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Roadway Geometry and Inventory Trade Study for IntelliDrive[SM] Applications

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FOREWORD

This report documents the results of a trade study on roadway geometry and inventory data. The study objective was to identify and evaluate existing and emerging technical solutions for providing and updating roadway geometry and other roadway inventory information likely to be needed for IntelliDrive^{SM}[1] applications. This report will be useful to Federal, State, and local government agencies, research organizations, and private sector firms that will research, develop, and deploy IntelliDrive technologies.

Monique R. Evans
Director, Office of Safety
Research and Development

[1] IntelliDrive is a service mark of the U.S. Department of Transportation.

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16. Abstract
The U.S. Department of Transportation IntelliDrive initiative seeks to improve transportation safety and mobility while reducing the environmental impact of surface transportation through the use of networked wireless communication among vehicles, roadway infrastructure, and travelers' personal communication devices.

This report summarizes the findings of an investigation of existing and emerging sources of roadway geometry and inventory data (including public and commercial databases) as well as technologies and methods for collecting, maintaining, and updating roadway attribute information. These data sources are compared along several technical dimensions including geographic coverage, network connectivity, feature resolution, positional accuracy, included attributes, data format and size, and methods and frequency of updates and are evaluated relative to potential near-term IntelliDrive application data needs as indicated by prior research and discussions with IntelliDrive stakeholder groups. The study also examines the workflow practices and business models of current data providers and their capacity for delivering the roadway data needed for future IntelliDrive applications. Based on the findings from the trade study, current roadway geometry and inventory data gaps are identified. Recommendations are proposed for specific research activities and institutional and regulatory options to address data gaps.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	Three-dimensional
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ADAS	Advanced driver assistance system
APE	Advanced Pavement Evaluation
ATMS	Advanced traffic management system
BRT	Bus rapid transit
BTS	Bureau of Transportation Statistics
Caltrans	California Department of Transportation
CAMP	Crash Avoidance Metric Partnership
CAN	Controller-area network
CCTV	Closed-circuit television
CONUS	Contiguous United States
DHML	Digital Highway Measurement Laboratory
DHMS	Digital Highway Measurement System
DMS	Dynamic message signs
DOT	Department of Transportation
DSRC	Dedicated Short Range Communication
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GDF	Geographic Data File
GIS	Geographic information system
GPS	Global Positioning System

GTFS	Google™ transit feed specification
HAZMAT	Hazardous materials
HOT	High-occupancy/toll
HOV	High-occupancy vehicle
HPMS	Highway Performance Monitoring System
HRCI	Highway Rail Crossing Inventory
HTRIS	Highway Traffic Records Information System
IFSAR	Interferometric Synthetic Aperture Radar
IRI	International roughness index
ITS	Intelligent transportation systems
LIDAR	Light detection and ranging
LTD	Lane Transit District
LRS	Linear referencing system
LYNX	Central Florida Regional Transportation Authority
MDOT	Michigan Department of Transportation
METRO	Metropolitan Transit Authority of Harris County
MIRE	Model Inventory of Roadway Elements
MPE™	Map and Positioning Engine
MPO	Metropolitan planning organization
MTA	Metropolitan Transportation Authority
NAD	North American Datum
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NDFD	National Digital Forecast Database
NDGPS	National Differential Global Positioning System

NHPN	National Highway Planning Network
NHS	National Highway System
NYCDOT	New York City Department of Transportation
NYCT	New York City Transit
OEM	Original equipment manufacturer
PC	Point of curvature
PND	Personal navigation device
POI	Point of interest
PT	Point of tangency
RCI	Roadway Characteristics Inventory
SFGPR	Step-frequency ground penetrating radar
SHRP2	Strategic Highway Research Program 2
STAR*Map	Southeast Texas Addressing and Referencing Map
TFTN	Transportation for the Nation
TMC	Traffic management center
TRIPS	Transportation Information Planning Support
TSP	Transit signal priority
ULIP	Ultra-Light Inertial Profiler
USGS	U.S. Geological Survey
VDOT	Virginia Department of Transportation
VGIN	Virginia Geographic Information Network
VMT	Vehicle miles of travel
WaTrans	Washington Transportation Framework Project
WGS	World Geodetic System
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

PROJECT BACKGROUND AND PURPOSE

The U.S. Department of Transportation (DOT) IntelliDrive^{SM}[1] initiative seeks to improve transportation safety and mobility while reducing the environmental impact of surface transportation through the use of networked wireless communication among vehicles, infrastructure, and travelers' personal communication devices. The applications developed for the IntelliDrive initiative will require accurate positioning and temporally current information on roadway geometry and roadway features such as curve locations, number and width of travel lanes, presence and length of auxiliary turn lanes, roadway shoulder and median characteristics, posted speed limits, intersection characteristics, etc.

