DSB) enabling efficient fleet operation
- **INTRO Intelligent Roads** (<http://intro.fehrl.org>) – INTRO was a FP6 research project (2005–2008) aiming at developing innovative methods for increased capacity and safety of the road network. It combined sensing technologies and local databases with real-time networking technologies. In one deliverable, the road condition measurement application is considered in detail, using probe vehicles. The deliverable concentrates on the data accuracy and type of sensors and the inferred road condition from the measurements, rather than the data collection architecture.

3.3.1.3 Recent European Data Projects Focusing on Cooperative ITS

DRIVE C2X FOT

DRIVE C2X focused on communication among vehicles (C2C), and between vehicles, a roadside and backend infrastructure systems (C2I). Previous projects such as PReVENT, CVIS, SAFESPOT, COOPERS, and PRE-DRIVE C2X have proven the feasibility of safety and traffic efficiency applications based on C2X (Vehicle-to-X (V2X)) communication. DRIVE C2X went beyond the proof of concept and addressed large-scale field trials under real-world conditions at multiple national test sites across

Project name: DRIVE C2X
 Start and end date: 2011-2014
 Coordinator: Daimler, Germany
 Sponsors: European Commission
 Budget: 18.6 million Euro
 Website: <http://www.drive-c2x.eu/project>

Europe. The objective of DRIVE C2X was to carry out comprehensive assessment of cooperative Systems through Field Operational Tests in various places in Europe in order to verify their benefits and to pave the way for market implementation. Six test sites participated to the central data collection: Finland: Tampere, Sweden: Gothenburg, The Netherlands: Helmond, Germany: Frankfurt, France: Yvelines, Italy: Brennero, Spain: Vigo.

Different C-ITS functions or services were implemented and evaluated: Traffic jam ahead warning, Road works warning, Car breakdown warning, Approaching emergency vehicle, Weather warning, Emergency electronic brake lights, Slow vehicle warning, Post crash warning, Obstacle warning, Motorcycle warning, In-vehicle signage / Speed limit, Green light optimized speed advisory (GLOSA), Traffic information, Insurance and Financial Services, Dealer Management, Point of interest notification, Fleet management, Transparent leasing.

The DRIVE C2X technology was based on European standards developed in ETSI Technical Committee ITS and represents a reference implementation of the latest versions of the standards. DRIVE C2X verified the feasibility of implementing the standards in a multi-vendor environment and contributed to the standardisation process ongoing at ETSI TC ITS under the EC standardisation mandate 453. The DRIVE C2X Vehicle was equipped with radio hardware based on IEEE 802.11p and UMTS for data exchange with other vehicles or with the roadside infrastructure. The protocol stack supports ad-hoc communication based on GeoNetworking, which enables a rapid and efficient message exchange among vehicles using single-hop and multi-hop communication. The system is connected to the vehicle on-board network (CAN bus) to collect data within the vehicles, so that vehicle data can be exchanged between vehicles. Vehicles also support wireless Internet access, for allowing information to be sent directly to the central component.

FOTsis FOT

FOTsis (European Field Operational Test on Safe, Intelligent and Sustainable Road Operation) was a large-scale field testing of the road infrastructure management systems needed for the operation of seven close-to-market cooperative I2V, V2I & I2I technologies (the FOTsis Services), in order to assess in detail both 1) their effectiveness and 2) their potential for a full-scale deployment in European roads.

Project name: FOTsis
Start and end date: 2011-2015
Coordinator: OHL Concesiones
Sponsors: European Commission
Budget: 13.8 Mio Eur
Website: <http://www.fotsis.com/>

FOTsis involved 25 partners and was coordinated by OHL Concesiones. FOTsis reviewed the road infrastructure and communication networks required to secure a proper connectivity from the traffic control centres (and all the information they already have available, enhanced with the V2I data) with the users/vehicles. The project represented a major step forward to better connect vehicles, infrastructures and traffic management centres, the main focus being placed on the responsibilities of the road operator. Nine test sites participated in the project:

- Spain: A2 (1st stretch), road operator Autovía de Aragón Tramo 1 S.A.(OHL CONCESIONES), A2 (3rd stretch), road Operator: AUMECSA, M-12 (Airport Axis), road operator: Autopista Eje del Aeropuerto S.A.C.E. (OHL CONCESIONES)
- Portugal: Baixo Alentejo (IP8 Sines + A26), road operator: PLANESTRADA, Algarve Litoral (EN125 IC4 + EN125 10 + EN125 Faro), road operator: MARESTRADA
- Germany: A99: road operator: South-Bavarian Motorway Authority (ABDS), A9, road operator: South-Bavarian Motorway Authority (ABDS), A92, road operator: South-Bavarian Motorway Authority (ABDS)
- Greece: PATHE Motorway, road operator: NEA ODOS

FOTsis develop, tested and evaluated 7 FOTsis Cooperative Services. These services were S1: Emergency Management, S2: Safety Incident Management, S3: Intelligent Congestion Control, S4: Dynamic Route Planning, S5: Special Vehicle Tracking, S6: Advanced Enforcement, S7: Infrastructure Safety Assessment

FOTsis worked on the development of a common ITS Communications Architecture for the European infrastructures according to ETSI Standards and promoted the implementation of this architecture and the deployment of these Cooperative Services in the existing and future highways. Also Business Models were generated to promote these Cooperative Services.

The communications network interconnects the devices, fixed - CCs, RSUs, etc- and mobile ones - vehicles-. The infrastructure communications (I2I) were mainly based on existing technologies: IP-networks over Ethernet or using advanced protocols such as MPLS (MultiProtocol Label Switching) which are able to guarantee the desired functionality, QoS and security. These channels were implemented on the physical level using fiber optic. Additionally, the use of DMB (Digital Media Broadcasting) and DVB-H (Digital Video Broadcasting) provided broadcast and multicast tools used basically for the dissemination of information or control commands to infrastructure elements such as Variable Message Signs (VMS) or sensors.

UDRIVE

UDRIVE is the first large-scale European Naturalistic Driving (meaning that the behaviour of road users is observed unobtrusively in a natural setting) Study on cars, trucks and powered-two wheelers. UDRIVE will increase understanding of road user behaviour. Its objectives are two-fold: to identify well-founded and tailored measures to improve road safety and to identify approaches for reducing harmful emissions and fuel consumption in order to make road traffic more sustainable.

Project name: UDRIVE
Start and end date: 2014-2017
Coordinator: SWOV, The Netherlands
Sponsors: European Commission
Budget: € 10.617 mio
Website: www.udrive.eu

From a scientific and technical point of view, UDRIVE aims at:

- describing and quantifying road user behaviour in different European regions, in regular conditions and (near-)crashes, and provide a quantified estimate of the risk of particular safety-critical behaviours
- identifying new approaches, measures and tools to make the traffic system safer and more sustainable

The data is collected from trucks: The Netherlands, passenger cars: France, Germany, Poland and UK, and powered two-wheelers: Spain.

After it is concluded, the UDRIVE project will offer access (within the bounds of legal and ethical restrictions) to the collected data so that it can be consulted and used for subsequent analyses by road safety and environmental experts from all over the world. This will enable the exploitation of the data beyond the scope of the UDRIVE project.

COMPASS4D

The key driving force behind Compass4D is to deploy cooperative Intelligent Transport Services (C-ITS) to improve road safety, as well as enhance the energy efficiency of road transport.

Name Project name: COMPASS4D
Start and end date: 2013-2015
Coordinator: ERICO – ITS Europe
Sponsors: European Commission
Budget: €10.00m
Website: <http://www.compass4d.eu/>

Seven European cities/regions have united their forces in addressing road safety issues, traffic efficiency problems and the negative environmental impacts that road transport currently brings. These cities, together with the rest of the industrial and research partners from the Compass4D consortium, strongly believe that cooperative mobility solutions can bring benefits to the key stakeholders and improve the lives of their citizens. Compass4D partners work closely with their US and Japanese associates to ensure that the deployed cooperative mobility solutions will not only follow the latest global developments in this field, but also will actively drive them. This work is done in a close cooperation with the already established EU-US Task Force.

The project has the following objectives:

- Ensure successful deployment and after-project life of the three piloted services, aiming at proving both safety and energy efficiency benefits.
- Globally harmonize specifications for the three piloted services, through close cooperation with the US & Japanese counterparts, other CIP pilots and relevant standardization bodies.
- Establish and follow an agreed harmonized testing, installation, monitoring and assessment strategy, as well as a common strategy for deployment of all three specified cooperative systems across all pilot sites.

- Prove safety and energy efficiency benefits to all relevant stakeholders by collecting critical mass of data in 12 months full-scale operations of selected cooperative systems at each pilot site.
- Collaborate with relevant standardization bodies, mainly but not exclusively ETSI and CEN, in order to ensure full interoperability of the deployed cooperative solutions.
- Create a set of best practices on the basis of the pilot site operations including guidelines, business models, manuals, and training material.

Test-sites are France: Bordeaux, Denmark: Copenhagen, The Netherlands: Helmond, UK: Newcastle, Greece: Thessaloniki, Italy: Verona, and Spain: Vigo.

The two safety-related Compass4D services, Road Hazard Warning (RHW) and Red Light Violation Warning (RLVW), will support the driver by providing (audio and/or visual) in-vehicle notifications when the driver approaches a dangerous situation, e.g. traffic queues in a dangerous location, or if the driver risks running a red light.

The Energy Efficiency services will provide recommended speed advices and traffic status countdown to drivers of all vehicles when approaching an intersection, depending on local policies. It will also give priority at intersections for given vehicle types, e.g. emergency vehicles or delayed buses.

A combination of mature technologies developed in earlier R&D projects and readily available (pre-) commercial equipment will be used. Dedicated Short Range Communication (i.e. ETSI G5) and cellular networks (i.e. 3G/LTE) will be used, following ETSI TC ITS standards.

Co-GISTICS

CO-GISTICS deploys cooperative ITS services for logistics. The integration of currently existing freight and transport systems, with innovative solutions such as cooperative services and intelligent cargo, will lead to increased energy efficiency and more sustainable mobility of goods.

Project name: Co-gistics Start and end date: 2014-2016 Coordinator: ERTICO Sponsors: European Commission Budget: € 7.492.000 Website: www.cogistics.eu

CO-GISTICS targets an effective increase of energy efficiency and a more sustainable mobility of goods through the deployment of Cooperative ITS services and technologies applied to logistics.

Each of the pilot sites includes all the partners for a successful after-project life, from public authorities to logistics operators. The user groups will include fleet operators, trucks, freight forwarders, terminal operators and logistics providers. The consortium will install the services on at least 325 vehicles (trucks and vans).

CO-GISTICS will not only prove the cost-efficiency and benefits of its services, but will also focus on deployment, scaling up and exchange of results. In order to ensure a successful continuation of the services after the project, CO-GISTICS will identify deployment barriers and propose appropriate solutions that are acceptable by the relevant stakeholders.

Special attention will be given to the collaboration with the European standardisation organisations ETSI and CEN for a pan-European and global deployment of the services.

CO-GISTICS services will be deployed in 7 logistics hubs: Arad (Romania), Bordeaux (France), Bilbao (Spain), Frankfurt (Germany), Thessaloniki (Greece), Trieste (Italy) and Vigo (Spain).

CO-GISTICS will deploy the following services:

- Intelligent parking and delivery areas: optimising the vehicle stops along their route, the delivery of goods in urban areas and the interface with other modes of transport.

- Multimodal cargo: supporting planning and synchronisation between different transport modes during the various logistic operations.
- CO2 emission estimation and monitoring: measuring the CO2 output of the vehicles and providing an estimation of CO2 emissions of specific cargo operation.
- Priority and Speed advice: saving fuel consumption and reducing emissions.
- Eco-drive support: supporting truck drivers in adopting a more energy efficient driving style and therefore reducing fuel consumption and CO2 emissions.

Co-cities

Co-Cities is a pilot project to introduce and validate cooperative C-ITS mobility services in cities and urban areas. The objectives are:

- To extend the number of cities which install the In-Time Commonly Agreed Interface and connect it to the traffic management centre for a regular feed of data and information.
- To develop a fast and reliable validation process for cooperative traffic information services by using a "reference platform".
- To make transport information services more attractive and appealing to users in urban areas.

Name Project name: Co-cities
Start and end date: 2011-2014
Coordinator: Austria Tech
Sponsors: European Commission
Budget: €3.90m
Website: www.co-cities.eu

It will develop a dynamic 'feedback loop' from mobile users and travelers to the cities' traffic management centers, and add elements of cooperative mobility to traffic information services. The result of this validation of cooperative mobility services will be an increased exchange of experience between public authorities and TISPs in Europe and a faster take-up of best practices.

Pilots are run in: Spain: Bilbao, Italy: Florence, Germany: Munich, Czech Republic: Prague, UK: Reading, and Austria: Vienna. Two types of services are tested:

- Interoperable and multimodal Real-Time Traffic Information (RTTI) services to end-users, using different hardware and software platforms such as personal navigation devices, smart phones and web services, and Europe-wide services based on regional traffic and travel data.
- Business-to-business services enabling Europe-wide Traffic Information Service Providers (TISPs) to cooperate with regional and urban authorities in fields such as strategy-based routing and adaptive mobility services

MOBINET

MOBiNET is "the Internet of (Transport and) Mobility". It is an Internet-based network linking travelers, transport users, transport system operators, service providers, content providers and transport infrastructure. It connects users (people, businesses, objects) with suppliers (operators, providers, systems), and brokers (or helps to broker their interactions). At its core is a "platform" providing tools and utilities to enable those interactions, with components both for users and for suppliers.

Name Project name: MOBINET
Start and end date: 2012-2016
Coordinator: ERTICO – ITS Europe
Sponsors: European Commission
Budget: €15.6 Million
Website: <http://www.mobinet.eu>

MOBiNET comprises a User Community and a Provider Community. Users may be private or business (end-users), as well as service and data providers who consume B2B services. Providers

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

are data (information and content) providers as well as applications (“apps”) and services providers for both end-users, suppliers and developers. The MOBiNET platform is a place to meet and exchange or buy location- and time-dependent transport and mobility services. MOBiNET develops solutions for both business (B2B) users and end (B2C) users (e.g. drivers and travelers):

- one-click access to a comprehensive directory of Europe-wide mobility and transport-related data and services;
- e-Marketplace as an e-commerce network linking end users, content- and service providers;
- single sign-on membership and billing account for end users valid for transport services throughout Europe;
- an open business environment enabling members of MOBiNET Provider Community to add third-party content and services contract-free to their own products;
- a platform-independent agent on end-user devices, including access to a MOBiNET App Directory and a connectivity manager providing intelligent selection of communication interfaces;
- a Service Development Kit enabling easy creation of MOBiNET-compliant services and a set of uniform Reference Services suitable for Europe-wide deployment, guaranteeing widespread availability and interoperability.

PRESERVE

The goal of PRESERVE (Preparing Secure Vehicle-to-X Communication Systems) is to bring secure and privacy-protected V2X communication closer to reality by providing and field testing a security and privacy subsystem for V2X systems. PRESERVE combines and extends results from earlier research projects, integrating and developing them to a pre-deployment stage by enhancing scalability, reducing the cost level, and addressing open deployment issues. It aims at providing comprehensive protection ranging from the vehicle sensors, through the on-board network and V2V/V2I communication, to the receiving application. As a result, PRESERVE will present a complete, scalable, and cost-efficient V2X security subsystem that is close-to-market and will be provided to other FOT projects and interested parties for ongoing testing. The objectives of PRESERVE are to:

Project name: PRESERVE (Preparing Secure Vehicle-to-X Communication Systems) Start and end date: 2011-2015 Coordinator: University of Twente, the Netherlands Sponsors: European Commission Budget: 5.438 M€ Website: https://www.preserve-project.eu
--

- Create an integrated V2X Security Architecture (VSA) and design, implement, and test a close-to-market implementation termed V2X Security subsystem (VSS).
- Prove that the performance and cost requirements for the VSS arising in current FOTs and future product deployments can be met by the VSS, especially by building a security Application-Specific Integrated Circuit (ASIC) for V2X.
- Provide a ready-to-use VSS implementation and support to FOTs and interested parties so that a close-to-market security solution can be deployed as part of such activities.
- Solve open deployment and technical issues hindering standardization and product pre-development.

The acquisition of data has been realized in the frame of the evaluation of the V2X Security Subsystem (VSS) which has been carried out through two distinct field testing activities:

- An internal FPGA-based (Field-Programmable Gate Array) VSS FOT done at University of Twente.
- A joint trial with the SCORE@F French FoT project (JFT), using the VSS integrated into the OBUs and RSUs platforms developed by Score@F.

A strategic objective of PRESERVE is to contribute to on-going harmonization and standardization efforts at the European level. Project partners have contributed to the work of the Harmonization Task Groups of the EU-US ITS Cooperation, particularly for group #1 on Security and Management Protocols and group #3 on Joint protocols for safety and sustainability services.

SATIE

The SATIE support action is working on bringing forward the concept of innovation based test beds in ITS, addressing societal goals for environment, safety and transport efficiency.

The SATIE concept includes the model of ITS incubators, an approach so far little applied in this domain. Based on existing test-beds and gathering the different actors of the innovation eco-systems, the incubators will be market driven, and will have as main objectives the creation of businesses, the provision of innovative products and services and increased competitiveness of the ITS industry and research community.

Project name: SATIE Start and end date: 2011-2014 Coordinator: ERTICO – ITS Europe Sponsors: European Commission Budget: €1,877,594 Website: www.satie.eu
--

In order to accelerate the deployment of ICT for sustainable mobility and transport, the SATIE Support Action will prepare the way for successful launch of a European large scale action ("Elsa"), as introduced in the 2009 EC Communication "A Strategy for ICT R&D and Innovation in Europe: Raising the Game". SATIE will explore the key elements of an Elsa and provide assistance for potential Elsa participants in the form of an "Elsa Handbook" offering guidelines for the design, construction and operation of an Elsa.

- Elaborate concepts and procedures to achieve the added value of a European large scale action;
- Raise awareness of and consult with key stakeholders across Europe regarding the possibilities of an Elsa for transport-ICT;
- Map existing implementations and possible future initiatives that could be integrated into an Elsa approach.

The SATIE approach is based on establishing a partnership of national, regional and local key stakeholders from both demand and supply sides to share in the implementation of ICT solutions for mobility and transport at a larger scale than hitherto seen in Europe. The Test-beds identified were: AIM (DE), BRISA (PT), CAR2ROAD (FR), DITCM (NL), EMN (NO), Hessen (DE), ITS Factory (FI), ITS Platform (DK), MIRA (GB), Netport (SE), SCOREF (FR), TDA – E16 (SE), Thessaloniki (GR) and VIGO ITS (ES).

3.3.2 European/Regional Activities

3.3.2.1 Regional Initiatives

Amsterdam Group (<http://www.amsterdamgroup.eu/>)

The Amsterdam Group, a strategic alliance of road operators and industry on a European level, is coordinating the efforts towards deploying cooperative ITS. Involved are CEDR as an organization of public road operators, ASECAP as an umbrella association of the toll road operators, POLIS as an umbrella association of cities and the Car2Car-Communication Consortium representing the automotive manufacturers and associated industries.

The stakeholders seen by the Group are the users (drivers) and the road operators. The motivation of PVD is the need to know traffic and environment information also in case where NO hazards or other events occur (which are anyway disseminated by Decentralized Environment Notification (DEN) messages). The Probe Vehicle Data Service has been selected among the cooperative services planned for deployment starting 2015 (Day One Services).

ERTICO ITS Europe (www.ertico.com)

ERTICO – ITS Europe was founded in 1991 as a platform for the cooperation of all relevant stakeholders to develop and deploy ITS in Europe. The ERTICO Partnership is a public/private Partnership consisting of over a hundred Partners across 8 different sectors, all working towards bringing intelligence into mobility of people and goods in Europe. One of the activities of ERTICO is interoperability testing to support deployment of interoperable ITS solutions.

ERTICO supports the development, deployment and maintenance of services in the context of Traffic and Traveller Information (TISA), Traffic Management (TM2.0), navigation/digital maps linked to Advanced Driver Assistance Systems (ADASIS), eMobility ICT Interoperability Innovation (eMI3) and Transport Network ITS Spatial Data (TN-ITS). TM2.0 may be the most relevant for this report and is described below.

TM2.0 Platform (<http://tm20.org/>)

The TM2.0 ERTICO Platform originated in 2011 from TomTom and Swarco-Mizar and now regroups more than 20 members from all ITS sectors focusing on new solutions for advanced active traffic management. It aims to agree on common interfaces to facilitate the exchange of data and information from the road vehicles and the Traffic Management and Control Centres (TMC), and back, improving the total value chain for consistent management and traffic services as well as avoiding conflicting guidance information on the road and in the vehicles.

TM2.0 builds upon deployment of connected vehicles and travelers in order to achieve convergence of mobility services and traffic management. TM2.0 combines actions of the individual travelers with the collective mobility objectives. TM2.0 connects the innovative developments in the vehicle and on the road while giving value to the legacy and creating new business opportunities.

CEDR and TEN-T (<http://www.cedr.fr/> and http://ec.europa.eu/transport/modes/road/index_en.htm)

CEDR is the conference of European Directors of Roads. Its mission is mainly to contribute to future developments of road traffic and networks as part of an integrated transport system under the social, economical and environmental aspects of sustainability.

CEDR, supported by the EC, is actively contributing to the harmonisation efforts of the ITS infrastructure on the Trans-European Transport Network (TEN-T). A series of projects are currently active, each of them focussing on a specific part of Europe:

- The URSA MAJOR project cover roads linking the North Sea ports, the Ruhr and Rhine area, as well as metropolitan areas in southern Germany and northern Italy. Austria and Switzerland are also involved in the project as transit countries.
- The CROCODILE project includes three main road corridors: Baltic-Adriatic (linking Germany to Italy and Slovenia), Rhine-Danube (Germany to Bulgaria) and Orient-East-Med (Germany to Greece).
- The NEXT-ITS project will deal with the Scandinavian-Mediterranean Corridor from Oslo and the Finnish-Russian border in the north via Copenhagen, to Bremen and Hannover in Germany.
- The MedTIS project will deploy ITS services in Italy, France, Spain and Portugal along the Mediterranean corridor, linking several major sea ports and connecting the Mediterranean with the Atlantic coast.
- The Arc Atlantique project will link key economic nodes in The UK (Belfast, Glasgow, Cardiff, London), Ireland (Dublin), (France (Calais, Lille, Paris, Lyon, Bordeaux, Toulouse), The Netherlands (Rotterdam, Amsterdam), Belgium (Antwerp, Brussels, Charleroi, Liège), Spain (San Sebastian, Bilbao, Valladolid, Santander, A Coruña) and Portugal (Porto, Lisbon).

Among others the TEN-T ITS efforts focus on the provision of road navigation services with reliable information on travel conditions, to plan the most cost-efficient journeys and receive accurate travel time estimations.

A series of other projects potentially collecting large amount of probe data through the deployment of C-ITS will be launched in 2015.

3.3.2.2 Local and Regional Corridors and Test-beds

Cooperative ITS Corridor Rotterdam – Frankfurt/M. – Vienna

It is planned that the roadside cooperative ITS infrastructure for the initial services in the Cooperative ITS Corridor Rotterdam – Frankfurt/M. – Vienna will be installed by 2015.

The Netherlands, Germany and Austria have signed a Memorandum of Understanding to realise this new technology in close cooperation. The deployment of the corridor has been agreed with industry.

Two cooperative ITS services are first planned for use in the corridor:

- Roadworks warning (RWW) from the traffic control centers via the roadside infrastructure to the drivers 2
- Probe Vehicle Data (PVD) vehicles transmit data about the current situation on the road to the roadside infrastructure and the traffic control centers

In both cases, communication from the vehicle and infrastructure is established via short range communication (Wifi 802.11p, 5.9GHz) or the cellular network (3G, 4G).

Austria

Various activities are taking place in the Vienna testbed:

- Floating Car Data from Vienna broadcast taxis are used for AnachB.at since 2006:
www.anachb.at
- A model region for FCD has been established in Salzburg:
<http://www.salzburgresearch.at/projekt/fcd-modellregion-salzburg/>

- In the C-ITS Projects Eco.at and Testfeld Telematic probe data from cars has been used: eco.at.info/home.html
- Several Research Projects used Floating car data: Veriflow, QM4ITS...

These probe data activities will be continued and extended. A big Project "EVIS.at" will harmonise various regional activities and form a nationwide distributed system and competence network for traffic status collection and calculation. Probe data will come mostly from cars and mobile apps. If Telecom Providers are willing to provide mobile phone Connection data at reasonable costs, then floating phone data will be included.