The purpose of this study is to investigate existing and emerging sources of roadway geometry and inventory data, including both commercial and public databases, as well as technologies and methods for collecting, maintaining, and updating roadway data items. These data sources are evaluated relative to potential near-term (within the next 5 years) IntelliDrive application data needs that were proposed and vetted through representative stakeholder groups. The study also examines the workflow practices and business models of current data providers and their capacity for delivering the roadway geometry and inventory data needed for future IntelliDrive applications.

INTELLIDRIVE DATA NEEDS

An initial list of roadway geometry and inventory data items was developed jointly by U.S. DOT staff and the study team. The list was compiled from data items identified in several earlier research studies, which were then evaluated against a set of potential IntelliDrive applications.

This initial list was vetted among IntelliDrive stakeholder groups to ensure that the specific roadway geometry and inventory data fully addressed the perceived needs of the IntelliDrive community. Stakeholder outreach was conducted through a series of Web meetings held in November 2009. A total of 30 individuals participated in the meetings, with participants representing the following stakeholder groups: State DOTs, county transportation agencies, traffic signal manufacturers, traffic management system integrators, automobile manufacturers, the trucking industry, university transportation research centers, IntelliDrive equipment developers and integrators, and the U.S. DOT.[2]

Based on stakeholder feedback, a few additional data items were added and used for the remainder of the study. The features and attributes included in the revised list can be grouped into four general categories: roadway geometry, roadway inventory, intersection characteristics, and other geospatial features.

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[1] IntelliDrive is a service mark of the U.S. DOT.

[2] Code of Federal Regulations defines a State DOT as "that department, commission, board, or official of any State charged by its laws with the responsibility for highway construction." (23 CFR § 420.105) Throughout this report, the term "State DOT" is used to refer to the state transportation agency that is primarily responsible for collecting and maintaining roadway geometry and inventory data.

ROADWAY DATA SOURCES

An initial screening was conducted to identify major commercial and public domain developers of roadway network databases covering the United States. In addition to the roadway network databases, the study team identified national, statewide, local highway, and public transit roadway inventory databases that can be linked to a geospatial roadway network. Based on the initial screening, the following roadway data sources were selected for inclusion in the detailed trade study:

- **National roadway network databases:** ALK Digital Maps™, DeLorme North America Data Set™, Google Maps™, NAVTEQ™ Road Network Database, Tele Atlas® MultiNet®, and the Census Bureau TIGER/Line®.

- **National roadway inventory databases:** Highway Performance Monitoring System (HPMS), the National Bridge Inventory (NBI), and the Highway-Rail Crossing Inventory (HRCI).

- **State roadway inventory databases:** California, Florida, Michigan, Virginia, and Washington.

- **Local roadway inventory databases:** Broward County, FL; Palm Beach County, FL; and TranStar in Houston, TX.

- **Public transit operators:** Central Florida Regional Transportation Authority (LYNX), Lane Transit District (LTD), Metropolitan Transportation Authority (MTA) New York City Transit (NYCT).

- **Innovative data collection firms:** Intermap Technologies, Mandli Communications, Inc., Fugro Roadware, and the Federal Highway Administration (FHWA) Digital Highway Measurement System (DHMS).

TRADE STUDY RESULTS

The roadway data sources were analyzed and compared based on the technical characteristics of their databases and the operational and business processes of the data providers. The findings from these analyses are summarized in this section.

Technical Analysis

Coverage

Successful deployment of IntelliDrive applications will require a geospatial roadway network that provides nationwide coverage and includes roadway geometry for all public roads. The investigation of potential roadway data sources found only six geospatial roadway networks that meet these criteria. Five of the networks are proprietary, developed for specific applications by commercial database developers. Only the Census Bureau's TIGER/Line® roadway network is in the public domain.

Roadway networks developed by State DOTs rarely extend beyond the borders of the State and often include updated information only on higher functional class roads for which the State DOT has administrative or maintenance responsibilities. Local roadway agencies do not typically develop or maintain their own roadway networks. Local agencies that have geographic information system (GIS) capabilities most often use either the State DOT roadway network, the Census TIGER/Line® roadway network, or one of the commercial networks.

The investigation also identified three public roadway inventory databases with nationwide coverage that include some of the listed IntelliDrive data items. Each of the three databases, HPMS, NBI, and HRCI, are compiled and maintained by the U.S. DOT from data submitted by State DOTs in compliance with federally mandated reporting requirements.

Network Connectivity

Several key roadway attributes required for IntelliDrive applications (e.g., locations of intersections, locations of entrance and exit ramps on freeway interchanges, and the identification of overpasses and underpasses) are best represented through the structure of the roadway database itself, using network connectivity. Network connectivity is also a prerequisite for roadway databases used to support vehicle navigation and routing. Of all the geospatial roadway networks investigated in this study, only the five commercial roadway networks provided full network connectivity at the time of the investigation.

Feature Resolution

IntelliDrive stakeholders identified the need for sufficient feature resolution to distinguish between individual travel lanes on a roadway and to provide certain attribute information on a lane-level basis. None of the geospatial roadway networks, public or commercial, provided lane-level feature resolution at the time of this study. Nearly all of them define roadway features as the centerline of the travel way or paved surface. The number of lanes associated with each roadway segment is defined as an attribute of the roadway segment.

Two of the commercial roadway network database developers, NAVTEQ™ and Tele Atlas®, offer enhanced lane information for certain roadway segments at freeway interchanges and at complex urban intersections with dedicated turning lanes. The enhanced lane information does not explicitly represent lanes as separate geospatial features and is not available for all urban areas.

Geospatial Accuracy

Potential IntelliDrive applications require a level of positional accuracy for roadway features and georeferenced attributes of 3.28 ft (1 m) absolute error or better. Current geospatial roadway networks have a positional accuracy ranging from 16.4 to 49.2 ft (5 to 15 m), depending on how and when they were originally constructed. This level of accuracy is sufficient for most public and commercial applications, including vehicle navigation. NAVTEQ™ and Tele Atlas® are improving their roadway network to a geospatial accuracy of 3.28–16.4 ft (1–5 m) absolute error to support potential IntelliDrive applications.

Attributes

Roadway attribute data are usually closely linked to the geospatial roadway network used to display them. The five commercial roadway networks include a significant number of the roadway attributes identified by IntelliDrive stakeholders that are also required for vehicle navigation applications. The Census TIGER/Line® roadway network includes relatively few of the identified IntelliDrive data items.

Except for the data items specified by Federal reporting requirements, roadway inventory data collected and maintained by State DOTs and local roadway agencies vary considerably from one agency to another. There are currently no standards and relatively limited guidance for roadway data collection at the State or local level.

Additional effort would be required to verify the accuracy and timeliness of even those attributes that are compiled for the national inventory databases. Other than consistency checks on attribute domain values little if any of the data submitted by State DOTs to the national inventory databases are independently verified by the U.S. DOT.

Commercial roadway database developers take a much more proactive role in verifying and updating roadway inventory data in their databases. They utilize multiple sources, including ongoing contacts with State and local roadway agencies, feedback from database customers, and in-house field teams to verify and reconcile attribute changes reported from other sources.

Data Format and Size

Roadway geometry and inventory data to support IntelliDrive applications must be stored in a format that can be read and utilized by a vehicle's on-board processors and that can be efficiently updated and transmitted for specific geographic areas and attributes. Nearly all of the public domain geospatial roadway networks are stored and distributed in one or more standard commercial GIS formats. These formats are reasonably effective for exchanging entire databases, but additional processing is required to transmit and integrate geographic subsets into a geospatial roadway network. Roadway attribute data that are linked to a geospatial roadway network using a linear referencing system (LRS) require even more processing because both the attribute data and any updates to the LRS must be transmitted and integrated into the geospatial roadway network.

At least two of the commercial roadway network developers store their roadway geometry and attribute data using multiple formats, including Geographic Data File (GDF)—a geographic data format that has become the de facto international exchange standard for navigation databases. While this ultimately may not be the most efficient format for storing or transmitting roadway data needed for IntelliDrive applications, it has at least proven to be an operationally practical format for in-vehicle roadway navigation databases.