Regarding standards and privacy issues, in the Project EVID.at a national harmonized Standard based on international Standards will be established. All probe data are anonymized as early as possible in the data flow. Great care is taken, that data cannot be tracked back to individual users.

International Standards such as ONR 16742 and ISO/TR 12859 are followed closely, national experts for privacy in ITS provide consulting and advice. We make sure, that the operational systems and business logic does not deal with personal data.

Scandinavia: ScandicWay Corridor

The proposed action, NordicWay, is a pre-deployment pilot of Cooperative ITS (CITS) services in four countries (Finland, Sweden, Norway and Denmark) which will be followed by wide-scale deployment and potentially to be scaled up to Europe. NordicWay has the potential to improve safety, efficiency and comfort of mobility and connect road transport with other modes. NordicWay is the first large-scale pilot using cellular communication (3G and LTE/4G) for C-ITS. It offers continuous interoperable services to the users with roaming between different mobile networks and cross-border, offering C-ITS services across all participating countries. NordicWay puts emphasis on building a sustainable business model on the large investment of the public sector on the priority services of the ITS Directive. NordicWay is fully based on European standards and will act as the last mile between C-ITS research and development and wide-scale deployment.

ITS Test Sites Sweden

"ITS Test Sites of Sweden", is the common platform for the cooperation. The four operators are ITSdalarna, Kista Science City, Lindholmen Science Park and NetPort. Karlshamn. The cooperation is coordinated by ITS-Sweden.

The test area for NetPort.Karlshamn covers Sweden's southernmost counties, Skåne and Blekinge. The area is primarily focused on the development of intelligent systems for information handling in traffic, transports, goods and logistics. Cooperation between different modes of transport is an important element, as is the development of transactions and payment solutions in a mobile, international and competitive environment.

ITS development in Kista Science City is influenced by Stockholm's need for innovative traffic solutions. Here, the focus is on developing and testing new services that enable people to make smarter choices when to travel – or not. Located here are the global headquarters for Ericsson, creator of future communication solutions and IBM, creator of Stockholm's congestion tax system, as well as Stockholm University Department of Computer and Systems Sciences, the Royal Institute of Technology (KTH) and Swedish ICT including Acreo, SICS, the Interactive Institute and Viktoria Institute.

The ITSdalarna cluster has built the test arena TDA E16 allowing roadside tests and demonstrations. It is a permanent arena with test sites adjacent to European Highway E16. The location is in the immediate proximity of the Swedish Transport Authority's Head Office and the Dalarna University.

Service is offered to anyone wanting to use the arena. Traffic volume, weather sensors, traffic cameras, safe parking, travel planning for tourists, rural ITS and other tests can be performed.

The heart of the Swedish vehicle cluster is located in Western Sweden. Lindholmen Science Park in Gothenburg coordinates several arenas for larger pilot, test and demonstration projects within ITS, in cooperation with many partners, both Swedish and international. The following programs connected to ITS are operated at Lindholmen: Test Site Sweden, SAFER, Closer, TUCAP, Visual Arena and Security Arena.

Testsite E18 is an open research facility, from which data could be received from the database connected to this website via a CSV Export webpage or SOAP Webservice. The testsite is owned by the Swedish Transport Administration. Measurement data is divided into four groups with four different organizations responsible for each. The testsite is located to the new E18 motorway (opened in the autumn of 2010) between Enköping and Västerås approximately 80 km west of Stockholm. Besides the above mentioned data measurement groups, there is also a RWIS-station at the site (data collection to the Transport Administration). An application has also been done to install the new patented "BIRDS" (Black-Ice Infrared Detection System) and include that into the database. This is a passive measuring device of the road surface.

Karlshamn: Netport

At NetPort the focus has been on Road User Charging data related to the EETS-directive. This means very much satellite positioning data. <http://www.arena-ruc.se/en/>. Lindholmen (the Closer organisation) has been working a lot with City Logistics and of course tests related to the fact that the 2 Volvo companies have their main activities there. Volvo Cars and Volvo Trucks. The latter means to a large extent self-driving cars. Stockholm has traditionally a lot of experience around public transport and mobility data collected in different ways. ITS Dalarna is more focused, as far as I understand, on provide a physical environment for test and then it's up to each tester to provide the tools necessary. There is no active cooperation between the test sites in terms of actual joint projects.

Regarding the funding and the costs the funding comes from national and international sources, such as Vinnova, Trafikverket and Transportstyrelsen (in Sweden) and EU-sources. I have no detailed information about the other test sites but at NetPort the funding is from national public sources. Very little from private organizations.

Regarding data availability, it depends on the funding of the activities and the requirement on the financing part. There is no general rule.

Regarding data privacy, the privacy issues are according to the national rules. Ownership depends of the funding. IPR are normally settled in an agreement before starting activities. There are no general standards defined.

Danish initiative

In the next few years lots of resources will be allocated to the ITS field in Denmark. Among other initiatives it has been decided to introduce road pricing and to implement eCall. One of the larger ITS initiatives is conducted in The North Denmark Region, which intends to be the Danish ITS region where new technologies are developed and tested before they are implemented throughout the country. The ITS Platform is the first large project and thus the first step in realizing out this vision: an ITS Platform which is open and available for new applications. ITS Platform has a total budget of DKK 34.7 million (5M euros) and a project period from 2010-2013. The project is funded with DKK 17.4 million from EU regional Funds and North Jutland development funds. The remaining funding comes from Aalborg University and two North Jutland companies: Inntrasys and GateHouse.

ITS Platform Northern Denmark is an open platform to test ITS solutions and to provide a basis for developing ITS. The platform is open to third-party applications. The platform consists of an OBU installed in 420 cars and enabling the mobile network to communicate with a backend server and WLAN connection with the neighborhood. The platform has a backend server, OBUs and communication infrastructure. An application thus consists of a number of programs in the OBU/ backend server, probe data provision through backend server, and web/smartphone-based applications as user interfaces. Each OBU has a General Packet Radio Service (GPRS) connection and/or a WLAN connection with the back-end sever. The OBU samples its own position and its acceleration data at an interval of 1 Hz and 10 Hz, respectively and forwards it to the back-end. In case of network outage, the PVD is buffered until it can be sent. The OBU can be remotely updated or even new applications can be installed. The position, speed, acceleration as well as calculations on the risk and eco factors of the drivers are used for several applications.

These probe data are used for applications, which the driver can make use of. The OBU has been developed especially for mobile ITS services. Dedicated services and applications can run on the OBU through a set of open interfaces. The OBU is easy and inexpensive to install and can be updated with new applications and features via GPRS on a regular basis. The most significant demo applications are an automatic parking payment service, customized traffic dynamic information, a driver log including eco and risk indices, and an interactive traffic statistics application for road authorities. In addition, a number of new projects, which are being planned for the ITS Platform, are introduced.

North Jutland: ITS Platform Denmark

TS Platform Northern Denmark is an open platform to test ITS solutions and to provide a basis for developing ITS. The platform is open to third-party applications. The platform consists of an OBU installed in 420 cars and enabling the mobile network to communicate with a backend server and WLAN connection with the neighborhood. The platform has a backend server, OBUs and communication infrastructure. An application thus consists of a number of programs in the OBU/ backend server, probe data provision through backend server, and web/smartphone-based applications as user interfaces. Each OBU has a General Packet Radio Service (GPRS) connection and/or a WLAN connection with the back-end sever. The OBU samples its own position and its acceleration data at an interval of 1 Hz and 10 Hz, respectively and forwards it to the back-end. In case of network outage, the PVD is buffered until it can be sent. The OBU can be remotely updated or even new applications can be installed. The position, speed, acceleration as well as calculations on the risk and eco factors of the drivers are used for several applications.

These probe data are used for applications, which the driver can make use of. The OBU has been developed especially for mobile ITS services. Dedicated services and applications can run on the OBU through a set of open interfaces. The OBU is easy and inexpensive to install and can be updated with new applications and features via GPRS on a regular basis. The most significant demo applications are an automatic parking payment service, customized traffic dynamic information, a driver log including eco and risk indices, and an interactive traffic statistics application for road authorities. In addition, a number of new projects, which are being planned for the ITS Platform, are introduced.

ITS Platform was finalized by the end of 2014 data: 15 million km driving will form basis in a new project DiCYPs for new applications.

Regarding the funding and the costs, the total funding is near to 4.8 million €. Half from regional funding and half from the three partners (Aalborg Uni, Gatehouse and Inntrasys). The main operational costs were development and operation of OBUs in 420 cars, development and operation

of backend server and development of the four applications while the cost of communication was about 1,5% of total budget.

Regarding data availability, data are available for others, if they make cooperation with one of the three partners in the project. Any organizations in question should be ready to sign relevant contracts regarding privacy, anonymizing and ownership of data. If this is full-filled it is possible to use data for third parties.

Regarding data quality, standards and data privacy, each observation is associated with a quality measure, but we don't have general filter while no specific standards are followed. The three partners own the data. We can share them for research purposes. The participants have agreed that we are allowed to use data for research purposes as long as their privacy is protected. We have a significant number of data on each drivers personal information and several questionnaires showing their attitude to various topics related to transportation and ITS. Data are in the moment placed in a PostgreSQL server. Data flow was Car to server via GPRS. Some data was send back as part of applications. Part of applications were fully server based while others were partly server based and partly OBU based.

SCOOP@F Part 1&2 (France)

SCOOP@F is a Cooperative ITS pilot deployment project that intends to connect approximately 3000 vehicles with 2000 kilometers of roads. It consists of 5 specific sites with different types of roads: Ile-de-France, "East Corridor" between Paris and Strasbourg, Brittany, Bordeaux and Isère. SCOOP@F is composed of SCOOP@F Part 1 from 2014 to 2015 (ongoing) and SCOOP@F Part 2 from 2016 to 2018. Its main objective is to improve the safety of road transport and of road operating staff during road works or maintenance. SCOOP@F Part 2 includes the validations of C-ITS services in open roads, cross border tests with other EU Member States and development of a hybrid communication solution (3G-4G/ITS G5). SCOOP@F Part 2 will cooperate with ongoing European pilot projects and the EU C-ITS platform. The project aims at reaching a critical mass in the number of tested vehicles, roads and services, in order to provide a representative evaluation of C-ITS.

Thessaloniki (Greece)

The Thessaloniki test-bed is the result of various funded projects executed during the last 10 years which equipped the city with various set of sensors and back office capabilities for data hosting, analyzing and services provision. The cost for running the services and maintaining the network of sensors is provided by the public authorities (region and municipality) and by CErTH-HIT. The main data sources are conventional traffic sensors (loops and cameras), Bluetooth devices detectors, Floating car data and data coming from social networks.

General data format standards are used for the collected and processed data, but not data interoperability standards. Regarding data availability, all the collected data is processed and provided for free through the various services developed by CErTH-HIT while raw data can be exchanged in bilateral collaborations after achieving an agreement.

Regarding data privacy, data is anonymized by aggregating it both temporally and spatially during the data processing.

Conventional data sources in Thessaloniki

There are three sets of conventional mobility data sensors in Thessaloniki:

- The surveillance system of the Peripheral Ring Road, monitoring a total of more than 100000 vehicles per day in both directions.
- Thessaloniki's Urban Mobility Management System installed in the city center, monitoring more than 50000 vehicles per day.

- The traffic lights management system of the wider metropolitan area of the city.

Stationary probe data

The Bluetooth detectors network of the city of Thessaloniki is comprised of 43 roadside devices, installed at selected intersections throughout the road network of the city. More than 100000 Bluetooth-equipped devices are detected every day, generating a total of 300000 detections at the 43 locations.

Floating car data

The network of moving sensors (Floating Car Data) is comprised of a more than 1200 taxi vehicles, circulating in average between 16 and 24 hours per day, which periodically (each 6 seconds) send pulses containing their location and speed. The total amount of data collected and processed reaches 2500 pulses per minute, with daily totals at approximately 1.5million. The quality of FCD will be significantly enriched with the provision of cooperative mobility services (connected vehicles and infrastructures) to more than 250 taxis. These vehicles will be able to provide data related to their position and speed per second as well as to detect congestion.

Social Media

The data obtained from social media content is related to individual Facebook check-ins in various locations of the city, which are obtained at real-time. A total of 1500 locations in the city center account for more than 35000 daily check-ins of Facebook users.

Flanders

In Flanders, Belgium, two pilot projects are working with probe data: Floating Car Data for network traffic management and evaluating the use of services based on Floating Car Data within the network management processes of the traffic center Flanders. The first pilot aims to answer the question to what extent can probe data be useful as an additional or alternative source of traffic data, to develop a methodology of data control and to evaluate the quality of probe data vs. ANPR/Bluetooth measurements. Probe data is provided for 3 kinds of trajectories (depending on road class and the presence of permanent or temporary measurement equipment): E313 direction Antwerp (highway, permanent equipment, Bluetooth), A12 (combination highway + traffic light crossings, Bluetooth), and N16 (regional road, 2x2, traffic lights, Bluetooth). The results of probe data were evaluated in different situations. Reference measurements were collected by the traffic center Flanders for all roads. The strengths of this approach were travel time data is really measured (and not deduced from data measured from roadside equipment), the relatively simple deployment of the system, limited maintenance cost, data gathering independent from road infrastructure / no physical installation along the way, and costs could be shared. However, probe data is a statistical measurement method, and thus less accurate on roads with low intensities, there is the possibility for a delay in detecting unusual situations, and there are no data on the number of vehicles available. The developed control methodology was used to check the probe data with the reference measurements and there was a good to very good correlation, so probe data can serve as additional information for traffic management

The second pilot, to evaluate the use of probe data based services within the network management processes consisted of two parts: (1) Travel times on roads to support the setup of diversions in corridors and (2) Early warning and early information. 16 corridors in Flanders were considered (8 corridors and their reverse). On these corridors, diversions on long distance are applied several times a week. Travel times and delay times were delivered on one webpage, with additional webpage with detailed data (like time-road diagrams). This was very useful in the operator room; diversions could be started and stopped faster.

With probe data, speed drops resulted in an alarm for the operator. With a camera image, the operator could check if a real anomaly in the traffic flow is concerned, this is especially useful on roads without or with few information by means of cameras, loops, etc. The general conclusion is that probe data can be useful for (especially in sections without or with few cameras or fixed measurement equipment) for managing corridors, providing information for the road users via VMS, and for support for incident detection.

- The traffic center Flanders wants to complement its own data with external data, especially events such as traffic jams and incidents, in order to get a full view of the current traffic flow. Therefore, the traffic center is performing a pilot project to gain experience with external events and to tune its internal operation on this.
- At the end of 2014, the traffic center Flanders started an open tendering procedure concerning the provision of instantaneous real-time travel times on established routes that can dynamically be adapted. This has not been awarded yet.

Finland ITS Factory

The ITS Factory is to provide a high quality proving, testing and demonstration environment for ITS innovation and demonstration projects in Tampere Region. Open data is recognized to be one of the key success factors in an open proving, testing and demonstration activities and facilities. All public data in the Tampere Region are made available for ITS Factory participants and projects against minimum bureaucracy and formalities.

(http://www.hermiagroup.fi/@Bin/1536387/LUMIAHO_KULMALA_Open_Data_as_Enabler_for_ITS_Factory_final.pdf)

Support for the developers and other users of the data is given by Developer support of ITS Factory. ITS Factory Developer wiki provides access to open data in standardized format. Data sources include real-time public transport data, road conditions, traffic flow, weather, parking, cycling, and incidents and roadworks. The open data API on traffic announcements provides information about roadworks, accidents and other incidents that affect road traffic. These announcements complement the national announcements given by the Finnish Transport Agency. Infotripla collects traffic information feeds that are combined from various information sources, most notably Finnish Transport Agency and Finnish Meteorological Institute. Also a number of vehicle fleets from third parties are collecting sensory data for Infotripla which is then used to enrich the content – especially real time traffic flow information. This information is collected and published as a dedicated Tampere Datex II Service which provides published Datex2 -messages at 1-minute intervals. (<http://wiki.itsfactory.fi/>)

Tampere collects traffic data from various sources and Infotripla Ltd collects, combines and refine the data. Floating Car Data (FCD) is collected from a local taxi company (over 400 taxis) in Tampere region. Real time traffic information is calculated from FCD data combined with Tampere area traffic light and fixed measurement data. There are also some road weather stations in Tampere city which provides information in addition to Finnish Road Administration measurements.

Finnish-Russian initiative: Smart Transport Corridor Helsinki - St. Petersburg

The E18 motorway in Finland has been the telematics test area for the Finnish Transport Agency from the mid-1990's. Now the E18 section Helsinki - St. Petersburg will part of the Smart Transport Corridor, which is currently being setup in cooperation between Finnish and Russian stakeholders. The goal of the Smart Transport Corridor is to improve mobility, safety and sustainability of passenger and freight transport with interoperable Intelligent Transport Systems and Services (ITS). Another goal is to increase cooperation between Finnish and Russian actors in private and public sectors.

Today, information e.g. about road conditions or traffic is difficult to obtain after crossing the border and crossing the EU border is time consuming. Information about the traffic and road is currently collected

in both countries, but sharing of the data does not exist. New ITS with interoperable information services, based on open data and standardized interfaces, can enable more efficient utilization of existing road networks including border crossing facilities.

This initiative aims to implement the first interoperable cross-border ITS services for E18 section Helsinki – St. Petersburg. The roadmap for ITS deployment will be defined and plans to setup a test corridor for upcoming ITS services. The first interoperable ITS pilot services will be targeting to automated road weather, incident detection and real-time traffic information services. The Smart Transport Corridor concept will provide example and guidelines for other cross-border routes.

The initiative was officially started in 2012. The Ministry of Transport and Communications together with Ministry of Transport of the Russian Federation are the commissioners and supervisors of the project.

3.4 Comparison of Probe Systems

Table 3-5 compares the characteristics of the connected vehicle systems implemented in the US, and the ETC2.0 system deployed in Japan. Note that this comparison effort was completed before the European team joined the work group, so only the probe systems in the US and Japan are included in the table.

Table 3-5. 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	ETC2.0
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 and National Highways
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 and some RSEs on National Highways
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)	360,000 ITS Spot compatible navigation systems installed on vehicles (as of July 2014)

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	ETC2.0
								103 transit vehicles (3 integrated+100 VAD) 100 medium trucks (100 VAD)	
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 Other messages unknown	SAE J2735 Probe data messages Other messages unknown	BSM Part 1 and other messages to support evaluation	ETC2.0 probe data
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

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	ETC2.0
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 ETC2.0 roadside unit 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
Data Storage and Cleaning	Anonymized, cleaned data at USDOT RDE	Anonymized, cleaned data at DCM Prototype Data Environment (USDOT RDE planned)	No information	Anonymized, cleaned data at USDOT RDE	No information	No information	Anonymized, cleaned data at USDOT RDE	Anonymized data at USDOT 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 owns Test Bed hardware, software; IPR unknown	No information	FDOT and its partners own in-vehicle devices and software, USDOT owns RSEs; IPR unknown	No information	No information	MCDOT and its partners own Test Bed hardware and software; IPR unknown Data ownership not	UMTRI, CAMP, and its partners own Safety Pilot hardware and software; IPR unknown	Probe data are owned by MLIT, expressway companies ETC2.0 Roadside Units are owned by MLIT 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	ETC2.0
	USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on USDOT RDE	Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on USDOT RDE		Data ownership not identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on USDOT RDE			identified; USDOT may have access to federally-sponsored data, and subset of anonymized data may be available on USDOT RDE	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 USDOT RDE after NHTSA analysis	Expressway Holding and Debt Repayment Agency Probe Servers are owned by MLIT
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	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This comparison effort was conducted in 2013.

4 Summary of Probe Data

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

4.1 Probe Data in the US

4.1.1 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 3.1.1. For example, the VIIC POC and NCAR test data sets were generated during field operational tests conducted on the Michigan V2V/V2I Test Bed.

4.1.1.1 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.

San Diego Test Data Set

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] [46]. The data set includes data from mobile devices (i.e., GPS-based data from ALK Technologies) [47], traffic sensors deployed on the major freeways [48], NOAA (National Oceanic and Atmospheric Administration) weather stations [49], and incidents and lane closures (for I-5) [50].

Probe Data: GPS-based data are available from ALK Co-Pilot in-vehicle navigation devices operating in the San Diego region [47]. 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 [48]. 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). 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 USDOT 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 USDOT RDE.
- Storage – The data set, with the exception of the ALK trip data, is stored on the USDOT 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 USDOT RDE.
- Cost – The data set will be available at no cost through the USDOT RDE.

Seattle Test Data Set

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 [51].

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 [52].

- 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 [53]. 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 [54].

- 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. 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 USDOT RDE.
- Storage – The data set that is available to the USDOT for connected vehicle research is stored on the USDOT 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 USDOT RDE.

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

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

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

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 [54] that is documented in this section was integrated and formatted by Noblis for the DCM Program [55].

Probe Data: Raw and processed probe data messages logged by the vehicles OBEs [56] and probe data messages received by the RSEs [57] 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) [58]. Figure 4-1 shows the locations of the RSEs and ESS (identified as C3800 and C4114) [58].

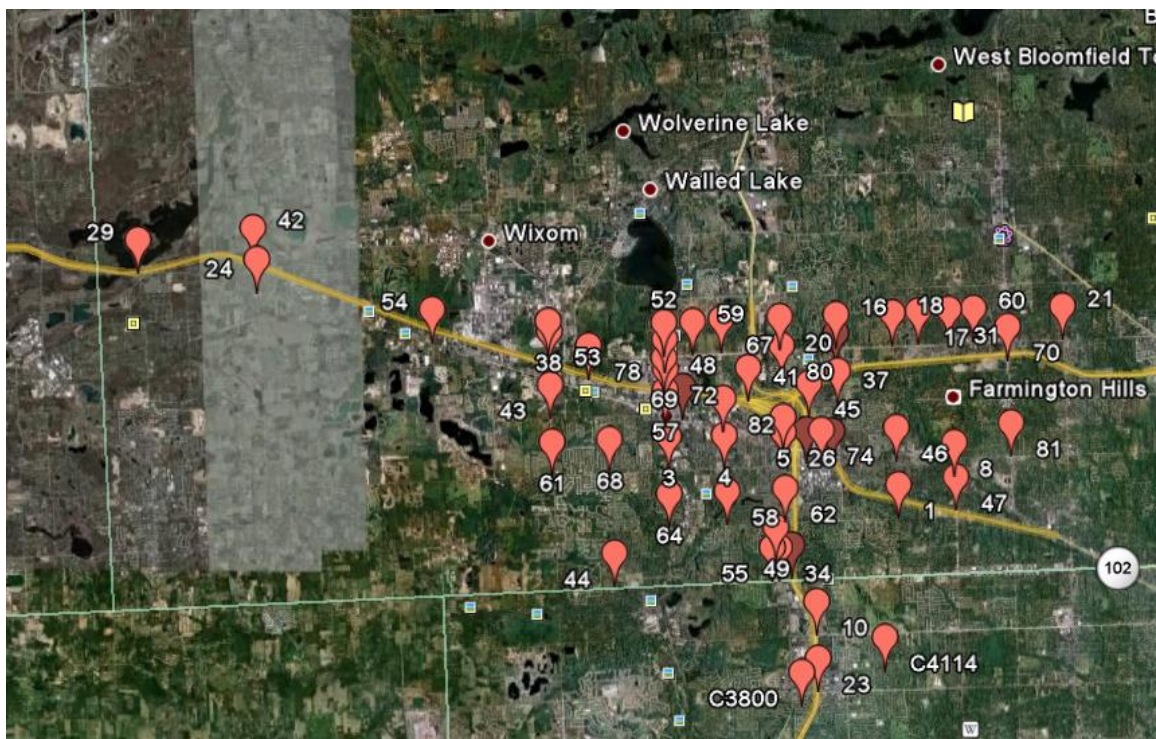


Figure 4-1. Location of RSEs and Environmental Sensor Stations (ESS) (Source: USDOT)

- 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 [55]. 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 [58].
- Privacy – The POC test data set does 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 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 USDOT Research Data Exchange (RDE). It is included as an appendix in the document entitled, Metadata Guidelines for Research Data Exchange [55].
- Storage – The POC test data set is stored on the USDOT RDE and is available to the public for research [54].
- 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 USDOT RDE.

4.1.1.3 NCAR Data Set

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 [59][60].

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 [59]. 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 [60]. 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 [58].
- 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) [55].
- Storage – The NCAR data sets are stored on the USDOT RDE and are available to the public for research [54].
- 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 USDOT RDE for research.
- Cost – The data set will be available at no cost through the USDOT RDE.

4.1.1.4 TFHRC Data Set

The TFHRC data set includes data generated at the TFHRC Test Bed. 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 USDOT RDE. The automated routine will be revised in the near future to send the data to the USDOT RDE.

Probe Data: Raw and processed probe data messages received by the two RSEs and passed through the SDN are available [61]. 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 USDOT RDE.

4.1.1.5 Integrated Mobile Observation (IMO) Data Set

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 [62].

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 [63].

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 [64].

- 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 USDOT 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 USDOT RDE for research.
- Cost – The data set will be available at no cost through the USDOT RDE.

4.1.1.6 Florida Test Bed Data Set

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 USDOT 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 USDOT 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 USDOT 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 USDOT 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 USDOT RDE for research.
- Cost – The data set will be available at no cost through the USDOT RDE.

4.1.1.7 Mobile Millennium Data Set

The data were collected during the Mobile Century experiment run by UC Berkeley and Nokia, funded by Caltrans [65]. 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 4-2. 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.

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.

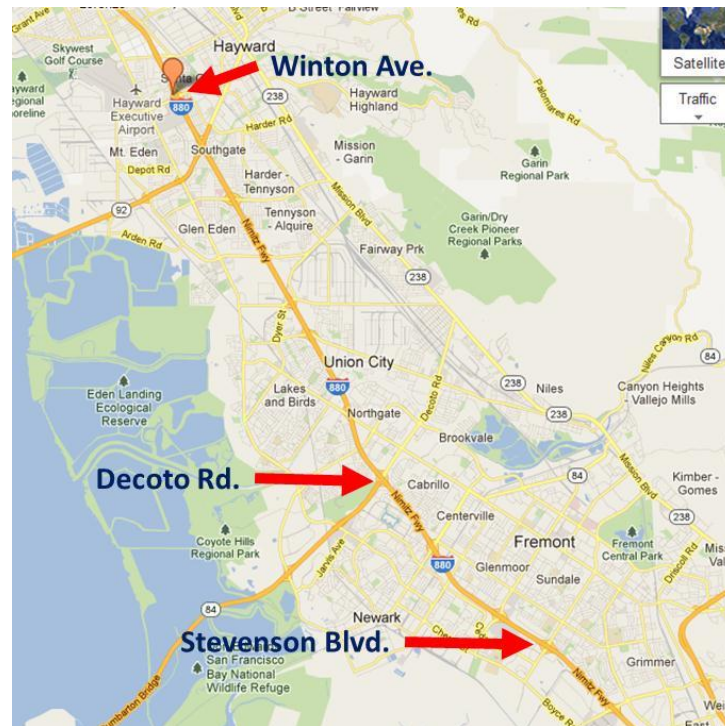


Figure 4-2. Intersection used for Ground Truth Travel Time Estimations (Source: University of California - Berkeley)

- **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 [66].
- **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 [66], 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.

4.1.2 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 [67] 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 4-1 of the report summarizes the survey results [67]. 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 USDOT 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 [27]:
 - 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 4-1. 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.
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.

4.1.3 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 [68]. 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 [67]. 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 [68]. 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 4-2). 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 USDOT 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 USDOT 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 USDOT RDE. When data are not archived by the data collector, the USDOT may choose to store the data and make it available on the USDOT 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 [69]. Alternately, highly restrictive data sharing agreements can prevent broad utilization of data, even in federally-funded research programs [69]. 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 USDOT 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 4-2. 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

4.2 Probe Data in Japan

4.2.1 Probe data of Japanese Government

Configuration of Probe Data

The probe data collected by ETC2.0 roadside units 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 ETC2.0-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 ETC2.0-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 4-3). The maximum storage capacity of an ETC2.0-compatible car navigation systems corresponds to approximately 80 km (50mi) of travel. Table 4-3 lists the data items that are collected.

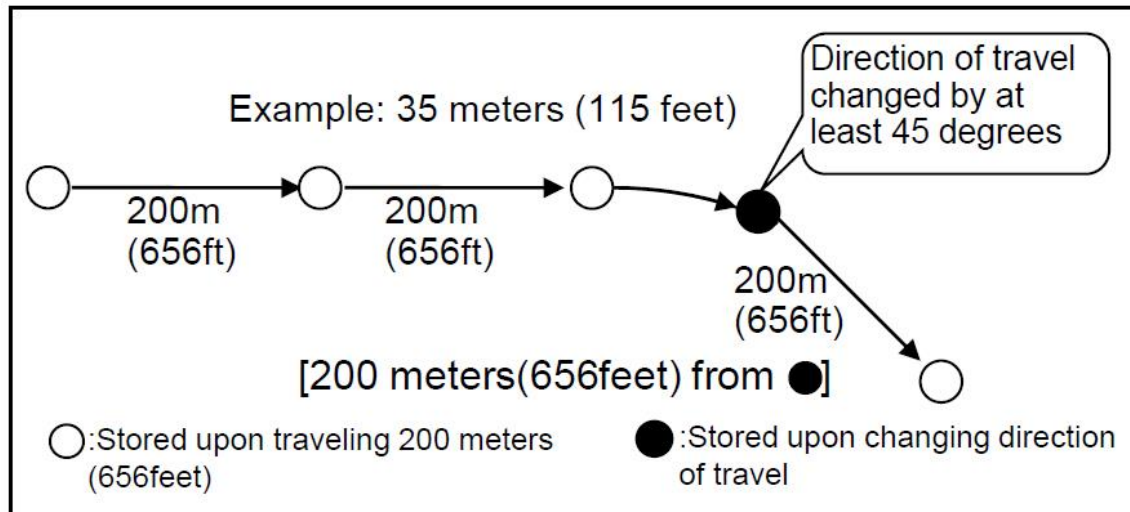


Figure 4-3. Timing of travel record data storage (Source: MLIT)

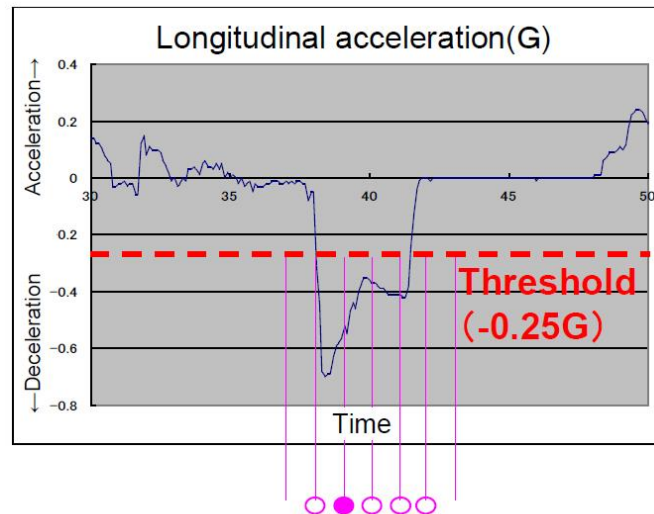
Table 4-3. Travel record data items (Source: MLIT)

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 ETC2.0-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 4-4 and Figure 4-4). Up to 31 events can be stored. Table 4-5 lists the items of data that are collected.

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

Table 4-5. 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 4-6.

Table 4-6. Probe Data Retention Periods (Source: MLIT)

Category	Type of Data	Retention Period
Raw Data	Basic Information Travel Record Information Behavior Record Information	90 Days
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 ETC2.0-compatible car navigation systems through ETC2.0 roadside units. 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.

4.2.2 Private sector probe data

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

4.3 Probe Data in Europe

The ITS directive² aims at supporting the coordinated deployment and use of Intelligent Transport Systems (ITS) in Europe providing necessary standards for the development of specifications for actions related to the following priority areas:

- Optimal use of road, traffic and travel data
- Continuity of traffic and freight management ITS services
- ITS road safety and security applications
- Linking the vehicle with the transport infrastructure

The PSI directive³ establishes a set of rules for the re-use of information from the public sector in Europe.

4.3.1 European initiatives supporting open data in Europe

Data in Europe was not directly available and in most cases one could not get in a simple way data to use in research. However, the latest trend in data management is the promotion of the openness of the data. The European Commission has developed an Open Data Strategy for Europe in order to

² <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0040>

³ <http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:02003L0098-20130717>

open its data assets, establish a level playing field for Open Data across the EU and fund research on data handling technologies (European Commission, 2013). In this context, some initiatives have started with their primary goal to be the promotion of the Open Data concept. One of those initiatives is the European Public Sector Information (EPSI) platform that investigates the advances and promotes policies and guidelines towards Open Data in Europe (www.epsplatform.eu). As shown in Figure 4-5, the Open Data Barometer is used to measure and rank the Open Data policies in Europe. The measures used can be categorized in readiness, impacts and some dataset characteristics (i.e. innovation and accountability).

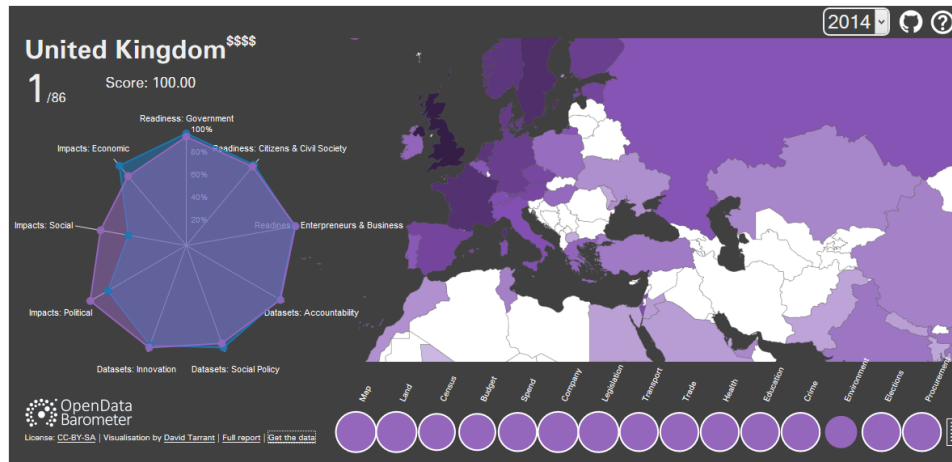


Figure 4-5. Open Data Barometer (Source: barometer.opendataresearch.org)

In Europe there are several initiatives to make data more available and to stimulate sharing of data⁴. These initiatives may concern the data that are collected in European projects, but also data that are available from other projects, and data collected or financed by public bodies.

For European projects funded under the Horizon2020 programme, the Open Research Data Pilot has been established which aims to improve and maximize access to and re-use of research data generated by projects. Participants will be required to deposit their data and enable access for third parties. The creation and use of Data Management Plans is an integral part of projects. Not all projects are yet required to open their data, such as the projects in the transport area. However, projects are stimulated to participate on a voluntary basis.

According to the MULTITUDE COST action⁵ the existing mobility data can be classified depending on its usability and availability levels in the following examples of data:

- Useful and available data: EUROFOT, simTD
- Potentially useful data: ICC FOT, DaCoTa, Pay as you speed Aktiv, CNDS, SHRP2
- Useful data but not available: TeleFOT, PROLOGUE, SeMiFOT

The above mentioned are some of the data available while the MULTITUDE COST action includes additional databases that provide open data to researchers. In most cases the data is available after

⁴ Various open data portals can be found at <http://ec.europa.eu/digital-agenda/en/open-data-portals> while a detailed description of public sector open data can be found in http://www.epsplatform.eu/sites/default/files/A%20year%20of%20Open%20Data%20in%20the%20E%20MEA%20region_0.pdf

⁵ Methods and tools for supporting the use calibration and validation of traffic simulation models. <http://www.multitude-project.eu/>

e-mailing the corresponding person indicated. This data includes trajectory data from various studies such as driving simulator data (Farah & Toledo, 2010) real time data (Punzo, Formisano, & Torrieri, 2005), Loop detectors data, from many countries in the EU and Section data.

There are several European projects funded by the European Commission that provide support for open and big data.

4.3.1.1 Cross-Sector initiatives

Big Data Value PPP (<http://www.bigdatavalue.eu/>)

The Big Data Value PPP aims at fostering the cooperation between European industry, research and academia establishing Public-Private Partnerships for cooperating in data-related research and innovation, enhance community building around data and paving the way for a data-driven economy in Europe.

Open Transport Data Manifesto

The EPSI platform organized a workshop on Open Transport Data forming an Open Transport Data Manifesto to engage scientist in this challenge and allow for cooperation to make transport data open (EPSI platform, 2012). Figure 4-6 presents the manifesto introducing the reasons Open Transport Data is not reality and suggesting the way to make it happen. As quantity of data increases, the main challenges are the quality of data and the incorporation of the transport data with the focus on the lately used data sources (i.e. Floating Car Data, Probe Vehicle Data) in the Open Data Concept.



Figure 4-6. The Open Transport Data Manifesto (Source: www.epsiplatform.eu/transport)

EUDAT (<http://www.eudat.eu/>)

EUDAT is a three-year project (started in 2015, but building on an earlier project) that will deliver a Collaborative Data Infrastructure (CDI) with the capacity and capability for meeting future researchers' needs in a sustainable way. Its design will reflect a comprehensive picture of the data service requirements of the research communities in Europe and beyond. EUDAT also provides the opportunity for data-sharing between disciplines and cross-fertilisation of ideas. EUDAT's vision is to enable European researchers and practitioners from any research discipline to preserve, find, access, and process data in a trusted environment, as part of a Collaborative Data Infrastructure (CDI) conceived as a network of collaborating, cooperating centres, combining the richness of numerous community-specific data repositories with the permanence and persistence of some of Europe's largest scientific data centres. EUDAT Services for Research Infrastructures and Data Centres include services for synchronizing and exchanging, and sharing and storing data. Website: eudat.eu

OpenAIRE2020 (www.openaire.eu)

The OpenAIRE2020 project started in 2015, for a total duration of 42 months. OpenAIRE aims to establish an open and sustainable scholarly communication infrastructure responsible for the overall management, analysis, manipulation, provision, monitoring and cross-linking of all research outcomes (publications, related datasets, software and services) across existing, planned and future repositories. It promotes the discoverability and reuse of data-driven research results, across scientific disciplines and thematic domains.

SUPERHUB (<http://www.superhub-project.eu/>)

SUPERHUB: SUsustainable and PERSuasive Human Users moBility in future cities is a European co-funded project strongly committed to the 2014 realization of an open source platform and mobile app able to plan customized urban routes, combining all mobility offers in real time.

The SUPERHUB Project provides a user-centric, integrated approach to multi-modal smart metropolitan mobility systems. The project involves designing and testing an open platform able to combine all mobility offers. Together with a set of enabling mobility services able to address user's mobility needs, SUPERHUB can redesign transport route options. Furthermore, the user can utilize SUPERHUB to encourage desired behavior changes. Several partners from all over Europe are engaged in the realization of a user-centric, integrated approach to multi-modal smart metropolitan mobility systems. SUPERHUB creates a new urban mobility services ecosystem. All mobility options being presented, the user is able to choose the options and develop the behaviors they desire. The platform is able to:

- Gather real time data from all mobility sources
- Provide matchmaking and negotiation between providers and consumers of mobility offers for optimal routing decisions
- Develop mobility services which can both perform as desired and nudge user towards their self-determined behavior goals.

4.3.1.2 Initiatives supporting data exchange in transport**BigDataEurope** (www.big-data-europe.eu)

BigDataEurope is a three year coordination and support action. It started in 2015 and is coordinated by Fraunhofer. Its mission is to lower the barrier for using big data technologies, assist in establishing cross-lingual/organisational/domain data value chains and to show societal value of big data. The project addresses not only transport but also other societal challenges: Life Sciences & Health, Food

& Agriculture, Energy, Climate, Social Sciences, and Security. The project is engaging with a diverse range of stakeholder groups. It will design, realize and evaluate a big data aggregation platform. Interest groups will be established, with at least 3 workshops, and interviews with stakeholders.

FOT-Net Data (www.fot-net.eu)

Most public data-sets available in Europe have been generated by large funded Field Operational Tests. Several partners from these projects have analyzed the data but sharing of data has been limited to consortium partners. Although most consortiums have made preparations for sharing data with third parties, including detailed documentation and legal agreement templates, no official data sharing frameworks or policies have been defined so far.

FOT-Net Data is a Coordination and Support Action in the EU 7th Framework Programme for Research. The project's full name is Field Operational Test Networking and Data Sharing Support. It is a three-year project, started in 2014, whose main aim is to make traffic data collected in Field Operational Tests (FOTs) more widely available to researchers.

The project FOT-Net Data is a continuation of FOT-Net's activities. FOT-Net is a networking platform open to all stakeholders interested in FOTs. It was established in 2008 as a European support action to let FOT experts benefit from each other's experiences as well as to give an international dimension to local activities. It organizes international workshops, publishes a series of newsletters and promotes FESTA – a European handbook on FOT methodology. The main objectives of FOT-Net Data are to:

- Support efficient sharing and re-use of FOT datasets
- Develop and promote a framework for sharing data
- Build a detailed catalogue of available data and tools
- Operate an international networking platform for FOT activities.

FOT-Net Data compiles a framework and a set of guidelines to assist FOT organizers in practicalities of data sharing. The framework will address legal topics such as test user consent forms, participants' privacy and topics to include in data sharing agreements. It also addresses documentation of key information from FOT execution and collected datasets, ensuring that the datasets can be reused. The framework will provide guidance on financial aspects such as data release costs and arranging support for new analysts. The framework will complement the FESTA Methodology.

FOT-Net Data is compiling the first European data catalogue for driving studies and field trials, in tight co-operation with similar international efforts and the FOT community. The datasets included in the catalogue will be available for further research work and described in reasonable detail for potential re-users.

The work is based on the current FOT-Net Wiki (wiki.fot-net.eu), which already contains a FOT Catalogue section describing projects across the world. The list of FOTs will be complemented with a FOT Data Catalogue. The datasets included in the Data catalogue must be available for further research work under defined conditions and they will be described in reasonable detail for potential re-users. FOT-Net will come up with a format and definitions for the data catalogue by considering current best practices for FOT dataset documentation and existing catalogue standards. Feedback and further input will be gathered from the FOT-Net community, especially from dataset owners. The main purpose of the Data Catalogue is to support potential data re-users in identifying suitable datasets for their purposes and to facilitate data sharing. The catalogue has three main principles:

- Extension of the current FOT Catalogue (wiki)
- Ease-of-use

- Data remains with their owners

The development work of the FOT Data Catalogue is currently on-going and in internal piloting phase. It is foreseen that the catalogue will be publicly launched around the summer 2015. Then the whole FOT-Net community will be invited to add datasets and provide feedback on the catalogue.

4.3.2 National initiatives

There are many national initiatives to make data available, such as national data warehouses. In this section we only name a few. More information can be found in the State of the Art of Probe Data Systems in Europe (Sandford and Paulin, 2013)⁶.

4.3.2.1 Germany- MDM Mobility Market Place (www.mdm-portal.de)

There are data suppliers/providers and data clients/consumers while the MDM acts as a data broker/platform to bring those two together. Clients can search the MDM looking for the desired data sets and subscribe to the providers of their choice. Providers can describe the data they offer, their so-called publications, using metadata in order to make it searchable. They may also use metadata to describe how they ensure the quality of their data or to give other additional information. Choices regarding push or pull services can be made by providers and clients, both types of service are offered.

- Quality – The MDM checks for a valid data scheme, but it does not analyse or describe the quality of the information contained in the distributed data. The providers of traffic data can use metadata fields to give information on how they obtain/process/ensure the quality of the data sets they are offering.
- Privacy – Since the MDM itself is not providing any traffic data on its own, privacy is in the scope of the data providers, but not of the MDM.
- Standards – Standard used for data exchange are DATEX II and XML. Different types of data can be included using a special container format.
- Metadata – Providers can use metadata in order to describe the data they offer and make it searchable as publications on the MDM web portal. They may also use metadata to describe how they ensure the quality of their data or to give other additional information.
- Storage – The MDM does not store data. For each publication, providers deliver a set of data with a certain date/time stamp, which gets replaced when a data set with more recent time stamp becomes available.
- Data Ownership and Intellectual Property Rights (IPR) – The MDM acts as a data broker that does not provide any traffic data on its own. The ownership of the data remains with the data provider and usage rights for the transferred data are negotiated by data providers and data clients.
- Cost – Paid or free data sets can be offered via the MDM. The service offered by the MDM itself is free of charge today.

⁶ <http://fot-net.eu/literature-study-on-the-state-of-the-art-of-probe-data-systems-in-europe/>

4.3.2.2 Denmark: DiCyPS

A new large-scale research center founded by Innovation Fund Denmark will be initiated on Aalborg University in 2015. It is called: Centre for Data-Intensive Cyber-Physical Systems (DiCyPS).

Cyber-Physical Systems (CPS) refer to the close connection and coordination between calculating and physical resources. CPS are big distributed systems (often embedded in network) where a large number of calculation units work in physical environments.

CPS requires software for surveillance, analyses, and managements of the single sub systems and their complex coordination. Big data are generated from each sub systems with the purpose to integrate and analyse. Examples of these are integrated car systems, interacting medical equipment, energy management in buildings, and solar cells in smart grid. Hence, CPS are complex and data-intensive and works in close connection with end users the future smart society.

DiCyPS will boost the development and building of the IT infrastructure for data-intensive cyber-physical systems and their interaction with the end users. Generalization and usability of results will be demonstrated in close cross-disciplinary cooperation with researchers and enterprises from the transport and energy domain.

The center combines five international leading research groups (including the two most cited Danish computer science researchers) and a unique international consortium comprising enterprises, researchers and public authorities to build the basis for the IT infrastructures in the future smart society.

The center will run for six years and has a total budget of € 10 million, of which over € 1 million are earmarked to Intelligent Transport System.

4.3.2.3 The Netherlands: National Data Warehouse (www.ndw.nu/en/)

In the Netherlands, the National Data Warehouse for Traffic Information (NDW) is an alliance in which 24 public authorities work together on collecting, storing and distributing traffic data.

The Dutch National Data Warehouse is also an example of Open Transport Data in Europe. Through the designed system users can download freely historical and real time traffic counts from various locations in the Netherlands (<http://www.ndw.nu>). It combines data from various sources with its goal to be the better utilization of transportation services. The Dutch NWD uses the DATEX II European standard for recording and exchanging traffic data.

This data is used to provide traffic information, to ensure effective traffic management, and to conduct accurate traffic analyses. It has an enormous database of both real-time and historic traffic data. Its goals is to apply the right data to obtain optimal traffic management and to provide road users with the best possible information resulting in less congestion, lower emissions of CO₂ and other pollutants, and improved safety. The partners in NDW are: the central government, all the provinces, all the urban regions, and the municipalities of Amsterdam, Rotterdam, The Hague and Utrecht.

4.3.2.4 DLR Clearing House

An interesting case concerning open data is the DLR Clearing House that collect data from several studies in one data warehouse⁷. The DLR Clearing House include data from several countries in Europe mainly from studies that affiliated parties have conducted. In most cases data is provided free

⁷ <http://daten.clearingstelle-verkehr.de>

of charge while the main way to obtain the data is by requesting it via e-mail to the indicated correspondent. Figure 4-7 illustrates a snapshot of the DLR Clearing House.

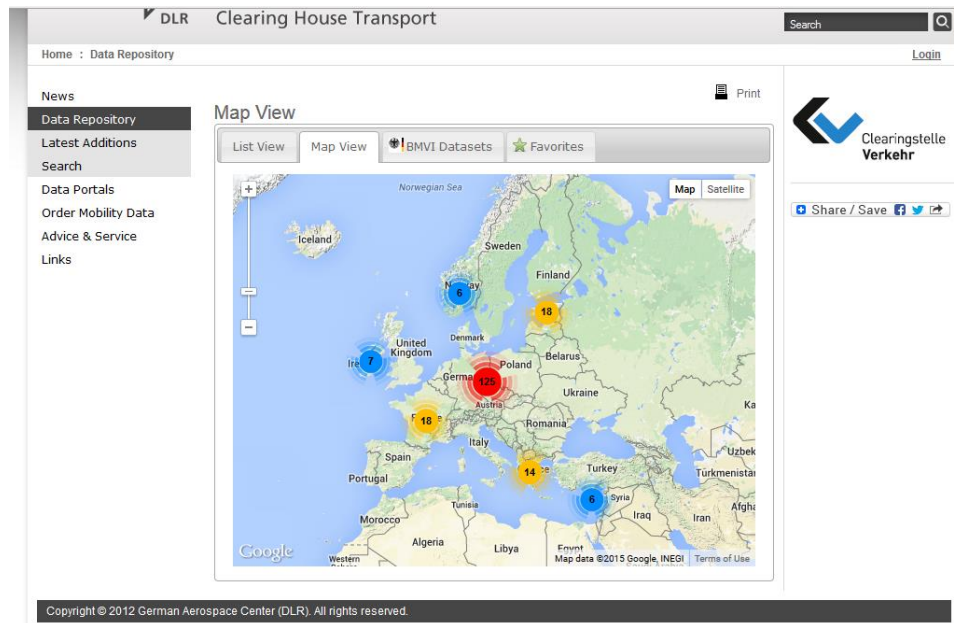


Figure 4-7. A snapshot of DLR Clearing House (Source: DLR)

4.3.3 Example of private sector probe data: Tomtom

There are numerous private sector initiatives dealing with probe data. This overview is not complete, but summarizes some of the main players. More information can be found in the State of the Art of Probe Data Systems in Europe (Sandford and Paulin, 2013)⁸.