Methods and Frequency of Updating

IntelliDrive applications will require that updates to roadway attributes critical to vehicle safety (e.g., bridge height, weight clearances, one-way street designations, turn prohibitions) are transmitted and incorporated into the vehicle roadway database soon after they are implemented.

None of the existing geospatial roadway networks or roadway inventory databases investigated in this study are updated and disseminated anywhere close to real time. The national inventory databases receive updates from State DOTs on an annual basis, but some of the data items reported by the States are based on periodic inspections or data collection activities that take place on 2-, 3-, or even 4-year cycles.

Commercial roadway databases obtain updates on a continual basis from multiple sources. Data updates are verified, reconciled, and incorporated into a master internal roadway database. At least three of the commercial roadway database developers create new versions of their master internal database on a weekly basis. Updated versions of the master roadway database are published at regular intervals ranging from as frequently as once a month to every 6 months, depending on the perceived requirements of the database customers.

Maintenance and Operations Analysis

Data Collection and Updating Technologies

Roadway geometry and inventory data collection sources use similar technologies for collecting and updating their databases. The primary methods currently used by both commercial roadway database developers and State DOTs include airborne orthoimagery and roadway data collection vehicles equipped with a differential Global Positioning System (GPS) recorder synchronized with various data capture technologies such as video cameras, pavement measurement equipment, and increasingly, mobile light detection and ranging (LIDAR).

Emerging data collection technologies, including airborne interferometric synthetic aperture radar (IFSAR) imagery and mobile LIDAR, can significantly increase the positional accuracy and resolution of roadway features and measured attributes. IFSAR imagery could be used to produce a geospatial roadway centerline database with measurements of curvature and grade at a consistent accuracy level of 3.28–9.84 ft (1–3 m) nationwide. Mobile LIDAR can be used to obtain even higher positional accuracy measurements (0.328–3.28 ft (0.1–1 m)) of roadway attributes and features relative to the roadway data collection vehicle.

While nearly all of the roadway inventory data identified by IntelliDrive stakeholders could be captured using current data collection technology, the level of effort and associated costs to process videolog or LIDAR imagery in order to identify, locate, and measure specific roadway features typically forces State DOTs to prioritize what roadway features they extract and measure, as well as what road segments they collect data on. As improvements in automated feature extraction and measurement techniques reduce the costs of data processing, State DOTs may be more able and willing to maintain additional roadway attribute data.

Work Flow Processes

Roadway data to support IntelliDrive applications need to come from stable, reliable data sources with well-defined processes for data collection, storage, updating, quality control, and dissemination. In general, these work flow processes are more clearly defined and better integrated among the commercial roadway database developers than among public agency sources. The reason for this is that the roadway database is a marketable product that represents a primary source of income for commercial database developers. The better the product, the higher the market share and greater the revenue. For public agencies, data collection is conducted either to respond to a statutory requirement or to support specific internal applications.

Among State DOTs, collection of specific roadway data items has historically been compartmentalized, with each operating division collecting the data that it needs for its own internal applications. The result has been an assortment of “legacy” databases scattered throughout the agency, using different data formats, storage media, data collection and updating procedures, quality control standards, and location referencing methods. While many State DOTs have tried to develop enterprise data repositories to facilitate data sharing across organizational units (using geographic location as the common identifier for roadway features and attributes), the success of these efforts has been mixed. State DOTs generally have been successful in developing a statewide geospatial roadway network and one or more LRS methods to enable them to link different legacy databases to the roadway network. However, few State DOTs have successfully implemented agency-wide data collection standards.

National inventory databases such as HPMS represent a compilation of data items submitted by individual State DOTs and are subject to a standard data reporting format. U.S. DOT staff conduct consistency checks to ensure that attributes’ values are within acceptable domain ranges and that summary statistics are reasonable. The U.S. DOT does not conduct independent verification of attributes reported by State DOTs for specific road segments.

All of the commercial roadway database developers have established work flow procedures for collecting, verifying, updating, and disseminating the data items included in their roadway network databases. Each of the commercial developers employs a staff of GIS technicians to input, verify, and edit geospatial and attribute data that they receive from various primary sources. These sources include publicly obtained roadway vector and orthoimagery, updates from State DOTs and local roadway agencies, error reports from database users, and other user-generated content, such as GPS vehicle tracks. The new data are checked, verified, and reconciled against other data sources and incorporated into the master roadway network database on a continual basis. Periodically, a copy of the master roadway network is published as a new version of the commercial database.