Probe Data has provided TomTom with an innovative method for measuring what is happening on the road and lies at the core of its business model. Probe devices in vehicles, which may be cellular phones, or more commonly GPS devices, provide TomTom this kind of data and help TomTom measure traffic everywhere probe vehicles are travelling. This continuous collection of probe data by the company, has resulted in the creation of one of the most global and uniform traffic datasets in the market.

Specifically, since 2008, trillions of anonymous GPS based measurements have been collected from TomTom GPS users around the world. With over 100 million TomTom GPS navigation devices and apps already in use, and growing every day, the historical traffic information collected in this way gives valuable insight into the traffic situation on the road network throughout any day for the past 7 years.

Historical traffic information is collected by millions of TomTom navigation device users who voluntarily agree to share their anonymous usage statistics. When connecting their GPS device to their computer or when GPS devices are connected to our servers with a connection, these users report data anonymously for each of their journeys. The use of GPS only ensures accurate positioning following the accuracy given by GPS (+/- 10 meter). This database is primarily filled with information from passenger cars as opposed to delivery fleets or goods vehicles. This means that the TomTom Historic

⁸ <http://fot-net.eu/literature-study-on-the-state-of-the-art-of-probe-data-systems-in-europe/>

traffic database provides a clear picture of the traffic—unrestricted by speed limiters or heavy goods movement or delivery patterns.

In order to generate aggregated products and services, TomTom follows the following steps:

- The collected GPS data is extracted from the historical database and transformed into routes. These routes can be defined due to the fact that each trip has its own and unique identification code during the trip. Based on this unique identifier it is possible to match all of the stored GPS Points together in a route.
- The following step is to match the routes to the digital map whereby TomTom follows certain location referencing steps. This location referencing is focused on identifying all relevant entry and exit points
- The third step is to match all of the trips in the historical database with the specified product.

Historical traffic is made available to governments and enterprises via the TomTom Traffic Stats web portal. Services and products based on the wealth of our historical traffic probe data include speed profiles, custom area analysis and custom travel times. The TomTom Traffic Stats portal, which is also based on this extensive probe data set, offers governments and enterprises access to the largest historic traffic database in the world via an easy-to-use web portal. They can measure location accessibility for site selection, identify road network bottlenecks and noise emission hotspots, perform before and after studies relating to infrastructure changes or analyses intersection design and performance.

All services and products emanating from the TomTom Historic traffic database are based on TomTom created content listed in Figure 4-8. Table 4-7 summarizes private sector data products and services in Europe.

Name	Country
AnachB	AT
Coyote	FR
Infoblu	IT
Sanef	FR
Be-mobile	B
AROBS	RO
Infotrip	GR
AMV	A
Nokia HERE	FIN
Google Maps	US
TomTom HD live	NL
Waze	US

Figure 4-8. Content in TomTom Traffic Database (Source: TomTom)

Table 4-7. Summary of Private Sector Data Products and Services in Europe

	INRIX	here	TomTom	Waze
Data Available [a]	S, TT, I, Q	S, TT, I, Q, V (portion of network)	S, TT, I, Q	S, TT, I
Services Available [b]	D, A	D, A	RD, A, PM	D
Data Source [c, d]	State installed sensors, commercial fleets, consumer GPS	State installed sensors, commercial fleets, consumer GPS	Consumer GPS, Fleet GPS	GPS enabled cell phones
Aggregation Levels for Historical Usage	15-60 minutes	15 minutes	1 hour	Unknown
Accuracy Checks Performed	Independently verified in large-scale testing	Data checks prior to map matching. Comprehensive drive testing.	Data checks prior to map matching.	Traveler verifies accuracy and reports anomalies with travel times and maps.
Documented Quality Levels	Accuracy above 95% Availability above 99.9%	None provided.	None provided. Stated they meet section 511 requirements.	None provided.
Pricing	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.	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.

4.4 Comparison of Probe Data

This section compares the characteristics of probe data generated by connected vehicle systems in the US and ETC2.0 in Japan. Table 4-8 specifically compares SAE J2735 BSM Part 1, elements of SAE J2735 Probe Data Message that are common to BSM Part 1, and ETC2.0 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 4-8 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 ETC2.0 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 4-9 provides a summary comparison of the data elements included in BSM Part 1, Probe Data Message, and ETC2.0 probe data.

Note that this comparison effort was completed before the European team joined the work group, so only the probe data in the US and Japan are included in the table.

Table 4-8. Comparison of Probe Data Generated by Connected Vehicle Systems and ETC2.0

Probe Data Elements	BSM 1 [a]- Data Generation Frequency	PDM [b] - Data Generation Frequency [c]	ETC2.0 [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ETC2.0 – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ETC2.0 – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ETC2.0 – 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
Latitude	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	No	See corresponding entry	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]	ETC2.0 [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ETC2.0 – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ETC2.0 – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ETC2.0 – Unit
		“Time Stamp”			for “Time Stamp”							
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
Brake system status (Brake applied, traction)	See corresponding entry for “Time Stamp”	See corresponding entry for	Not available	No	See corresponding entry	Not available	See corresponding entry for “Time Stamp”	See corresponding entry for “Time Stamp”	Not available	See note [k]	See note [k]	Not available

Probe Data Elements	BSM 1 [a]- Data Generation Frequency	PDM [b] - Data Generation Frequency [c]	ETC2.0 [d]- Data Generation Frequency [e]	BSM 1 - In Vehicle Storage	PDM - In Vehicle Storage	ETC2.0 – In Vehicle Storage	BSM 1 - Data Transmission Frequency	PDM - Data Transmission Frequency	ETC2.0 – Data Transmission Frequency	BSM 1 - Unit	PDM - Unit	ETC2.0 – Unit
control, stability control, ABS, brake boost, auxiliary brake)		“Time Stamp”			for “Time Stamp”							
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

Note: This comparison effort was conducted in 2013.

[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] ETC2.0 (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 4-9. Summary Comparison of Data Elements in J2735 BSM Part 1, J2735 Probe Data, and ETC2.0 Probe Data

Data Elements	US		Japan- ETC2.0
	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)	✓	✓	

Note: This comparison effort was conducted in 2013.

5 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.

5.1 Candidate list proposed by USDOT

This section summarizes six high-priority bundles of applications identified by USDOT's Dynamic mobility Applications (DMA) Program, three transformative concepts identified by USDOT's Applications for the Environment: Real-Time Information Synthesis (AERIS) Program, and four concepts proposed by USDOT's Road Weather Management Program.

5.1.1 High-Priority Mobility Bundles Proposed by USDOT

The DMA Program identified, with input from stakeholders, six high-priority bundles of applications [70] 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.

5.1.1.1 *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, 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 were used without supplementary data to provide comprehensive picture of the travel conditions.

5.1.1.2 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, 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).

5.1.1.3 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, 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.

5.1.1.4 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, 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, 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:

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

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

5.1.1.5 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, 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.

5.1.1.6 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, 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.

5.1.2 Transformative Environmental Applications Proposed by USDOT

The AERIS Program identified three transformative concepts [71] 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.

5.1.2.1 *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.

5.1.2.2 *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.

5.1.2.3 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 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.

5.1.3 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) [72].

5.1.3.1 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 [72]. 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.

5.1.3.2 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.

5.1.3.3 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 [72]. 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.

5.1.3.4 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.

5.2 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 5-1 and Table 5-2, probe data are being used in actual road administration, and practical research is also being promoted.

Table 5-1. 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 time 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)

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

Use Level	Applications	Specific Uses
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 (origin0destination 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	Examples of sue in assisting analysis of detours in the event of a disaster

Table 5-2. Candidates for Probe Data-enabled Applications (Source: MLIT)

Use Level	Candidates Applications
Level 3 Possibilities for future	Advanced congestion length survey
	Advanced origin-destination survey
	Identifying congestion-prone locations
	Determining traffic conditions on community roads
	support of detection of obstacles or stopped vehicles on roads
	Support for monitoring passage of special vehicles and vehicles loaded with hazardous substances
	Deterring 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

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

5.2.1.1 *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 5-1 [73] and Figure 5-2 [74] 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 5-1 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 5-2 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.

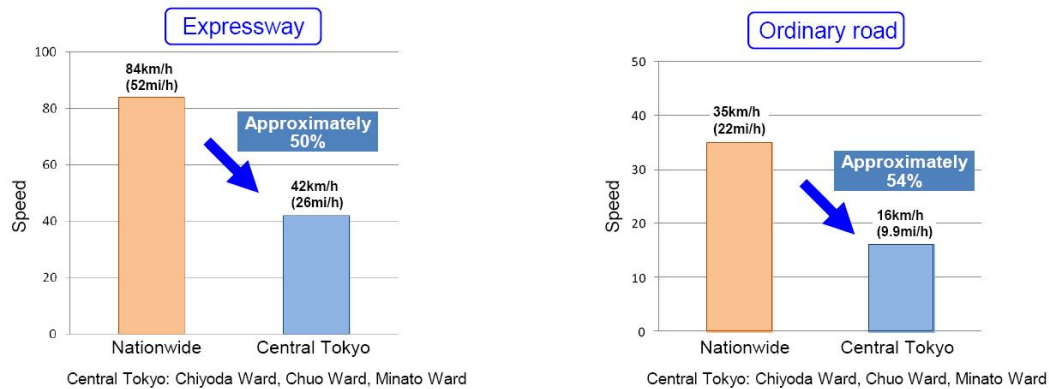


Figure 5-1. Comparison of average travel speed on major roads nationwide and in central Tokyo (Source: MLIT)

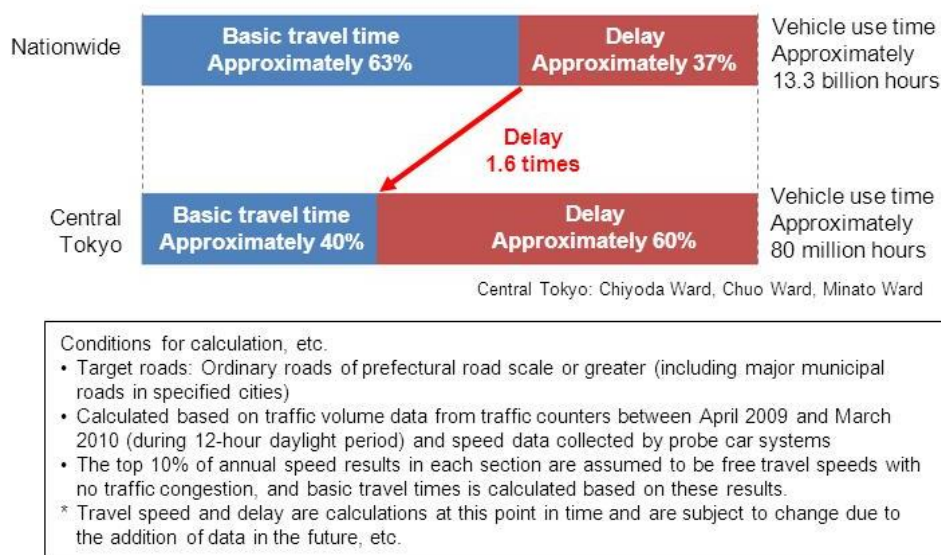


Figure 5-2. Proportion of automobile use delay due to traffic congestion nationwide and in central Tokyo (Source: MLIT)

5.2.1.2 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 5-3 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 5-4 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.

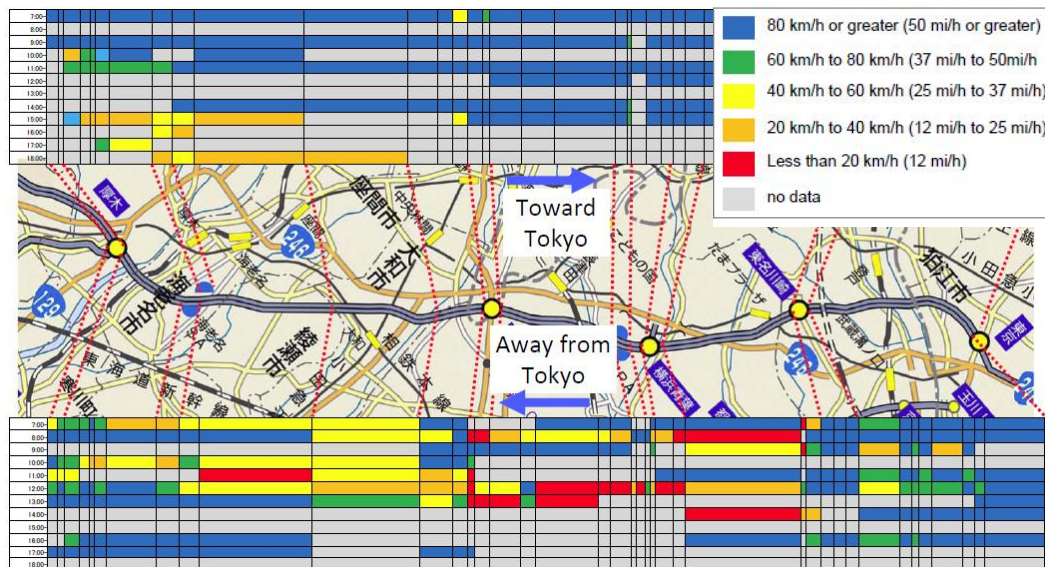


Figure 5-3. Average travel time per time period between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT)

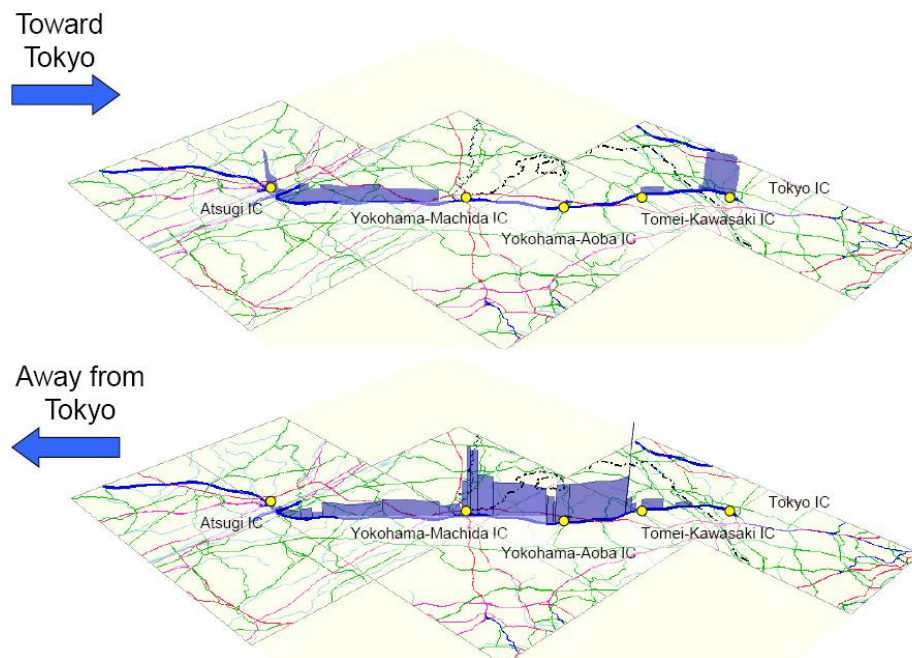


Figure 5-4. Delay due to traffic congestion between Atsugi IC and Tokyo IC on the Tomei Expressway (April 29-May 8, 2011) (Source: MLIT)

5.2.1.3 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 5-5 [75] 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).

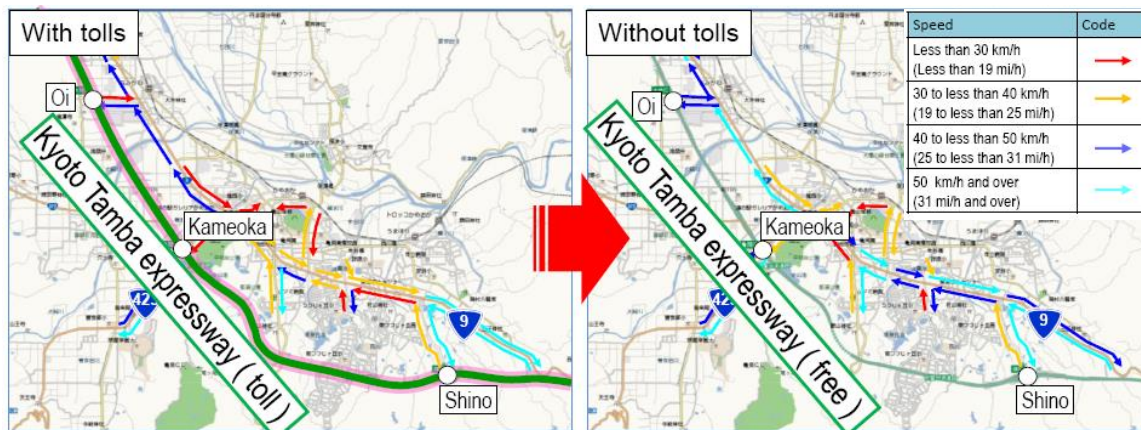


Figure 5-5. Comparison of average speed on secondary roads before and after social experiment of eliminating tolls on the Kyoto Tamba Expressway (Source: MLIT)

Figure 5-6 shows the result of impact survey conducted by NILIM in spring of 2015. The result indicates that a newly developed section on the Tokyo Metropolitan Expressway has realized shorter and more reliable travel time between two important points in Tokyo, namely Tokyo-Haneda airport and Shinjuku having Tokyo metropolitan government headquarters.

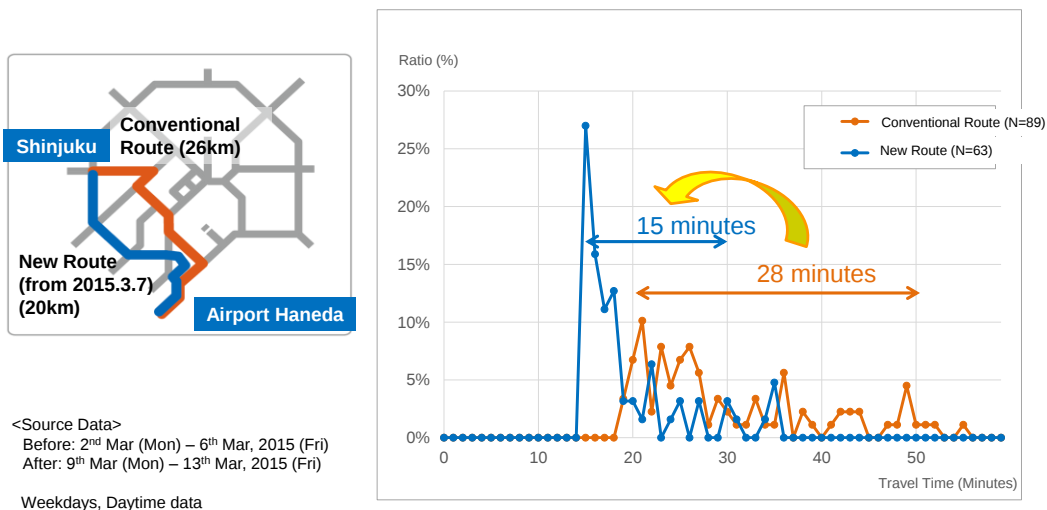


Figure 5-6. Impact Analysis of a New Urban Expressway in Tokyo (Source: NILIM)

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

5.2.1.4 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 5-7) [76].

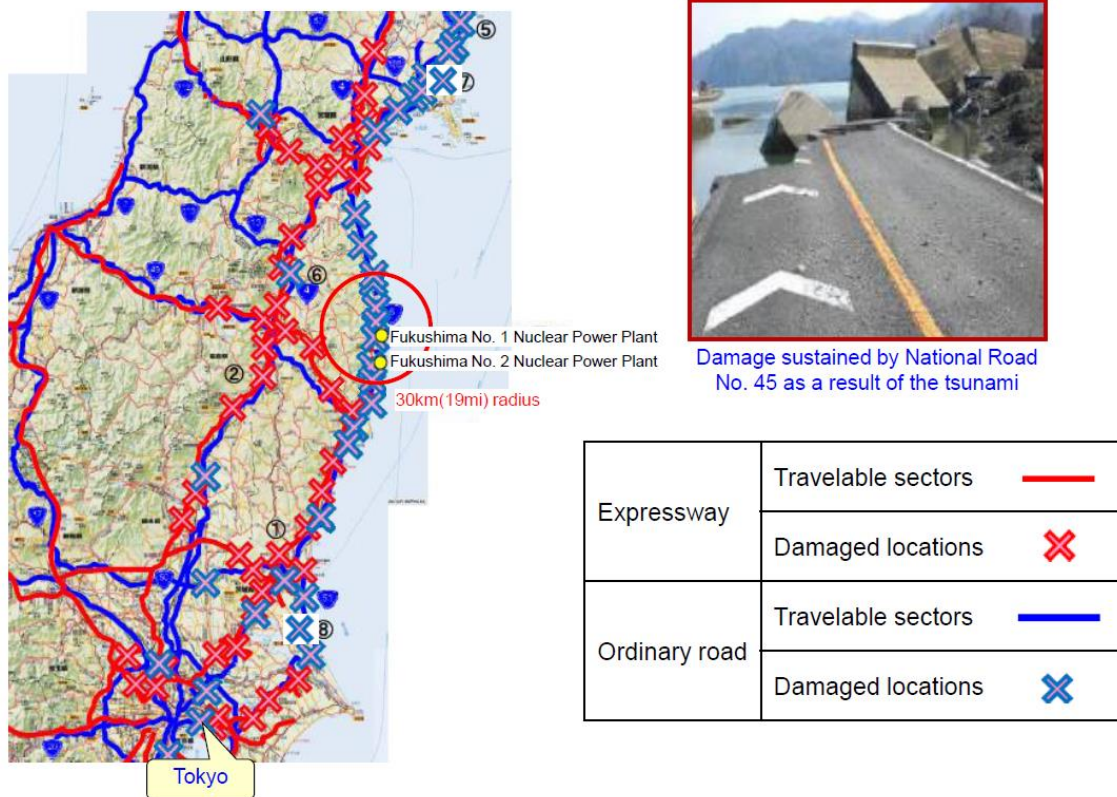


Figure 5-7. Sectors closed to traffic as a result of the Great East Japan Earthquake (Source: MLIT)

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 5-8, 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 [77].

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 5-8. Map of information on roads usable by automobiles (Source: ITS Japan) [76]

5.2.2 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.

5.2.2.1 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 5-9 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 ETC2.0-compatible car navigation systems become more and more popular, it is anticipated that such locations will be collected on ordinary roads as well.

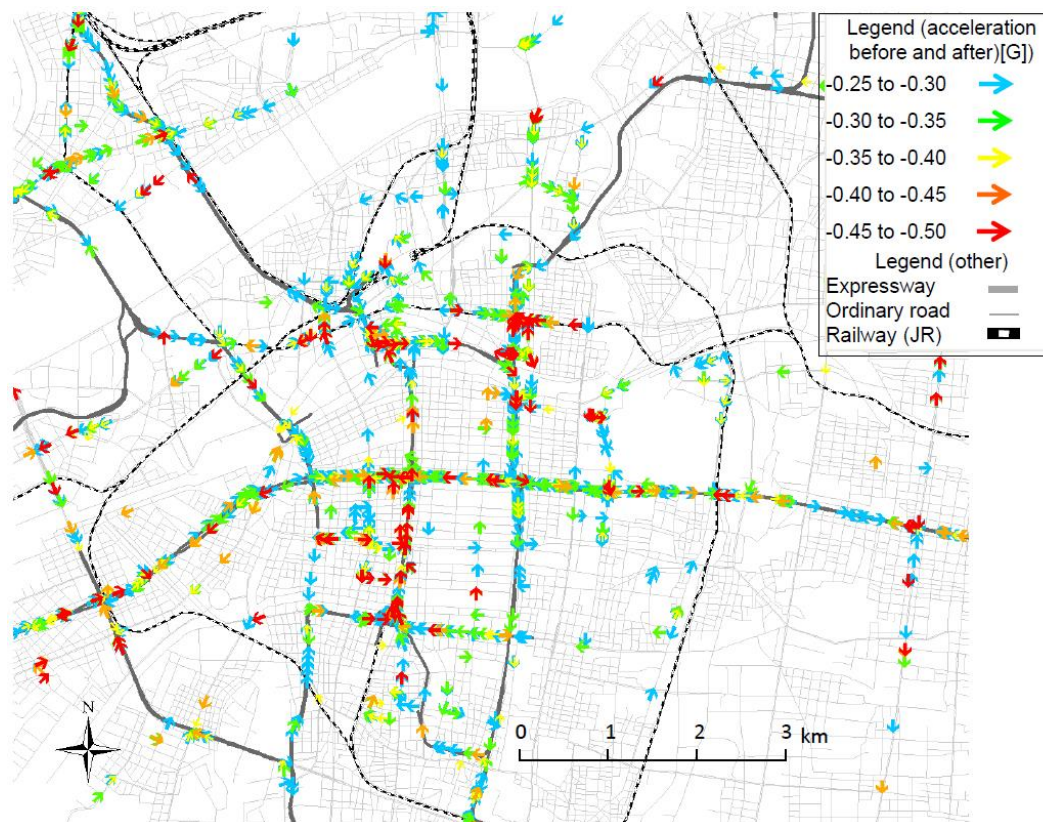


Figure 5-9. Collection of behavior records (acceleration before and after) in central Osaka (Source: MLIT)

5.2.2.2 Determining Route Data (Origin-Destination data)

Field Operational Test of ETC2.0 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 ETC2.0 roadside units 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 5-10) [78]. 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.

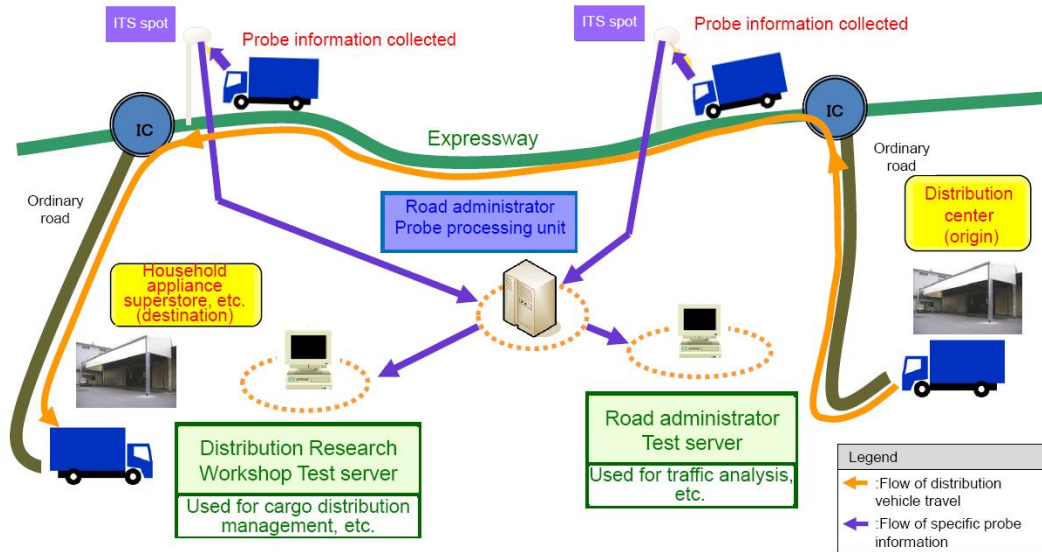


Figure 5-10. Field operational test for assisting distribution operations (Source: MLIT)

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 5-11).

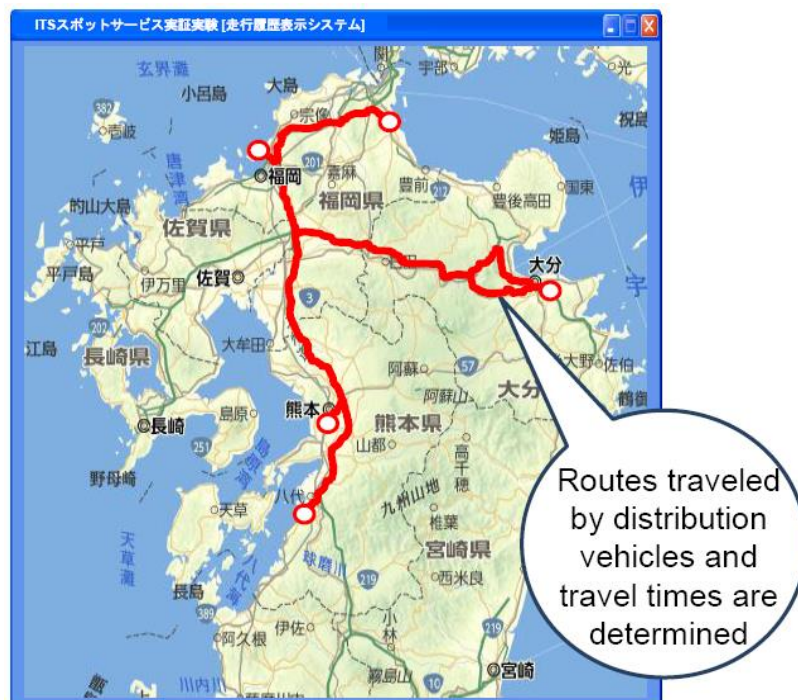


Figure 5-11. Display of routes traveled (Source: MLIT)

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 5-12). This is expected to ensure driving safety and reduce CO2 emissions.

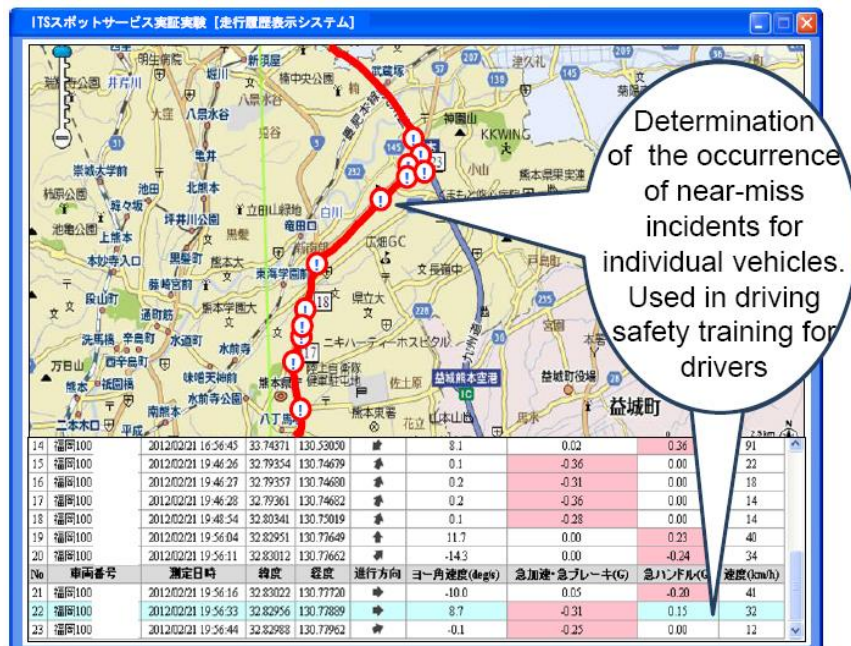


Figure 5-12. Display of status of near-miss incidents and sudden acceleration (Source: MLIT)

5.2.2.3 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 5-13 [79] 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.

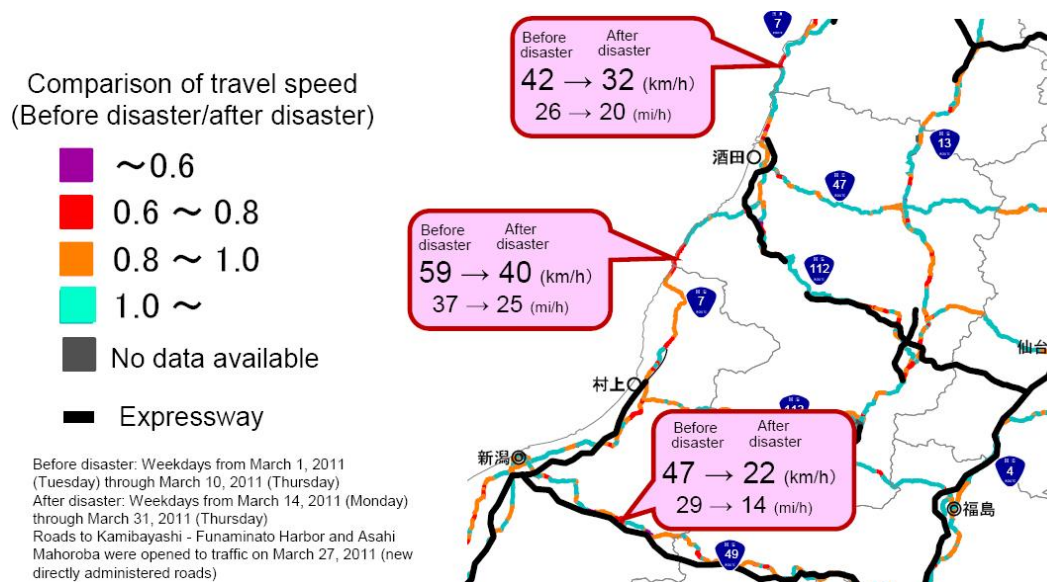


Figure 5-13. Status of traffic on major roads on the Japan Sea side that functioned as detours at the time of the Great East Japan Earthquake (Source: MLIT)

5.2.3 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.

5.3 Consolidated list of candidate applications

Table 5-3 shows a consolidated list of applications that are currently of interest to USDOT and MLIT, and are potential candidate applications for future collaboration.

Table 5-3. 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		✓

6 Prioritized Probe Data-Enabled Applications

This chapter prioritizes the 19 applications identified in Section 5.3, and identifies three applications for future collaboration on further research and development or deployment.

6.1 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

6.2 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.

6.3 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 the previous chapter. Prioritizations were done using the criteria specified in Section 5.1:

- 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.

7 Assessment of Three Priority Applications and Identification of Issues for Practical Implementation

This Section documents an assessment of the three high-priority applications: Traffic Management Measures Estimation, Dynamic Speed Harmonization, and Operational Maintenance Decision Support Systems. Each application is defined, expected benefits are discussed, and then examples of deployments or tests from around the world are provided. In addition, challenges and issues associated with the specific application are discussed (cross-cutting challenges and issues are covered in Section 8).

7.1 Traffic Management Measures Estimation Application

7.1.1 Purpose

The traffic management measures estimation application uses probe data as input to estimate key traffic operations performance measures. The scope includes real-time and near real-time applications as well as applications that use archived historical data.

7.1.2 Application Summary

Figure 7-1 provides a graphical illustration of the application concept. Data from vehicles, including speed, location, time stamp, and heading/direction, and possibly ancillary data from the vehicle such as hard braking events, lights and wiper status are collected as well if the equipment providing the probe data has access to information from the vehicle's CANbus. Some additional data such as vehicle length/width may also be collected. Travel data from all vehicles that drive through a road section are aggregated for the section and processed to estimate measures. Fundamental measures include section travel time, speed, and delay (congestion level). In addition, locations of bottlenecks, evolution and causes of frequent congestion (e.g., at a lane drop), and locations with frequent hazardous events (e.g., hard braking) and shockwaves may also be observed.

The system may also anonymize and aggregate origin and destination data to generate data for planning purposes, such as Origin-Destination matrices. This is most likely to occur on a voluntary "opt-in" basis in order to protect privacy.

Public authorities have an interest in issuing Key Performance Indicators (KPI) for the traffic conditions in the road network, focusing on congestion. The KPI's could include number of hours with congestion, socio-economic calculation of the total delay in vehicle hours for all travelers, variability of travel times on certain sections of the road network, etc.

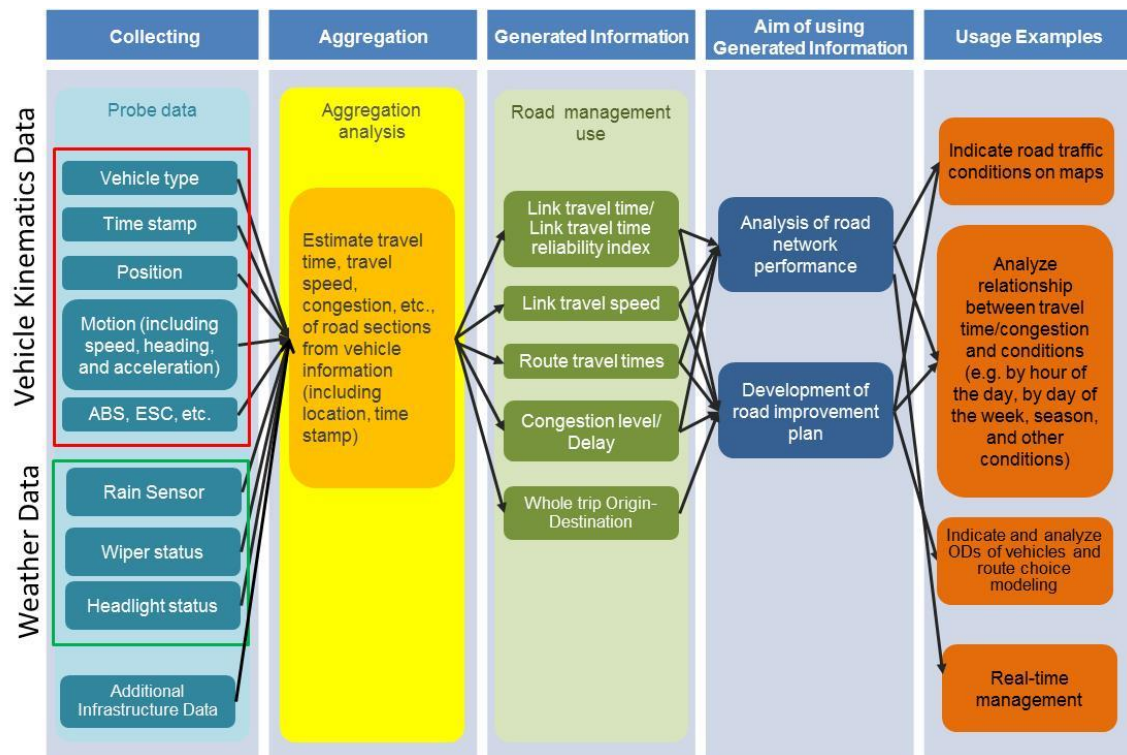


Figure 7-1. Traffic Management Measures Estimation Application Concept (Source: USDOT)

(Figure is illustrative, not all possible data parameters are shown)

7.1.2.1 Data Needs

Probe data needs are shown graphically in column 1 of Figure 7-1 and listed below in Table 7-1⁹. The figure and table list both required and desired data elements. Not all elements shown are required to implement a version of this application. Only time stamp, location, speed, and heading are essential. The other data provides additional information which may be useful. For example, wiper status and lights status may provide input to help correlate variations in speeds with external events, such as rain storms. As shown in Table 7-1, some of the data will be generated and sent periodically at regular, pre-set intervals, while others are event-driven. For some applications that don't require real-time or near real-time data, the data can be stored locally on the vehicles and sent later, e.g., when a known Wi-Fi hotspot is detected.

The minimum required frequency for probe updates may be based on distance traveled, time, or a combination of the two. The minimum required update frequency is being established through testing and deployment and will be agreed upon through the standards development process.

Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., a state change, or when a value exceeds a specific threshold. Examples of event-triggers are: vehicle heading/direction changes; vehicle starts and stops; hard braking occurs; light and windshield wiper status change; Anti-lock braking system (ABS), traction control system, and hazard lights are active;

⁹ Table 7-1, Table 7-2, and Table 7-3 are based upon information in Vehicle Information Exchange Needs for Mobility Applications, Version 3.0 (10), with modifications based upon discussions of the trilateral working group on probe data.

airbag is deployed, or the vehicle is disabled. These are just example of event-triggered messages and the list may grow over time.

Data may be sent as it is generated, or it may be temporarily stored in the vehicle, with multiple reports bundled and sent less frequently.

It is important to combine the data with the infrastructure sensor data as they offer complementary information that helps to derive key performance indicators. An example is the Socio-economic estimation of level of service, or reliability in travel time estimation.

Table 7-1. Desired Probe Data Elements for Traffic Management Measures Estimation

Data Element	Source	Exchange Type
Motion (includes speed, heading, and acceleration)*	All vehicles	Periodic
Position (local 3D)*	All vehicles	Periodic
Time Stamp*	All vehicles	Periodic
Antilock Brake System active over 100 msec	All vehicles	Event Driven
Exterior lights (status)	All vehicles	Periodic
Lights changed	All vehicles	Event Driven
Stability Control activation	All vehicle	Event Driven
Hard braking	All vehicle	Event Driven
Rain sensor	All vehicles	Periodic
Road coefficient of friction	All vehicles	Periodic**
Traction Control System active over 100 msec	All vehicles	Event Driven
Weight	All vehicles	Periodic
Wiper status	All vehicles	Periodic
Wipers changed	All vehicles	Event Driven

* These are the minimum required data elements for implementing Traffic Management Measures Estimation

** An accurate method of measuring this parameter in standard vehicles has not yet been found

7.1.2.2 Communication Needs

Probe data from vehicles may be communicated by short range communications (e.g., DSRC), longer range communication (e.g., IP-based cellular) or using opportunistic connections such as home or available en-route Wi-Fi (for applications that don't require near real-time data). There is no specific need to use DSRC for this application, although DSRC can meet all needs provided roadside DSRC units are deployed along the roadways of interest..

7.1.3 Expected Benefits

Near real-time applications of Traffic Management Measures Estimation will:

- *Increase capability to predict and forecast traffic*, due to availability of comprehensive, accurate, and precise information on traffic state, allowing for the development and implementation of countermeasures for traffic congestion at particular road sections or intersections

Non real-time applications will:

- Improve awareness of traffic network recurring problems and their causes, due to increase 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;
- Improved decision making and Improve design of the road network, increased speed with which the road network problems can be identified and solutions can be provided to decision makers;
- Improve planning and evaluation models, due to increased capability to more accurately estimate origin-destination of traffic demand as well as driver behavior.

7.1.3.1 Use Cases Describing How the Benefits May Be Achieved

Use Case 1: Estimation of travel time along routes

A road management office could aggregate the link travel time of whole road links or obtain it directly through the timestamps of the probe data. The road management office can also identify the congestion area and details of the congestion (congestion patterns including time, date, weather factors and others). This information could reduce the time and cost efforts of road management.

Also, a road management office could plan and implement more appropriate countermeasures for reducing traffic congestion because their aggregation data of link travel time will have much higher accuracy, providing a better understanding of congestion patterns and allowing countermeasures to be applied as congestion is developing.

Use Case 2: Aggregation of origin and destination data

A road management office could investigate more appropriate road network deployment plan and/or city structure plan incorporating the basic traffic patterns information including traffic O-D demand. O-D data does not need to breach personal privacy, since data origins and destinations are aggregated into zones for the generation of the OD matrices. In this case, the road management office could aggregate not only the OD statistical data, but also the demand of driving routes from origins to destinations. This information could reduce time and cost efforts for the road management office as well as increase the reliability of the traffic models.

Use Case 3: Identification of cause of recurring traffic problems

A road management office could use probe data to identify the cause and location of roadway congestion. Road agencies have used probe data to systematically identify where and how recurring road congestion starts (e.g., small delays at exit ramps, and how they gradually impact the flow of traffic in other ramps of a highway junction). A case by case analysis allows one to identify and tackle localized issues (e.g., the timing and phase of a crossing at an exit ramp).

7.1.4 Relevant Examples in the US, Japan, and the EU

In the US, private and public sector probe data have been used to estimate measures such as travel times and delays. The private sector continues to be active in collecting probe data on US roadways to estimate key measures (e.g., INRIX [32], Waze [36], and ALK Technologies [31]). The information calculated using this probe data is often then sold to the public sector, either for one-time analysis or on a subscription basis.

In Japan, ITS Spot probe data has been collected, aggregated and shown as congestion level or travel time according to each section and each hour by MLIT in order to support 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 impact evaluation such as determining current travel measures and comparing travel speed before and after a project; traffic safety measures such as determining travel speed before and after implementing safety measures to reduce speeds; and disaster countermeasures such as monitoring the status or occurrence of congestion on routes affected by a disaster and detour routes in real time when a disaster occurs.

In the EU, most of the studies use conventional road sensor data to derive their Traffic Management Measures Estimation. Some countries like Denmark have been using a limited amount of probe data from volunteer vehicles (mostly commercial fleets delivering the data for free) for exclusive use by the road authority. This enabled new analysis opportunities to improve the design of the network and relatively cheap measures to help identify and solve the source of the problems.

7.1.5 Application Specific Challenges

This section presents some illustrative examples of technical, operational, and institutional challenges faced by the deployment of the Traffic Management Measures Estimation application. In addition to the application-specific challenges listed here, there are common challenges affecting all three applications.

- *Accuracy and freshness of derived and estimated metrics:* In the near term, low market penetration will present a challenge, especially for determining items such as shockwaves, queues, and queue length. It is currently unknown what minimum level of market penetration is required for accuracy or if there is an upper level of market penetration, after which the probe data need only to be sampled.
- *Data coverage.* To get sufficient coverage both with respect to roads covered and coverage during the day and night a certain level of market penetration will be needed.

7.2 Dynamic Speed Harmonization Application

7.2.1 Purpose

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

7.2.2 Application Summary

Figure 7-2 provides a graphical illustration of the application concept. The application concept reflects an operational environment in which speed recommendation decisions are made at an operations center and then communicated to the affected traffic. In such an environment, the speed harmonization application resides within the center or other infrastructure-based entity and is external to the vehicle. 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 ACC, CACC and 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 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.
- 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.
- 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. The recommendation could be transmitted, after validation by the driver, to the speed limiter or cruise control system of the vehicle. In addition, motives for speed harmonization (e.g., presence of shockwave, wet pavement, poor visibility, work zones) may also be provided to improve compliance.

A similar application is Variable Speed Limits (VSL), where a similar approach can be used, but the public agency modifies the legally enforceable speed limit rather than providing non-mandatory recommendations. A mechanism to inform all drivers, not just those equipped with V2I communications, would be needed for this application. VSL is considered a distinctly potential application, and is outside of the defined scope of the speed harmonization application.

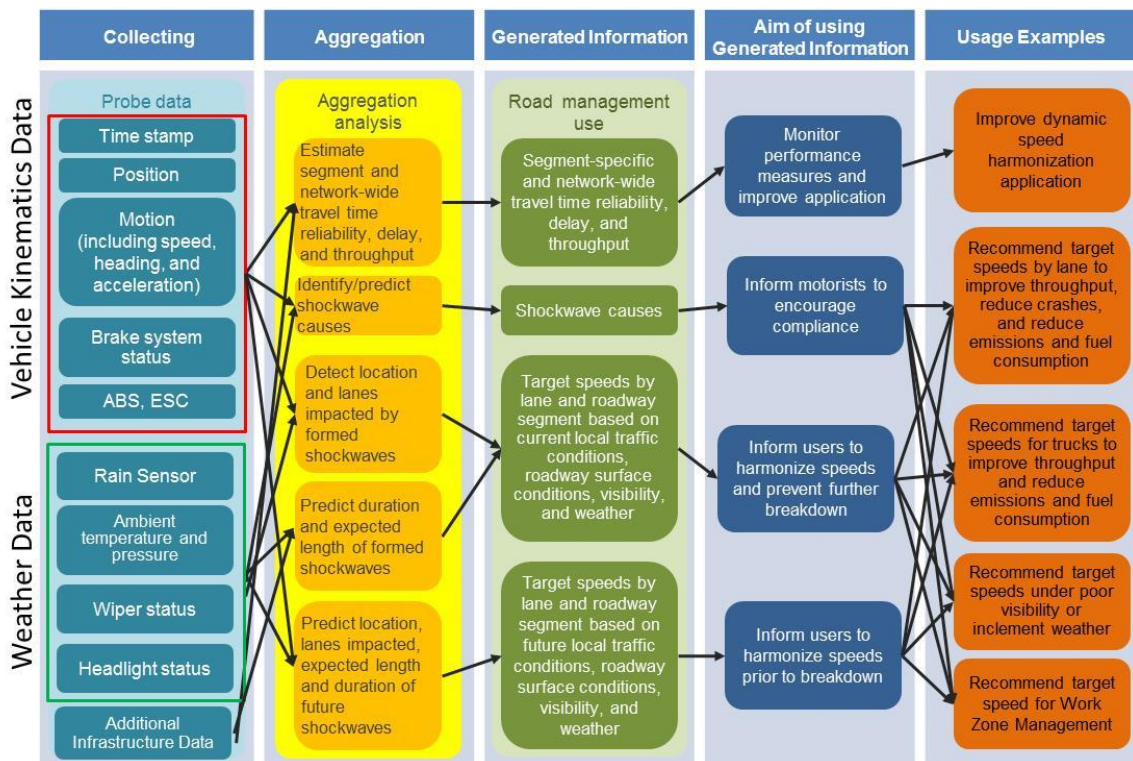


Figure 7-2. Dynamic Speed Harmonization Application Concept (Source: USDOT)

(Figure is illustrative, not all possible data parameters are shown)

7.2.2.1 Data Needs

Data needs from vehicles are shown graphically in Figure 7-2 and listed below in Table 7-2. The figure and table list both required and desired data elements. Not all elements would be required for implementation of Speed Harmonization. For example, rain sensor and wiper status can indicate the presence of precipitation, which may affect the desired speed, but speed harmonization could be successfully implemented without this information. The minimum data set might only include position, motion, and time stamp. As shown in Table 7-2, some of the information will be generated and sent periodically at regular, pre-set intervals, while others are event-driven.

As stated in Section 7.1.2.1, the minimum required frequency for probe updates may be based on distance traveled, time, or a combination of the two. The minimum required update frequency is being established through testing and deployment and will be agreed upon through the standards development process.

Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., a state change such as wipers turning on or off, or when a value exceeds a specific threshold, such as traction control active for more than 100 milliseconds.

Table 7-2. Desired Probe Data Elements for Speed Harmonization

Data Element	Source	Exchange Type
Motion (speed and acceleration)*	All vehicles	Periodic
Position (local 3D)*	All vehicles	Periodic
Time Stamp*	All vehicles	Periodic
Ambient air pressure	All vehicles	Periodic
Ambient air temperature	All vehicles	Periodic
Antilock Brake System active over 100 msec	All vehicles	Event Driven
Brake System status	All vehicles	Periodic
Cargo weight	Freight vehicles	Periodic
Compliance with target speed	All vehicles	Periodic
Current lane	All vehicles	Periodic
Differential wheel speed	All vehicles	TBD
Exterior lights (status)	All vehicles	Periodic
Impact sensor status	All vehicles	Event Driven
Level of brake application	All vehicles	Periodic
Lights changed	All vehicles	Event Driven
Rain sensor	All vehicles	Periodic
Rate of change of steering wheel angle	All vehicles	Periodic
Road coefficient of friction**	All vehicles	Periodic
Stability Control System activation	All vehicles	Event Driven
Traction Control System active over 100 msec	All vehicles	Event Driven
Trailer weight	Freight vehicles	Periodic

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

Data Element	Source	Exchange Type
Vehicle mass	Freight vehicles	Periodic
Wiper status	All vehicles	Periodic
Wipers changed	All vehicles	Event Driven

* These are the minimum required data elements for implementing speed harmonization

** An accurate method of measuring this parameter in standard vehicles has not yet been found

Data Quality Requirements

Some early speed harmonization tests have occurred, but have not focused on the specific requirements for probe data. Additional tests are in the planning stages and these tests will help to define the quality requirements for probe data, including accuracy, resolution, and timeliness. Quantitative estimates for these parameters are not available at this time. At this point in time, the closest related requirements relates to information that may be derived from probe and other data sources, rather than requirements for the probe data itself. Specifically, the INFLO Concept of Operations [80] states that for the Speed Harmonization application, variances in vehicle speeds should be calculated at least every 1-2 minutes, and that calculations every 30 seconds are desirable if there is enough data available to yield statistically significant results.

7.2.2.2 Communication Needs

Probe data for speed harmonization may be communicated from vehicles by either short range communication (e.g., DSRC) or long range communication (e.g., cellular) media. There is no specific need to use DSRC for this application, although DSRC can meet all needs provided roadside DSRC units are deployed along the roadway of interest. Information sent back to vehicles might be sent using point-to-point communications, broadcast communications, or a combination of the two.

7.2.3 Expected Benefits

The application is expected to have the following benefits:

- Enable a service level agreement from the road operator to the road users, such as a guaranteed travel time for vehicles complying with target speed recommendations
- Improved mobility by increasing throughput, improving travel time reliability, and decreasing delays;
- Improved safety by decreasing the number of shockwaves, stop-and-go situations, 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,
 - Managed lanes that include public transit access, and

- Freeway segments under inclement weather, poor visibility or low pavement friction conditions.
- Freeway segments experiencing major incidents, special events, or emergencies

Use Cases Describing How the Benefits May Be Achieved

Use Case 1: Providing much smoother traffic conditions (to drivers)

Drivers could drive their vehicles faster and smoother. This enables a reduced average travel time for the road sections.

Use Case 2: Providing much smoother traffic condition (to road management office)

Road management office could reduce the traffic congestion and realize high traffic capacity without additional investments for countermeasures including expansion of lanes.

Use Case 3: Provide a Service Level Agreement (SLA) on Managed Lanes

The road operator could provide a guaranteed service level to the vehicles respecting the instructions derived from the speed harmonization application.

7.2.4 Relevant Examples in the US, Japan and the EU

In the US, speed harmonization has been implemented over the past 30 years, 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 deployed. The USDOT has recently initiated several efforts to prototype speed harmonization using probe data, one in combination with queue warning using aftermarket devices, and another in combination with cooperative adaptive cruise control using vehicle-integrated devices.

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 Adaptive Cruise Control ACC-equipped vehicles in accordance with the traffic situation detected by roadside sensors for realizing smooth traffic on expressways including sag sections. Probe data is not utilized in this system at this time; however, there is a possibility for roadside sensors to be replaced with probe data in the future.

In EU, speed harmonization has been implemented in many trans-European roads. Also, section control enforcement proved to be very effective on dense and short sections of the highways where frequent incidents used to occur. The Netherlands have made extensive tests on a 5 km highway between Helmond and Eindhoven (A270). The experiments involving more than 100 volunteer drivers on single lane operation (no lane changes were allowed) showed that even 10% of speed harmonization compliance had a significant effect on the shockwave with rapid damping of the initial disturbance. This effect could be dramatically improved if the ACC of the vehicles were automatically adapting the speed.

7.2.5 Application Specific Challenges

Technical, operational, and institutional challenges that are specific to deploying a speed harmonization application include:

- Integrated approach for determining desired speeds: Multiple types of information and applications can trigger a change in the desired speed for a roadway segment. These include shockwave damping, flow control, adverse weather or road conditions, incidents, and poor

visibility. An integrated approach is needed to calculate the desired speed based on multiple types of information.

- **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. A connection could be made directly with automated cruise control settings, requiring only that the driver accept the recommended speed. It will be important to convey the benefits of compliance to drivers.

7.3 Operational Maintenance Decision Support System Application

7.3.1 Purpose

The purpose of the Operational Maintenance Decision Support System (OMDSS) application is to generate and send improved recommendations relating to road maintenance. This includes winter maintenance activities such as road-surface treatment plans to snow plow operators and drivers of maintenance vehicles by using road-weather data from maintenance and other probe vehicles. It also includes items such as dirt on road, visibility of traffic signs, and pavement.

7.3.2 Application Summary

Figure 7-3 provides a graphical illustration of the application concept. The center collects data in real-time from probe vehicles as well as snow plows and other road-maintenance vehicles. The data are processed to estimate, predict and forecast road-surface conditions. The hazard algorithms perform road hazard assessments of road conditions and weather data. For winter maintenance, three road weather hazard conditions are assessed: 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.

Additional uses include:

- **Hazardous location (black spot) detection:** A “black spot” is a location with a history of serious crashes or other incidents. Probe data could be used to better identify such locations through tracking a history of abnormal behavior such as hard braking or high yaw rates, even in the absence of crash data. This could be used to initiate a thorough analysis of the situation to determine if any roadway changes or countermeasures should be implemented.
- **Distance of visibility in the fog:** Fog detection can be achieved by monitoring the fog light status of probe vehicles. Computer-vision techniques using on-board cameras can estimate the distance of visibility in fog behind the vehicle. Then the aggregation of information from multiple vehicles allows to calculate an estimate of the distance of visibility on a given area or itinerary. This information could also be aggregated with visibility information automatically downloaded from weather stations located at most airfields (e.g. METAR messages).
- **Road surface diagnosis:** Recurring trigger of ABS, ESP and ASR systems on a given location are indices that could be interpreted as warning sign to detect area with reduced skid resistance. However their fusion with meteorological data is necessary to discriminate the

causes: rain, snow, ice or degradation of the surface pavement or combination of both causes.

- Detection of degradation of the surface: the presence in a given location of vehicles subject to abnormal vertical accelerations may indicate road surface degradation like ruts, potholes, ruptures, cracks, causing vertical movements of the car body. The probe vehicle must be equipped with sensors sensitive enough to detect these movements. Recent studies shows that sensors (accelerometers) integrated into some Smartphones have the required sensitivity.

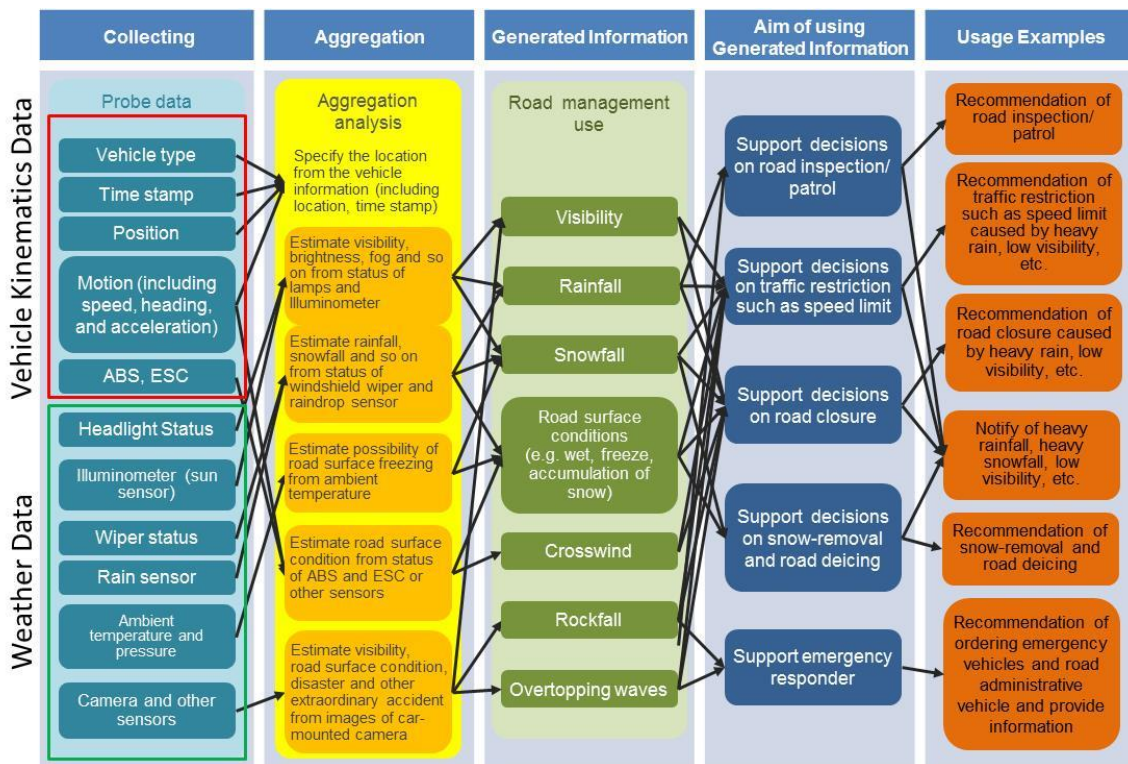


Figure 7-3. Operational Maintenance Decision Support System Application Concept (Source: USDOT)

(Figure is illustrative, not all possible data parameters are shown)

7.3.2.1 Data Needs

Data needs are shown graphically in Figure 7-3 and listed below in Table 7-3. The figure and table list both the required and desired data elements. Not all elements would be required for implementation of the Operational Maintenance Decision Support System application. All of the items shown in column 1 of Figure 7-3 except for the last box on the figure would be expected to be sent from all participating vehicles that are equipped with the required sensors (some vehicles may not have some of the weather-related sensors shown in the figure). In addition, fleet vehicles such as snow plows may be equipped with cameras and/or other special sensors, such as sensors tracking the type and amount of treatment chemicals being applied, but the Operational Maintenance Decision Support application could still function without this additional information. As shown in Table 7-2, some of the information will be generated and sent periodically at regular, pre-set intervals, while others are event-driven.

As stated in Section 7.1.2.1, the minimum required frequency for probe updates may be based on distance traveled, time, or a combination of the two. The minimum required update frequency is being established through testing and deployment and will be agreed upon through the standards development process.

Event-triggered probe data generation may occur due to changes in vehicle status elements, i.e., a state change, or when a value exceeds a specific threshold.

Table 7-3. Desired Probe Data Elements for Operational Maintenance Decision Support Systems

Data Element	Source	Exchange Type
Ambient air temperature*	All vehicles	Periodic
Position (local 3D)*	All vehicles	Periodic
Ambient air pressure	All vehicles	Periodic
Antilock Brake System active over 100 msec	All vehicles	Event Driven
Brake System status	All vehicles	Periodic
Cameras and other special vehicle and weather-related sensors	Specially equipped maintenance vehicles	Periodic
Cameras for visibility distance estimation	All vehicles with ADAS	Event Driven
Car body vertical movements and acceleration	All vehicles	Event Driven (by thresholds) or Periodic
Exterior lights (status)	All vehicles	Periodic
Lights changed	All vehicles	Event Driven
Illuminometer (Sun sensor)	All vehicles	Periodic
Motion (speed and longitudinal and lateral acceleration)	All vehicles	Periodic
Rain sensor	All vehicles	Periodic
Rate of change of steering wheel angle	All vehicles	Periodic
Road coefficient of friction	All vehicles	Periodic**
Stability Control System active	All vehicles	Event Driven
Time Stamp	All vehicles	Periodic
Traction Control System active over 100 msec	All vehicles	Event Driven
Vehicle Type	Fleet Vehicles	Periodic
Wiper status	All vehicles	Periodic
Wipers changed	All vehicles	Event Driven

* These are the minimum required data elements for implementing Operational Maintenance Decision Support Systems

** An accurate method of measuring this parameter in standard vehicles has not yet been found

Data Quality Requirements

Operational Maintenance Decision Support System tests are in the planning stages and these tests will help to define the quality requirements for probe data, including accuracy, resolution, and timeliness. Quantitative estimates for these parameters are not available at this time.

7.3.2.2 Communication Needs

Probe data from vehicles may be communicated via short range communication (DSRC), long range cellular data, or, for maintenance fleet vehicles dedicated long range radio data communications operated by the transportation agency. There is no specific need to use DSRC for this application, although DSRC can meet all needs provided roadside DSRC units are deployed along the roadway of interest. Information sent back to fleet maintenance vehicles might be sent using DSRC, commercial cellular data, or dedicated radio networks operated by the transportation agency.

7.3.3 Expected Benefits

This section presents the expected benefits of the application that makes use of probe data. Operational Maintenance Decision Support System applications that make 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;
- Provide prompt closure of roads due to low visibility or heavy rainfall or snowfall.
- Provide the road network operator with alert on possible hazardous locations (black spots) or inadequate speed limits,
- Optimize costs for road maintenance by reducing road service patrol vehicles usage to detect road degradation, e.g. roughness, potholes, ruts etc.

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.
- Improve ride quality and perception of comfort

Use Cases Describing How the Benefits May Be Achieved

Use Case 1: Higher road service level

Road management office could provide the higher road service level by operating high level maintenance including snow plow and improving pavement.

Use Case 2: Reducing time and cost for monitoring road conditions

If a road maintenance office uses probe data, they could monitor the pavement condition or road surface condition of the whole road network for which they are responsible. Currently, most of the road

maintenance offices need to monitor their road surface by driving their patrol vehicles or using infrastructure cameras, which provide limited coverage due to time and space constraints.

Use Case 3: Reducing time and cost for maintenance

If road maintenance office uses probe data, they could optimize their road maintenance teams operation for snow plow and other maintenance. This optimization reduces time and cost to the road management office.

7.3.4 Relevant Examples in the US, Japan and the EU

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. The traditional MDSS acquires data from fixed and remote sensors. The USDOT has partnered with Michigan, Minnesota, and Nevada departments of transportation to prototype and test the Enhanced-MDSS, which focuses on winter weather applications and incorporates mobile observations as another source of input data. This project is expected to be completed in the spring of 2015.

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.

Across Europe, many research programs, projects and commercial applications aim at improving road maintenance by means of probe vehicle data. One of the largest projects is the European research project TRIMM (Tomorrow's Road Infrastructure Monitoring and Maintenance), which was funded under the EC 7th Framework program. It will finish by the end of 2014. Work Package 4 (WP4), identifies the key technologies for advanced road monitoring in the areas of safety, structures, and functionality, and tests and develops these into practical techniques that can be implemented on the European network. This involves monitoring road inventory, surface condition, structural condition and road functionality. Among these techniques, an algorithm for identifying rough road sections, i.e. with poor ride quality based on probe data was developed.

Another European example is the project MOBIROMA (Mobile Observation Methods for Road Maintenance Assessments) that aimed to develop, test and evaluate affordable, moderate-cost road condition and performance assessment techniques. Finished in 2013, the output of the project was a web-based maintenance tool based on probe data technology for estimating pavement quality, load bearing capacity and winter road conditions on a road. The tool is available on the project's website (MobiRoma.eu). The project addressed an important issue in Nordic countries, namely the lack of monitoring data for gravel roads. There is a follow-up project running in Sweden, making use of 50 postal cars for data collection, proving that probe data technology has the potential of being a reliable complement to current road monitoring techniques.

A commercial Android-based software application called RoadRoid features an algorithm using the built-in accelerometer signal to estimate the IRI (International Roughness Index). By doing so, road sections with poor pavement condition can be identified and displayed on a map. The road condition data was divided into 4 different levels for visualization: Green for Good, Yellow for Satisfactory, Red for Unsatisfactory and Black for Poor. Research on this software is still ongoing and field tests around the world are being conducted. Similar to RoadRoid, the Austrian Institute of Technology developed a method to identify pavement roughness problems by using wheel speed signals and vertical and longitudinal accelerometer signals collected by probe vehicles. It has been demonstrated that road sections with poor surface condition can be accurately detected.

The ERA-NET Plus (EN Plus) Infravation is a transnational collaboration of 11 countries on road infrastructure innovation. The Infravation 2014 Call was launched on 3rd March 2014, pooling some 9 million Euro, including a one-third top-up of the European Commission (EC). Infravation aims to develop advanced market-ready products and services for road operations, either on the European, North American, national, regional or urban network. One of the call topics is "Rapid and non-destructive methods for routine quality and performance checks of materials and construction", which also involves in-car developments. This is the first time that the US (Federal Highway Administration) has contributed funding to an EN Plus Call.

In France, IFSTTAR developed computer vision algorithm to estimate visibility distance in the fog. Ongoing studies aim to connect visibility distance estimate from probe data to a ground truth. Regarding road diagnosis, research is underway to assess the potential of integrated sensors in a Smartphone. Results are promising and deployments of low cost solutions for pavement degradation detection are expected.

In Sweden, there has been a project called SRIS - Slippery Road Information System, which combined useful probe vehicle data (ESP, ABS, temperature, windshield wipers) and data from road weather stations. Field tests have been performed in 2006/2007 and 2007/2008. The later period covered 100 probe vehicles and 80 road weather stations. The performed field tests showed that collected data was possible to combine in a useful way to get an increased usability of the provided information. There has been a conclusion, that the system gives a very high social economic outcome when compared with the cost for SRIS. Project was ended at 2008 and there is no information of future plans. The project was a cooperation study between Swedish Road Administration, Semcon, Klimator, Logica, Bilia, Caran-Eis, Saab and Combitech. More information is available at: <http://www.sris.nu/>

Volvo, the Swedish Transport Administration, and the Norwegian Public Roads Administration are starting a new project. Volvo has announced, that 50 probe cars would participate in the pilot program, and that the "fleet would grow considerably" for next winter. The sensor data is based on "wheel-slip sensors" and the target is not only to alert road maintenance authorities, but also other cars. More information is available at <http://www.cnet.com/news/volvo-cars-become-road-maintenance-probes/>

In Finland, there are 3 separate probe vehicle studies:

- VTT Technical Research Centre has studied the utilization of heavy vehicle CAN-bus information when detecting slipperiness. The idea of the VTT Grip-project is to compare the speed of driving tires with free rolling front tires in relation to the motor power (all this information can be found already from the CAN-bus). The information achieved could be delivered as well to the driver on board as to the road weather information centers. According to VTT, the system is able to measure friction on the approximate level. VTT is trying to increase the amount of the probe vehicles to 1000 very soon. More tests of the system accuracy will be carried in the winter 2014/15.
- VTT Technical Research Centre has also another probe vehicle project aiming to get information of the road friction. The target is to combine information from roadside units and probe cars. Road side units are cameras, and pictures are analyzed automatically to assess the friction. The probe cars measure air and road surface temperature, ABS/ESP status, 3D accelerations and status of dashboard controls. The project is ongoing. More information is available at http://www.vtt.fi/files/news/2013/12_13092013/session4_p13_road_friction_monitoring_in_intelligent_traffic_system.pdf
- Finnish Transport Agency and TeliaSonera started a probe vehicle study "FCD road weather pilot" in 2012. The vehicle fleet consists of 150 cars operating in the south of Finland. The

ABS and ESP activation of the cars are recognized and information (with GPS-positioning and time stamp) is transferred immediately to the central database. The project is also including the user interface to follow the ABS and ESP observations on the map. The users are traffic center and maintenance operators.

7.3.5 Application-Specific Challenges

Technical, operational, and institutional challenges that are likely when deploying an Operational Maintenance Decision Support System application include:

- **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.
- **Image Processing Capabilities:** The accuracy and reliability of image processing capabilities to identify the roadway conditions captured by the onboard cameras is currently unknown.

8 Cross-Cutting Issues

This section identifies cross-cutting issues common to all three applications described in Section 7. The cross-cutting issues discussed are:

- Data usage and privacy
- Security
- Standards
- Compliance and certification
- Mobile wireless data communications options
- Acquisition, storage, and distribution of data
- Public and private sector roles
- Data quality and meta-data
- Other issues (e.g., operations and maintenance costs, CAN Bus Data Interface, incentives for opt-in applications and services)

This section presents just a preliminary discussion of the cross-cutting issues. Each of the trilateral partners is involved in conducting more in-depth analysis of each of these issues. The subset of topics that will be addressed collectively by the trilateral group is currently being determined.

8.1 Data Usage

Issues related to data usage include permissible uses of probe data, access, usage rights, data protection, and open versus proprietary data sets.

Clear guidelines need to be established for identifying usage rights for probe data and related supporting data. There is debate as to whether this is best handled through the concept of data ownership and licensing or through an alternate model. The question of whom, if anyone, is the owner of data associated with individual vehicles or drivers as well as aggregated data remain as significant issues. Open issues that continue to receive frequent discussion include:

- Who, if anyone, owns what data at the source? What is owned by the vehicle owner? By the driver? By the manufacturer? If there is no owner, what rules exist regarding data access, retention, use, and destruction?
- What are the necessary conditions before the data is transferred to a third party? Are regulations needed to avoid drivers being locked into specific vendors based, for example, on the vehicle manufacturer? Should consumers have a free choice to pick his or her service provider so that it ensures fair aftersales market and supports innovation and a variety of service offers?
- What is the situation if the data is broadcasted to all other vehicles and infrastructure? Who may use this data, and for what purposes?

- Are there lessons to be learned from the Automatic Identification System (AIS) used in maritime transport, and Automatic Dependent Surveillance (ADS) systems in air transport?
- Is there a need to establish widely agreed-upon categories of probe data and categories of purposes, in order to define allowed uses?
- Under what circumstances can data be obtained for use in either criminal or civil procedures?
- Should probe data be used for routine traffic law enforcement?
- To what extent, if any, is international harmonization of rules desirable and feasible

8.2 Data Privacy

Probe Data Collection generates large amounts of data concerning the location and the operation of the vehicle, some of which could be associated with a particular driver or vehicle. As a result, privacy is an important consideration. This is true throughout the world; however attitudes, legislation, and regulations vary. This section separately summarizes the current status of probe privacy thinking and activities in the U.S., Europe, and Japan.

8.2.1 United States

Private information relates to any data emitted, collected, or stored about individuals. A key concept in privacy analysis is Personal Identifiable Information (PII). PII is any information that can be used to distinguish or trace an individual's identity. PII is not specific to any category of information or technology, each case and associated risks must be individually examined for context and the combination of data elements that are provided or obtainable. Example of the types of PII is provided in Table 8-1.

Table 8-1. Types of Personally Identifiable Information (PII)

Type of PII	Definition	Examples
Non-PII	Information that is collected but cannot trace back to an individual	Browser Type, Local Time Zone, Date and Time of Visitor Requests, Device Type, Traffic Counter Information
Potential PII	Data elements that cannot be linked to a specific person until combined with other actual PII	Internet Cookies, IP Addresses, Credit reports
Actual PII	Information that can be used to locate or identify an individual	Names, Addresses, Telephone Numbers, any Identifying Number (e.g., VIN)
Locational PII	Information that can be used to identify an individual at a particular location	License Plate Numbers, GPS Device Location Information
Sensitive PII	PII which, if lost, compromised or disclosed without authorization either alone or with other information, carries a significant risk of economic or physical harm	Medical Records, Social Security Numbers, Bank Account Numbers, Passport Numbers

The USDOT has identified three types of controls that are needed to protect privacy:

- Physical Controls, such as tamper-proof casings

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

- Technical Controls, such as firewalls, access management, and encryption
- Policy Controls, including laws and regulations regarding unauthorized collection, storage, and disclosure of data, as well as voluntary Fair Information Practice Principles (FIPPS)

Physical and technical controls are discussed in Section 8.3, Security. This section discusses policy controls.

The US model regarding privacy protection is typically that industry self-regulates unless and until problems or needs emerge. At that time, new legislation is considered. At present, US Federal laws regarding privacy protection relate to activities of the Federal government (e.g., the Privacy Act of 1974) and to specific domains in the private sector, including health records, cable communications, and state motor vehicle records. There is currently no specific Federal legislation related to probe data systems and connected vehicle systems, however the Federal Trade Commission's Unfair Deceptive Trade Practices regulations apply, as may various state and local laws on privacy. For example, almost all of the 50 states have each established some sort of data breach law that broadly applies to all types of personal information collected by private entities. These laws require disclosure of events that involve the unlawful and unauthorized acquisition of personal information. The particulars of these laws vary from state to state.

A number of voluntary best practices have been developed both by government and industry. These are typically specific to a particular field or domain, and build upon the FIPPS. FIPPS define and provide guidance for implementing protections that address a number of facets of privacy protection, including:

- Transparency
- Individual Participation and Redress
- Purpose Specification
- Data Minimization
- Use Limitation
- Data Quality and Integrity
- Security
- Accountability and Auditing

Public and private sectors best practices guides include:

- Federal Enterprise Architecture Security and Privacy Profile, Version 3.0, developed by the National Institute of Standards and Technology, the Office of Management and Budget, and the Federal Chief Information Officers Council
- Best Practices: Elements of a Federal Privacy Program, produced by the Federal CIO Council
- Best Practices and Guidelines for Location Based Services, developed by CTIA
- Privacy sections of Best Practice Guidelines developed by the App Quality Alliance

Privacy protection related to probe data systems and connected vehicle systems is a very active area of research and analysis. Challenges include addressing the fact that probe data systems and services are operated by private entities and state/local agencies, rather than the Federal government, and are generally regulated on a state-by-state basis. In addition, efforts are looking beyond Federal policy and regulation to create voluntary industry standards.

8.2.2 Europe

Experience in Europe has shown that systems that can track location have been broadly accepted when there are clear advantages to using the system and when the consumers trust service providers to handle their personal data securely and responsibly within an explicit voluntary system. However, unlike the current environment in the U.S., probe data is subject to EU national laws, specifically laws transposing EU Directives 95/46/EC and 2002/58/EC as amended by Directive 2009/136/EU.

Based on 2002/58/EC article 5(3) as amended by 2009/136/EU collecting probe data from a car using a public telecommunications network (including cellular networks or Wi-Fi then relayed over fixed internet services) requires freely given, prior, informed consent in those cases where the probe data is not strictly necessary for the delivery of an information society service explicitly requested by the driver.

Based on 95/46/EC and opinions and judgments from EU Data Protection Authorities (DPAs) the following provisions apply:

- Location data continuously obtained from a car is to be regarded as personal data of a sensitive nature: the only legitimate basis for processing is freely given, prior, informed, unambiguous consent. Other interests or execution of a contract (e.g., through inclusion in terms and conditions of a service or device purchase) are not accepted as legitimate basis.
- Any other probe data elements can only be legitimately processed (including anonymization or pseudo-anonymization) based on one of the criteria from 95/46EU article 7.
- The purposes for the use of probe data need to be explicitly specified before any collection or processing commences and any (further) processing must not be incompatible with those purposes.
- The driver needs to be presented with:
 - Notification of all purposes for which probe data is obtained
 - How long the probe data will be retained (in identifiable form)
 - Who will have access to the probe data and where the probe data will be processed (especially when outside the European Economic Area).
- The notification can be structured in a layered fashion with increasing level of detail, should be presented in the language of the user and be easily accessible and user friendly (i.e. like a user manual, not like a contract or Terms and Conditions)
- Consent needs to be given by the driver, not the owner of the car.
- It is preferred that a clear, standardized visual indication is presented to the driver whenever probe data is collected
- Consent needs to be renewed at least every 12 months for autonomous probe data collection, unless a visual indication is presented to the driver
- When collection and processing is based on consent, the driver needs to be allowed to object to further collection and processing of probe data at any time, preferably in a granular way based on the purposes for collecting and processing.
- The driver needs to be able to exercise his right of access and correction of the probe data collected (as long as they exist in identifiable form).

- Location, speed data and g-force data obtained through probe data should not be kept in identifiable form for a period longer than 24 hours (preferably less and related to trip length), unless a specific purpose strictly requires it. (Note: location data associated with unique IDs or pseudo-IDs is to be considered as identifiable).
- Re-identification or singling-out of contributing drivers from anonymized location/probe data should be prohibited by technical, organizational and contractual means (e.g., by storing strings of location data as uncorrelated trips with a limited time span and allowing use only under strict conditions, enforced through legally binding documents)

Privacy protection remains a topic for further research and analysis within the EU. Key questions include:

- Will existing legislation be sufficient to ensure adequate privacy protection?
- How are instruments such as privacy by design, consent approach, opting-in versus opting-out to be considered in future policy, legislation, and best practices?
- What lessons can be learned from other sectors, e.g. computer, banking or other transport sectors?

Case Study: Private Sector Apps and Devices

This case study provides specific examples of how one European company is addressing privacy needs and requirements.

Notification and consent

The company's Personal Navigation Devices (PNDs), in-dash systems and apps for mobile phones can access the company's location based services, including traffic information services. In this context probe data also is collected. Before enabling delivery of the service in the app or on the device, at first time use an explanation of the use of the data is presented in a multi-layered fashion and unambiguous consent is sought. The consent is renewed every 12 months and on PND and in-dash systems upon language change and after device reset.

Multiple users

On shared systems (PND and in-dash systems) a setting exists which allows the owner of the system to trigger the consent question at each startup of the device/vehicle. The default is to not ask at every start-up in case of an app or PND, as both typically are used by a single user or in a family setting, but the owner can change the default behavior. On in-dash systems the existence of the setting and the default behavior depends on capabilities of the vehicle to identify individual users, e.g. through a key (card) or user profile settings. The company aims to minimize asking consent at every start-up as, dependent on context; it is considered a safety hazard due to potentially conflicting regulations. Also, creating circumstances in which users frequently and routinely click on "OK" will deteriorate the relevance of the explanation and the validity of the consent, so this is to be avoided.

Withdrawing consent

Consent can be withdrawn at any time through a setting in the app or on the device. All off board sending of location data will stop and on PNDs and in-dash systems the cellular connection is shut down in order to not leave spurious location traces in the cellular networks, which could still reveal the users whereabouts. Consequence of withdrawing consent is that traffic information will no longer be available and the user is made aware of this. All other features and functions of the app and device remain available, including navigation using the on-board map.

Collecting and using location data

When switched on with services enabled, the system automatically every few minutes sends its location in order to receive updates to traffic information in its vicinity. In concert, the system also uploads intermediary time stamped location data collected every few seconds since the last upload (probe data).

Pseudonymous and anonymous data analysis is conducted at the company's central servers. Both types of location data processing require prior, informed unambiguous consent and, per Dutch DPA judgment and cannot legitimately be performed (separately or combined) based on "execution of a contract" and/or "legitimate interest". According to the Dutch DPA the per few minute reception of location updates by the company in order to send back traffic information in the context of navigation (already) allows for "an intimate overview of someone's behavior". This requires the unambiguous consent, irrespective of the additional collection and subsequent processing of position information collected ever few seconds. For this reason and because probe data is indispensable for the generation of traffic information requested by the user, no separate or independent consent is sought for probe data in addition to the consent required to deliver location based traffic information.

Using probe data to generate proprietary traffic information

Location (probe) data related to the production and delivery of the company's traffic information is kept together with identifying numbers (such as the IP-address and the unique device identifier (MUID)) no longer than the duration of a trip + max. 20 minutes with an absolute maximum of 24 hours per trip. Trip duration + max. 20 minutes is: from start of access to the service until for a maximum period of 20 minutes no data has been received (e.g. due switching off the car or due to connection failure).

During this period the location (probe) data is kept transient and volatile (in RAM): it is not stored in permanent storage (hard disk, solid state disk). In this way no difficult to erase snapshot or backup copies exist and hence cannot be recovered. No transaction logging (server logging) containing location information is performed as well, to avoid spurious copies of location data to exist.

The unique IDs associated with the device are available to the traffic distribution platform only. Upon egress from the distribution platform, per trip an alias/pseudonym is randomly created at connection set-up to be used in association with location data (probe data) for subsequent use in the generation of traffic information, in which the unique device IDs no longer are used.

The relation (in a lookup table) between unique device ID and alias/pseudonym is broken after trip end by erasing the unique device ID/pseudonym entry from the table, prohibiting re-identification based on alias/pseudonym -> unique device ID. Every 24 hours the accumulated per trip location data is stored to permanent storage, without the alias/pseudonym. The Dutch DPA in its report of finding concluded that these remaining unidentified, time-limited, uncorrelated, per trip location traces do not constitute personal data, except for specific circumstances, such as when from areas with low population density or during nightly hours

The location (probe) data obtained is catenated on a per alias/pseudonym basis and used to generate and improve the company's traffic information service while correlated with the alias/pseudonym. After storing on a per trip basis without pseudonym, the information is used to generate or improve other products and services, such as speed profiles and routes based on actual travel times, reports regarding traffic flows, analysis of origin/destination etc. The data may only be used for these types of purposes and any re-identification or singling out of individual users is prohibited by an internal code of conduct. The data is not disclosed as-is externally to avoid re-identification using advanced analytical methods: only derivatives are disclosed which contain aggregated data or data which otherwise will not allow re-identification of the contributing user from the per trip location trace. The company has strict organizational and operational procedures in place to ensure this. This fully satisfied the Dutch DPA.

Law enforcement requests and e-discovery

The design and implementation of the processing of location (probe) data to align retention periods to the bare minimum required to meet the purpose for processing, has resulted in two important characteristics:

- 1) Probe data at the company exists in an indirectly identifiable and transient fashion only during trip + max. 20 minutes and never longer than 24 hours.
- 2) Speed information, derived from probe data in order to generate their traffic service data, is only available in their systems at the road segment level, not at the device, vehicle or user level.

The consequence is that real-time or historic location or speed information related to a specific, identified vehicle or user cannot be obtained from the company.

8.2.3 Japanese Experience with ITS SPOT

This section specifically discusses the Japanese experience with the ITS SPOT system, which is widely deployed throughout Japan. The ITS SPOT system provides dynamic route guidance, electronic toll collection, and “Assisted Safety Driving” (advanced warning of issues such as an object on the road, congestion behind a blind curve, or hazardous weather ahead. There are currently 1,600 roadside units deployed mainly on tolled expressways and additional 1,500 roadside units will be deployed on national arterial roads, and over 360,000 on-board units are in use. Several mechanisms are used by ITS SPOT to protect privacy:

- Users have the ability to opt out of uploading their data
- Data related to the origin and destination of trips are deleted from the stored records. The amount of data deleted is not specified, but data concerning the first and last 300-1,000 meters of each trip are typically deleted
- Spot services are protected by an advanced security system, as specified in the digital short range communications security platform (DSRC-SPF)
- The probe server converts the vehicle ID (which could be associated with an individual) to an anonymous ID number before storing the data, so that no personally identifiable information is stored.

There are two national laws that relate to privacy and the ITS SPOT system:

- Act on the Protection of Personal Information (Act No. 57 of May 30, 2003). The objective of this law is to protect the rights and interests of individual persons. It provides the basic idea relating to the protection of personal information as well as rules for handling personal information by certain private entities to be observed.
- Act on the Protection of Personal Information Held by Administrative Organs (Act No. 58 of May 30, 2003). The purpose of this Act is to protect the rights and interests of individuals while achieving proper and smooth administrative management by providing for the basic matters concerning the handling of personal information in administrative organs.

A revision of these laws is anticipated to occur within the next few years.

8.3 Security

An integrated approach is needed to address V2I security needs, including those of probe data. Figure 8-1 presents an overview of the types of security attacks that may occur (e.g., masquerading and disclosure), the categories of security services that protect against these threats (e.g., authentication and confidentiality), and the security objectives for the system (confidentiality, availability, integrity, and accountability). Note that confidentiality, availability, and integrity are terms used both for security services and for security objectives.

A comprehensive security assessment for the three applications has not been made, however some examples of threats, impacts, and potential remediation measures have been identified. These are described below.

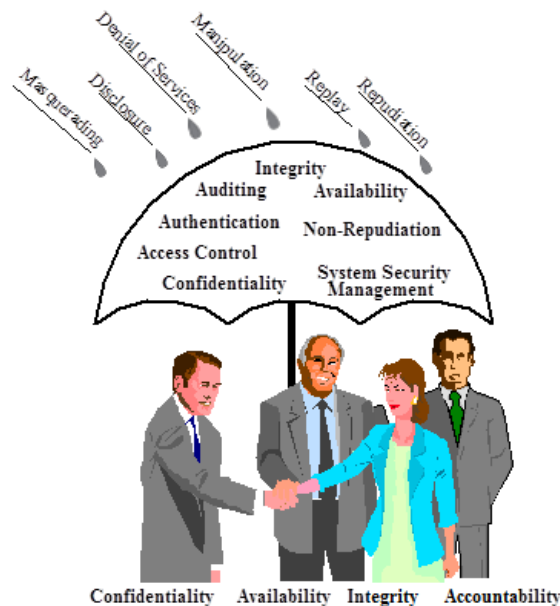


Figure 8-1. Information Security Assessment Components (Source: USDOT)

- Threat 1: Malicious entity might masquerade as an authorized device and manipulate data to deliver unauthorized data. This might confuse drivers due to false information, reduce application effectiveness, divert resources, and reduce confidence in probe data technology and applications. Security measures which would help to address this threat include:
 - Authentication of the sender (verification that the sender is authorized to send that type of information)
 - Encryption of data in a manner to allow for integrity checking.
 - Tamper resistant devices: This measure would make it more difficult to tamper with the internal workings of a device, or to reuse a device that is obtained from an out of service vehicle or other system.
- Threat 2: Malicious entity might intercept or eavesdrop on infrastructure to vehicle communication to acquire private information (e.g., credit card number). This may allow for theft and loss of privacy, and reduce confidence in probe data technologies and applications. A security measure which would help address this threat is encryption of data to provide confidentiality.

The U.S. / E.U. Harmonization Task Group 6 (HTG-6) is addressing gaps related to security management policies and approaches required for the implementation and operational aspects that span the cooperative systems (such as probe data systems and connected vehicle systems) security lifecycle (e.g., production, initialization, commissioning, operations, and end-of-life procedures and policies). This task group's intent is primarily to identify where harmonization is desirable by exploring the advantages and limitations of global versus local security policy alternatives, including economic benefits. HTG-6 task group members are seeking to identify the largest set of common approaches with justification for the benefits for commonality; and to identify those policies and approaches that need to differ regionally and document the reasons for divergence.

8.4 Standards

National, regional, and international standards promote interoperability and reduce the costs associated with providing probe data applications. Major international and national Standards Development Organizations (SDOs) have already standardized and published several standards related to probe data and its applications, however many of these standards are still being finalized and others will be needed. These standards, developed by multiple SDOs, are not always consistent with one another. The EU, 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. The USDOT's Connected Vehicle Reference Implementation Architecture (CVRIA) is investigating the need for modified or additional standards to support US deployment.

The following sections summarize existing standards that are directly related to defining probe messages, directly related to one or more of the three selected applications, or that relate to communications media that may be used to collect probe data.

8.4.1 International Organization for Standardization (ISO)

ISO Technical Committee (TC) 204 is responsible for ITS standards, including standards related to probe data. Probe data work is focused in Working Group 16, sub-working group 4. ISO standards related to probe data and the three selected applications are described below:

ISO 22837- Vehicle Probe Data for Wide Area Communications specifies the architecture and data format for probe messages sent from vehicles. Basic data includes the position data and time data. Other probe data includes vehicle velocity, vehicle direction, head light status, wiper status and other data monitored in vehicles.

ISO 24100:2010 - Intelligent transport systems -- Basic principles for personal data protection in probe vehicle information services specifies data protection and privacy guidelines for service providers who handle personal data in probe vehicle information services.

ISO/TS 25114:2010 - Intelligent transport systems -- Probe data reporting management (PDRM) provides a common framework for defining probe data reporting management (PDRM) messages to facilitate the specification and design of probe vehicle systems and gives concrete definitions of PDRM messages. It also specifies a reference architecture for probe vehicle systems and probe data which incorporates PDRM. It is consistent with and supplements ISO 22837.

ISO/TS 29284:2012 - Intelligent transport systems -- Event-based probe vehicle data specifies the probe data that shall be transmitted in the case that the event has happened, however most of data specified in ISO22837 will be transmitted periodically. ISO 29284 is consistent with, and supplements, ISO 22837.

8.4.2 SAE International

SAE J2735 - Dedicated Short Range Communications (DSRC) Message Set Dictionary defines standard data element and message contents and formatting for V2V and V2I information exchanges used in the U.S. (and which can be used worldwide), including a probe data message. SAE J2735 is fairly mature, however additional updates are expected.

SAE J2945 - Dedicated Short Range Communication (DSRC) Minimum Performance Requirements consists of multiple sections organized by application area (e.g., V2V safety or signalized intersection applications). This family of standards is under development. It will specify the minimum communication performance requirements and the specific SAE J2735 messages and data elements used to support the particular set of applications. For example, J2945-1 represents Basic Safety Message communication minimum performance requirements. A different volume of J2945 will be developed to specify requirements for probe messages associated with the three priority applications.

8.4.3 Institute for Electrical and Electronic Engineering (IEEE)

The IEEE has developed the standards for Dedicated Short Range Communications (DSRC) in the 5.9 GHz band. It is a part of the overall IEEE 802.11 family of standards for wireless Local Area Networks (LANs). These all deal with DSCR communications, not with the contents or syntax of probe messages or any specific applications. However they are included here as probe messages and/or other messages used to support the three applications may use DSRC.

IEEE 802.11p-2010 - IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments is the amendment to the IEEE 802.11 standard that defines the physical and medium access control layers for DSRC.

The IEEE 1609 Family of Standards for Wireless Access in Vehicular Environments (WAVE) defines the architecture, communications model, protocols, security mechanisms, network services, multichannel operation, use of Provider Service Identifiers, and how they work with the physical layer and media access layer defined in IEEE 801.11p. The primary architectural components defined by these standards are the On Board Unit (OBU), Road Side Unit (RSU) and WAVE interface.

8.4.4 ETSI

In ETSI, ETSI TC-ITS has been working for standards development and already published various standards for cooperative ITS. One of these is ETSI TS 102-637-2. This defines the standard message formats that is transmitted by each vehicle OBE in cooperative ITS. Message type includes the Cooperative Awareness Message (CAM) and the Decentralized Environmental Notification Message (DENM), both of which will be used as probe data.

8.4.5 ASTM

ASTM E2665-08 - Standard Specifications for Archiving ITS-Generated Traffic Monitoring Data provides definitions of the data elements to be archived from ITS traffic management systems, their interrelationships, and the procedures and methodologies for collection and calculation of traffic statistics. This standard specifies the rules and definitions for moving that data from the traffic systems to the Archived Data Management System (ADMS). In addition, this standard specifies the logical database schema of the ADMS to support integration of ITS-generated data with conventional traffic

count data. It may be relevant for managing and storing probe vehicle data or data derived from probe vehicle data.

8.4.6 National Transportation Communications for Intelligent Transportation System (NTCIP)

NTCIP is a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. NTCIP standards are developed jointly by the American Association of State Highway and Transportation Organizations, the Institute of Transportation Engineers, and the National Electrical Manufacturers Association.

NTCIP 2306 - Application Profile for XML Message Encoding and Transport in ITS Center-to-Center Communications (C2C XML) provides a mechanism for the implementation of communications interfaces defining the message form, usage and transport protocol used for transmitting information encoded in the eXtensible Markup Language (XML) between centers. It is relevant if eXtensible Markup Language (XML) is used as a coding mechanism for exchanging probe data or probe-related data between centers.

8.4.7 ITS Traffic Management Data Dictionary (TMDD)

The ITS TMDD family of standards was developed to support ITS center-to-center communications to support applications including corridor and arterial management, incident mitigation, and event management. TMDD standardizes the dialogs, message sets, data frames, and data used to exchange data with devices and in the regional sharing of data. TMDD was developed jointly by AASHTO and the ITE. It is relevant for exchanging probe-derived information between centers.

8.5 Compliance and Certification

Both hardware devices and software applications may, in some cases, have voluntary or mandatory requirements to comply with various standards. For example, each region has requirements that radio devices must meet in order to be sold in their respective countries. This creates a need for widely-accepted device and system certification programs to verify compliance. Compliance and certification requirements for systems and applications may vary depending on the safety-related issues associated with the particular uses (e.g., emergency electronic brake lights are likely to have strict performance requirements, whereas traveler information applications may not. Among the issues to consider are the extents to which compliance certification will be required, who will be accredited to conduct compliance certification (e.g., self-certification by providers and/or a requirement for independent certification) and who will grant accreditation to certifying organizations.

8.6 Mobile Wireless Data Communications Options

There are two primary mobile wireless data communications media to consider for collecting probe data: Dedicated Short Range Communications (DSRC) for V2V or V2I communication and commercial cellular IP-based data services for longer range communication. Each has advantages and disadvantage and both are feasible communications approaches for the three applications. Table 8-2 lists each of the three applications studied, briefly describes their communications needs, and assesses the communications options. The "Other Media" column addresses any additional options beyond DSRC and cellular.

Table 8-2. Applicability of Wireless Data Communications Technologies to the Three Applications

Application	Needs	DSRC	Cellular Data	Other Media	Assessment
Traffic Management Measures Estimation Application	Collection of relatively frequent (seconds to minutes) probe data from vehicles	DSRC can meet all needs; however its use requires appreciable market penetration of equipped vehicles as well as deployment of roadside equipment along every roadway of interest.	Cellular data systems are likely to meet all needs, however further study may be required. Cellular networks will need to scale up to handle high data throughput required for probe vehicles.	Not applicable.	DSRC has high capital costs if used throughout a nation's roadway network. Cellular is a potential alternative for general probe data, provided it can scale up to full market penetration. Either cellular or dedicated radio networks could be used to communicate with fleet vehicles, and the best option determined on a local basis.
Speed Harmonization	Collection of relatively frequent (seconds to minutes) probe data from vehicles and dissemination of recommended speeds and rationale back out to vehicles.	DSRC can likely meet all needs, however its use requires deployment of roadside equipment at every location where speed harmonization is provided and widespread market penetration of equipped vehicles	Cellular data systems can likely meet all needs, however at least two areas require further study: 1) can cellular scale up to handle very large market penetrations and 2) will standard commercial deployments of 4G allow for broadcast out of this type of data to help address scalability?	While not applicable to collection, satellite broadcast or FM HD radio could disseminate recommended speeds, as is sometimes done today for speed data	DSRC is well-suited for initial or Spot use, but has high capital costs if used throughout a nation's freeway network. Cellular will likely be a better approach provided it can scale up to support full market penetration.
Operational Maintenance Decision Support System Application	Collection of relatively frequent (seconds to minutes) probe data from vehicles, as well as additional information from fleet maintenance vehicles (e.g., snowplows) and dissemination of treatment plans back to maintenance vehicles	DSRC can likely meet all needs, however its use requires deployment of roadside equipment at every location of interest and equipped vehicles (some applications can be implemented by equipping only the maintenance vehicle fleet)	Cellular data systems can likely meet all needs, however at least one area requires further study: can cellular scale up to handle very large market penetrations of probe vehicles?	Collection and dissemination of information from fleet vehicles could be handled by dedicated radio networks operated by the transportation agency.	DSRC is well-suited for initial or Spot use, but has high capital costs if used throughout a nation's freeway network. Cellular is a potential alternative for general probe data, provided it can scale up to support full market penetration. Either cellular or dedicated radio networks could be used to communicate with fleet vehicles, and the best option determined on a local basis.

8.7 Acquisition, Storage, and Distribution of Data

The best means of collecting vehicle-based probe data and redistributing it to all parties of interest (both public and private) remains both a technical and policy issue. While many applications require real-time or near real-time acquisition, some might work with periodic updates. In addition, the large number of vehicles on roadways will be capable of generating enormous quantities of data. What data should be kept, how to keep it, and where to keep it are all unresolved issues. Some of the data elements are of value to multiple users in both the public and private sector. The best means to collect and distribute this information remains an open issue.

8.8 Public and Private Sector Roles

The various options for the roles to be played by public and private sector entities remain to be determined. In addition, public sector agencies need to know that the benefits will exceed the costs of deploying systems, and also, since they have limited budgets, need to know the most cost-effective mix of probe applications and traditional approaches for addressing specific transportation problems. Private entities need an acceptable return on investment, and both the public and private sector needs to understand what funding models are viable, both politically and financially. Related questions include:

- What services and applications will need public sector support for deployment?
- Are there services which should be accessible to everyone?
- Should the public sector be involved in collecting raw probe data or should it be left completely to the market?
 - Is there a cost associated if the public sector leaves it to the market?
 - How can the public sector be involved in defining needs and ensuring public use of data without discouraging the growth of the private sector
- How can the potential conflicts between public and private objectives be handled, and hence different but compatible business models be implemented?
- Currently, probe data is fragmented, with multiple entities collecting data. How can both public and private entities better coordinate and cooperate to exchange probe data?

8.9 Quality of the Data and Meta-Data

8.9.1 Data Quality

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. Each of these could be used to help establish service level agreements between data providers and data users. Work is underway in both the US and the EU to define the quality requirements for probe data, including accuracy, resolution, and timeliness. At this point in time, more work has been done that relates to information and services that may be derived from probe and other data sources, rather than requirements for the probe data itself. Probe data quality is difficult to measure while the quality of traffic information services could adhere to a number of agreed

indicators. For example, the speed provided average speed provided by traffic information services can be compared with the actual speed of test vehicles.

European Activities Underway

In Europe, the Traveler Information Services Association (TISA) is currently working on defining quality in the context of real time traffic information. TISA has more than 100 members coming from the public and private sectors with an interest and a focus on traffic and traveler information. The Quality Task Force of TISA focuses on defining the minimum quality criteria that should be present in real-time travel and traffic information services in the EU. At the same time, it liaises with EIP (European ITS Platform- successor of EasyWay), a cluster of Public Authorities which is supported by the EU Commission and which focuses on developing a framework which will enhance future ITS harmonization and deployment in Europe.

The EU is focusing on the following aspects in defining Quality in Probe Data [81]:

- Quality should already be present at the raw probe data
- Quality is a very important topic also with regard Traffic services.
 - However it exhibits different characteristics in the two aspects of Traffic Information (data vs services): Real Time Traffic Information Service is a process, with multiple actors and steps and each of the actors has to exhibit quality and each of the steps of this process has to answer to quality requirements:
 - availability of the data;
 - coverage of the area;
 - processing time between content detection and service delivery/presentation;
 - freshness (timeliness)

The above are currently some of the commonly used quality indicators among ITS stakeholders in Europe. All in all, reliability (quality in Traffic data) is difficult to measure while quality on Traffic Services could adhere to a number of agreed indicators. The latter can be measured by comparing the actual speed of the vehicle with the Real Time Traffic Information services. Nonetheless, in the case of Real Time Traffic Information Services, the value-chain has the ability to regulate itself in terms of quality. If there is an identified 'weakness' along the Real Time Traffic Information Services value chain, it gets identified by the actors involved and depending at which step it is along the chain, appropriate corrective action is taken in real time. As quality in Real Time Traffic Information services is competitive advantage, the market does indeed regulate itself, leaving low quality Real Time Traffic Information Service providers at a disadvantage.

U.S. Activities

Over the years there have been several efforts to develop guidelines and requirements for various programs. Voluntary guidelines were developed as early as 2000, with the publishing of Closing the Data Gap: Guidelines for Quality Advanced Traveler Information System (ATIS) Data by ITS America [82] and the U.S. Department of Transportation. More information on U.S. data quality activities can be found in the FHWA's Data Quality White Paper [83].

The U.S., the Code of Federal Regulations, Title 23, part 511, Real-Time System Management Information Program [84], sets mandatory information (not raw probe data) quality requirements for the Interstate Highway System as well as additional state-designated "routes of significance" in urban areas. These requirements include:

- Information accuracy of at least 85%

- Information availability of at least 90%

A number of approaches are currently in use for checking the quality of derived and aggregated information. Spot-checking against ground truth is one such practice, as is done by the I-95 Corridor Coalition of states. Reasonableness and outlier checks are another common practice. This process is used as part of the process used to check data provided under contract to USDOT as part of the Intelligent Transportation Infrastructure Program (ITIP) versus the data quality requirements that have been established for that program.

Japanese Activities

MLIT has studied the usage of private and other non-governmental probe data and they are very interested in the issue of data quality. In these studies, MLIT has confirmed that link travel time or other important traffic data can be calculated by using private and non-government probe data. However, the studies to date have shown that it is difficult or impossible to determine the quality standards associated with each data element for data sets obtained from these sources. This issue also relates to Meta-Data needs, discussed below.

8.9.2 Meta-Data

It is desirable to establish one or more metadata standards for probe and supporting data that would be adopted by public and private sector data providers to increase usability of their data. The USDOT's Metadata Guidelines for the Research Data Exchange [85] [86], although developed for research purposes only, may provide a useful starting point.

8.10 Other Issues

Several other cross-cutting issues have been identified in the course of the working group's activities. These include:

- **Operations and Maintenance Costs:** Adoption and integration of probe data systems will be gradual and uneven, which means that traffic management centers will have to support both legacy systems (for non-enabled vehicles) and probe systems. This will increase the training requirements and the operations and maintenance costs during the transition.
- **CAN Bus Data Interface:** Many of the probe data elements come from the vehicle, and are available over the CAN bus. However, it is desirable to have probe data transmitted by aftermarket and brought-in devices, as well as by built-in systems. Today, the only mechanism for connecting a 3rd party device is by using a vehicle's OBD-II port, which was not intended for this application, and, in addition, many of the parameters are coded using proprietary codes which differ by make, model, and year.
- **Opt-in issues:** There are applications where it would be valuable to have additional information that is not available anonymously, as well as applications that might best work using cellular communications, which is not free to the user. In these cases, it will be necessary to provide some value (not necessarily monetary) to drivers to convince a large enough set to opt in to certain applications and services.

9 Recommended Next Steps

Through the course of its work, the trilateral group identified several issues of mutual interest related to probe data as discussed in this report. The subset of topics that will be addressed collectively by the trilateral group is currently being determined. At this stage, the recommended next steps for future collaboration on probe data include:

- Conducting research on data accuracy and quality for the selected applications discussed in Section 7
- Using actual probe data as input in analysis to address the challenges on data accuracy, processing methods/algorithms, and aggregating/combining probe data with other data.
- Prioritizing and selecting a subset of the cross-cutting “horizontal” issues for more detailed investigation and discussions.

To support these or other collaborative research activities, the trilateral group may use tools beyond those discussed in this report. For example, the USDOT has developed a Trajectory Conversion Analysis (TCA) tool¹⁰ to conduct studies to assess the impacts on traffic measures using probe message modeling. The TCA allows emulated vehicles to generate and transmit Probe Data Messages (PDMs), Basic Safety Messages (BSMs), the European Union’s Cooperative Awareness Messages (CAMs), Japan’s ITS SPOT messages and the prototype Basic Mobility Message (BMM) by either Dedicated Short Range Communication (DSRC) or via cellular and to evaluate. The USDOT is also developing tools to assist with Dynamic Interrogative Data Capture (DIDC), which uses dynamic adjustment of data collection in order to better manage the volume of data collected while meeting all application needs.

These next steps will be assessed and follow up activity determined via continued dialog within the trilateral group.

¹⁰ <http://www.itsforge.net/index.php/community/explore-applications#/38/104>

References

1. Vasudevan, Meenakshy, et al., et al. US-Japan Collaborative Research on Probe Data: Assessment Report. s.l. : Federal Highway Administration, United States Department of Transportation, 2013. FHWA-JPO-13-091.
2. Core System Architecture Document (SAD), Revision C, Prepared by Lockheed Martin for the US Department of Transportation, October 14, 2011.
3. The Connected Vehicle Test Bed Information Brochure, USDOT, August 2012, http://www.its.dot.gov/connected_vehicle/pdf/DOT_CVBrochure.pdf, accessed August 8, 2012.
4. Final Report: Vehicle Infrastructure Integration (VII) Proof of Concept (POC) Test – Executive Summary, Prepared by Booz Allen Hamilton for the US Department of Transportation, February 2009, EDL# 14481.
5. VII Michigan Test Bed Program, Concept of Operations, Prepared by Michigan Department of Transportation, October 2005.
6. Saxton Transportation Operations Laboratory, Prepared by SAIC for USDOT, February 2012.
7. Connected Vehicles for a Connected World, <http://www.its.dot.gov/press/2008/2008TRB/SchagrinTRB2008Pres.htm>, accessed June 20, 2012.
8. Chan, C-Y. “Connected Vehicles In A Connected World: A Perspective from PATH & VITAL,” Presentation at the 2nd International Summit, CVTA, California PATH, UC Berkeley, September 29, 2010.
9. Briefing Slides from VII California Team Meeting, California PATH, UC Berkeley, August 26, 2008.
10. FDOT ITS Program’s General Consultant Connected Vehicle, FDOT, <http://floridait.com/ConnVeh.html>, accessed June 22, 2012.
11. Florida Department of Transportation’s Traffic Engineering and Operations Newsletter, December 2011.
12. Briefing Slides on Florida Intelligent Transportation System SunGuide® Connected Vehicle Subsystem and Data, Florida Department of Transportation, January 5, 2012.
13. Novosad, S., and E. Birriel. FDOT’s 18th World Congress Connected Vehicle Deployment and Beyond, Presented at the 22nd Annual Meeting and Exposition, ITS America, May 2012.
14. New York State Connected Vehicle Test Bed, Presented at the Test Bed Summit, July 19, 2012, Turner Fairbanks, Virginia.
15. Minnesota Connected Vehicle Test Bed, Presented at the Test Bed Summit, July 19, 2012, Turner Fairbanks, Virginia.
16. <http://www.dot.state.mn.us/mileagebaseduserfee/studies.html>, accessed August 9, 2012.

U.S. Department of Transportation
Intelligent Transportation System Joint Program Office

17. <http://www.its.umn.edu/Research/FeaturedStudies/intersections/index.html>, accessed August 9, 2012.
18. MCDOT SMARTDrive Handout, April 2012.
19. MCDOT SMARTDrive Program Demonstration Guide, April 2012.
20. MCDOT SMARTDrive Vehicle Demonstration, <http://www.mcdot.maricopa.gov/news/2012/smartdrive-demonstration.htm>, accessed 23 June 2012.
21. Safety Pilot Program Overview, RITA Intelligent Transportation Systems, USDOT, http://www.its.dot.gov/safety_pilot/index.htm, accessed 20 June 2012.
22. Safety Pilot Model Deployment and Driver Clinics Factsheet, USDOT, http://www.its.dot.gov/factsheets/connected_vehicle_Test_Bed_factsheet.htm, accessed June 18, 2012.
23. Fleet Owner, <http://fleetowner.com/technology/dot-will-pay-truckers-test-connected-vehicle-technology>, accessed 23 June 2012.
24. ITS-Michigan, 2012 ITS America Outstanding State Chapter Award Nomination, <http://statechapter.itsa.wikispaces.net/file/view/2012%20best%20chapter%20nomination.pdf>, accessed 23 June 2012.
25. Cronin, B. "Connected Vehicle Update," ITS Committee Meeting, January 25, 2012.
26. Notes from Michigan Connected Vehicle Working Group Meeting on April 30, 2012, http://www.michigan.gov/documents/mdot/MDOT_CVworkingGroup_30April2012_386176_7.pdf, accessed 23 June 2012.
27. "Real-Time Traveler Information Market Assessment White Paper," Prepared by Booz Allen Hamilton for USDOT, FHWA-JPO-10-055, February 2010.
28. Shah, V., and K. Wunderlich. "Effective of Different Approaches to Disseminating Traveler Information on Travel Time Reliability: Technology and Innovation Scan," Prepared by Noblis for Texas A&M Research Foundation under SHRP II L14, March 2010.
29. Real-Time Data Capture and Management State of the Practice Assessment and Innovations Scan: Lessons Learned from the Innovations Scan, Prepared by SAIC for the DCM Program, USDOT, July 18, 2011.
30. Real-Time Private Sector Traffic Information, Draft Memorandum Prepared by Noblis for the DCM Program, USDOT, June 2012.
31. ALK Technologies, <http://www.alk.com/about/default.asp>, accessed June 29, 2012.
32. INRIX Press Release, INRIX Triples Real-Time Traffic Flow Coverage in North America to Over 160,000 Miles, December 2009, <http://www.inrix.com/pressrelease.asp?ID=68>, accessed June 29, 2012.
33. NAVTEQ Press Release, NAVTEQ Traffic Announces Integration of Nokia GPS Data, September 3, 2009, <http://corporate.navteq.com/webapps/NewsUserServlet?action=NewsDetail&newsId=773&language=en&englishonly=false>, accessed June 29, 2012.

34. Google™ Official Blog, The bright side of sitting in traffic: Crowdsourcing road congestion data, August 25, 2009, <http://googleblog.blogspot.com/2009/08/bright-side-of-sitting-in-traffic.html#/2009/08/bright-side-of-sitting-in-traffic.html>, accessed June 29, 2012.
35. Google™ Lat Long Blog, Get typical traffic for roads, not just highways, April 2, 2012, <http://google-latlong.blogspot.com/2012/04/get-typical-traffic-for-roads-not-just.html>, accessed June 29, 2012.
36. Waze, <https://www.waze.com/>, accessed June 29, 2012.
37. Cellint, TrafficSense - Road Traffic Monitoring and Traffic Information Services, http://www.cellint.com/traffic_data/traffic_system.html, accessed June 29, 2012.
38. TrafficCast Data Fusion Engine, <http://trafficcast.com/technology-platform/data-fusion-engine/>, accessed June 28, 2012.
39. Triangle Software, http://www.trianglesoftware.com/?page_id=154, accessed August 7, 2012.
40. Real-Time Data Capture and Management State of the Practice Assessment and Innovations Scan: Lessons from Scan of Innovations, Prepared by SAIC for USDOT, July 18, 2011.
41. Sirius XM Traffic Market Coverage, <http://www.siriusxm.com/siriusxmtraffic/marketcoverage>, accessed July 27, 2012.
42. INRIX Press Release, Two Companies Collaborate on Navigation Systems That Boost Fuel Economy While Improving Urban Mobility, June 12, 2012, <http://inrix.com/pressrelease.asp?ID=158>, accessed June 25, 2012.
43. Locations of ITS Spots, The Ministry of Land, Infrastructure, Transport and Tourism, http://www.mlit.go.jp/road/ITS/j-html/spot_dsrc/tenkai.html, accessed November 21, 2012
44. An ITS Spot-compatible car navigation system and ITS Spot roadside equipment , The Ministry of Land, Infrastructure, Transport and Tourism, http://www.mlit.go.jp/road/ITS/j-html/spot_dsrc/tenkai.html, accessed November 21, 2012
45. Portal site of ITS Spot-compatible on-board units, ITS Service Promotion Association org., <http://www.dsrm-portal.jp/>, accessed September 30, 2013.
46. Glassco, R. "San Diego Test Data Set Metadata Documentation," Prepared by Noblis for USDOT, 2012.
47. README for Mobile Device Data CSV Files, Prepared by Berkeley Transportation Systems (BTS), Berkeley, California, for USDOT, 2012.
48. Data Dictionary for Freeway Data and Metadata CSV Files, Prepared by Berkeley Transportation Systems (BTS), Berkeley, California, for USDOT, 2012.
49. Data Dictionary for Hourly Weather Data CSV Files, Prepared by Berkeley Transportation Systems (BTS), Berkeley, California, for USDOT, 2012.
50. Data Dictionary for Incident and Lane Closure Data and Metadata CSV Files, Prepared by Berkeley Transportation Systems (BTS), Berkeley, California, for USDOT, 2012.
51. Glassco, R. "Seattle Test Data Set Metadata Documentation," Prepared by Noblis for USDOT, 2012.

52. Clean-up of existing data sets to support Dynamic Mobility Applications Development, Prepared by University of Washington, Seattle, Washington, for USDOT, May 2012.
53. Watkins, K. "Using Technology to Revolutionize Public Transportation," University of Washington, June 2011.
54. Proof-of-Concept Data, USDOT Research Data Exchange, <https://www.its-rde.net>, accessed 24 June 2012.
55. Jung, S., Wunderlich, K., and R. Glassco. "Metadata Guidelines for the Research Data Exchange," Prepared by Noblis for USDOT, January 2012.
56. Glassco, R. "Documentation of Onboard Equipment Files from the IntelliDrive Michigan Testbed," Prepared by Noblis for USDOT, 2011.
57. Glassco, R. "Documentation of Roadside Equipment Files from the IntelliDrive Michigan Testbed," Prepared by Noblis for USDOT, 2011.
58. Glassco, R. "Documentation of Weather Data for the IntelliDrive Michigan Testbed," Prepared by Noblis for USDOT, 2011.
59. NCAR 2009 Data, USDOT Research Data Exchange, <https://www.its-rde.net>, accessed 24 June 2012.
60. NCAR 2010 Data, USDOT Research Data Exchange, <https://www.its-rde.net>, accessed 24 June 2012.
61. Data Capture and Management Portal Service Delivery Node Feed, <https://datacapture.noblis.org/content/service-delivery-node-feed>, accessed 24 June 2012.
62. "Results from the ITS Mobile Observations Study, Final Report," Prepared by the National Center for Atmospheric Research for USDOT, 2012.
63. Pisano, P., Guevara, G., and M. Chapman. "Road Weather Management and the Connected Vehicle," July 27, 2011.
64. "IMO Data Collection and Application Demonstration Project in Nevada," Prepared by NDOT and NCAR for USDOT, March 13, 2011.
65. Herrera, J.C., et al. "Evaluation of traffic data obtained via GPS-enabled mobile phones: The Mobile Century field experiment". *Transport. Res. Part C* (2009), doi:10.1016/j.trc.2009.10.006.
66. Mobile Century data documentation, December 2009, <http://traffic.berkeley.edu/project/downloads/mobilecenturydata>, accessed June 27
67. Turner, S., et al. "Private Sector Data for Performance Management – Final Report," Prepared by Texas Transportation Institute and Battelle for USDOT, FHWA-HOP-11-029, July 2011.
68. Mulligan, B., D. Lukasik, E. Hubbard, and C. Cleary. "Dynamic Mobility Applications and Data Capture and Management: Focused Standards Coordination Plan – Draft," Prepared by SAIC for the USDOT, July 29, 2012.
69. Wunderlich, K. "Real-Time Data Capture and Management Program: Transforming the Federal Role," Prepared by Noblis for the USDOT, May 2010.

70. Rupert, R., et al. "Dynamic Mobility Applications Bundles Overview," Presented at the Mobility Workshop, May 24, 2012.
71. "AERIS Transformative Concepts and Applications Descriptions," Applications for the Environment: Real-Time Information Synthesis (AERIS) Program, June 2012.
72. Chapman, M., and S. Drebot. "Concept of Operations for the Use of Connected Vehicle Data in Road Weather Applications," Prepared by National Center for Atmospheric Research for the USDOT, April 2012.
73. Comparison of average travel speed on major roads nationwide and in central Tokyo, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, http://www.ktr.mlit.go.jp/honkyoku/road/3kanjo/whats/traffic_jam.htm, accessed November 21, 2012
74. Proportion of automobile use delay due to traffic congestion nationwide and in central Tokyo, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, http://www.ktr.mlit.go.jp/honkyoku/road/3kanjo/whats/traffic_jam.htm, accessed November 21, 2012
75. Comparison of average travel speed on secondary roads before and after social experiment of eliminating tolls on the Kyoto Tamba Expressway, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, accessed November 21, 2012
76. Sectors closed to traffic as a result of the Great East Japan Earthquake, Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism
77. Map of information on roads usable by automobiles, ITS Japan, http://www.its-jp.org/news_info/6568/, accessed November 21, 2012
78. Field operational Test for assisting distribution operations, Ministry of Land, Infrastructure, Transport and Tourism Press Release. Public-private demonstration test of increased distribution efficiency through the use of ITS Spot service, <http://www.nilim.go.jp/lab/bcg/kisya/journal/kisya20120220.pdf>, accessed November 21, 2012
79. Status of traffic on major roads on the Japan Sea side that functioned as detours at the time of the Great East Japan Earthquake, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, <http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/houkoku2/happyou/09.pdf>, accessed November 21, 2012
80. Mahmassani, Hani, et al., et al. Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO): Concept of Operations. s.l. : Federal Highway Administration, US Department of Transportation, 2012. FHWA-JPO-13-012.
81. Traveller Information Services Association (TISA). TISA Position concerning a public consultation of the European Commission on the Provision of EU-wide Real-time Traffic Information Services. tisa.org. [Online] 3 14, 2014. [Cited: 10 2, 2014.] http://www.tisa.org/assets/Uploads/Public/EO14005TISAPosition-paperPriority-Action-Bfinal_4.pdf. EO14005.

82. ITS America and the U.S. Department of Transportation. Closing the Data Gap: Guidelines for Quality Advanced Traveler Information System (ATIS) Data. s.l. : ITS American and U.S. Department of Transportation, 2000.
83. Ahn, Kyoungcho, Rakha, Hesham and Hill, David. Data Quality White Paper. s.l. : Federal Highway Administration, U.S. Department of Transportation, 2008. FHWA-HOP-08-038.
84. United States. Code of Federal Regulations, Title 23, Part 511, Real-Time System Management Information Program. s.l. : Government Printing Office, United States of America. Code of Federal Regulations, Title 23, Part 511.
85. Jung, Soojung, Glassco, Richard and Wunderlich, Karl. Metadata Guidelines for the Research Data Exchange. s.l. : Federal Highway Administration, US Department of Transportation, 2012.
86. McGurrin, Michael. Vehicle Information Exchange Needs for Mobility Applications, Version 3. s.l. : Federal Highway Administration, US Department of Transportation, 2013. FHWA-JPO-13-065.

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

Acronym	Meaning
EMS	Emergency Medical Services
ESS	Environmental Sensor Stations
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

Acronym	Meaning
NOAA	National Oceanic and Atmospheric Administration
NSP	Northern State Parkway
NTCIP	National Transportation Communications for ITS Protocol
NYS	New York State
NYSDOT	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

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

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-16-356



U.S. Department of Transportation