Business Models

There is a clear dichotomy between public and commercial data sources with respect to the primary customers for whom the roadway data are collected. Public agencies, particularly State DOTs and local roadway maintenance agencies, collect roadway data either to meet federally mandated reporting requirements or to support internal business needs for roadway construction, maintenance, or operations. Data collected by State and local agencies in response to Federal reporting requirements is typically not utilized directly by the State or local agency for its own business needs.

Federal roadway data inventories are designed primarily to collect and preserve statistical information on the condition and performance of nationally significant roadway infrastructure components. These inventories rely almost exclusively on State DOTs for data accuracy and quality control. Federal agencies conduct little or no independent verification of the accuracy of individual data items reported by the States.

For commercial roadway database developers, the roadway data are either the primary product or an integral part of the product or service that the commercial developer is selling. The content and quality (i.e., geospatial accuracy, frequency of updates) of the data are tailored to meet the perceived needs of the target market. These target markets may include specific niche customers or services unrelated to potential IntelliDrive applications, in which case the data provider is unlikely to add new roadway inventory data.

However, at least two of the commercial roadway database developers, NAVTEQ™ and Tele Atlas®, have stated that IntelliDrive represents a promising new market area and have already begun making enhancements to their current roadway data products in anticipation of future IntelliDrive requirements.

CONCLUSIONS AND RECOMMENDATIONS

Research Needs

The study identified several roadway geometry or inventory data items that were not being collected extensively enough to be useful for nationwide IntelliDrive applications. This suggests that one or more research efforts could be undertaken to investigate the feasibility and practicality of collecting specific data items using existing or emerging technologies and new methods for data integration and standardization across multiple data sources. Some examples of specific research studies include:

1. Evaluating the feasibility of using IFSAR technology for collecting roadway geometry nationwide.

2. Evaluating the feasibility and cost of using mobile LIDAR to collect selected roadway geometry and inventory data.

3. Coordinating IntelliDrive roadway data research with safety research activities currently underway through the Strategic Highway Research Program 2 (SHRP2).

Institutional and Regulatory Options

The U.S. DOT could implement one or more of the following options to help increase and/or focus roadway data collection among State and local roadway management agencies to better support IntelliDrive data needs:

1. Allow and facilitate State DOTs to submit additional road inventory data for HPMS.

2. Encourage data collection on rural roads under FHWA's rural safety program.

3. Monitor and participate in ongoing national roadway data sharing initiatives.

4. Consider availability of local roadway data as a selection criterion for future IntelliDrive demonstration grants.

CHAPTER 1. INTRODUCTION

PROJECT BACKGROUND AND PURPOSE

The U.S. DOT IntelliDrive initiative seeks to improve transportation safety and mobility while reducing the environmental impact of surface transportation through the use of networked wireless communication among vehicles, infrastructure, and travelers' personal communication devices.

Many potential IntelliDrive applications require accurate positioning and temporally current information on roadway geometry and specific roadway features, including curve locations, locations of signalized or signed intersections, number and width of travel lanes, presence and length of auxiliary turn lanes, roadway shoulder and median characteristics, posted speed limits, etc. Some of these data are available in geospatial road databases created by government transportation agencies or commercial database developers, but there is currently no single data source that can provide all of the required data on a consistent, nationwide basis at the appropriate levels of positional and temporal accuracy.

The purpose of this study is to investigate existing and emerging sources of roadway geometry and inventory data, including both commercial and public databases, as well as technologies and methods for collecting roadway data items. These data sources are evaluated relative to potential near-term (within the next 5 years) IntelliDrive application data needs that were proposed and vetted through representative stakeholder groups. The study also examines the workflow practices and business models of current data providers and their capacity for delivering the roadway geometry and inventory data needed for future IntelliDrive applications.

REPORT ORGANIZATION

This report summarizes the approach, findings, and recommendations from the roadway geometry and inventory trade study. The report is composed of six chapters.

Chapter 2 describes the approach taken by the study team to propose an initial list of roadway data items, vet the list among potential IntelliDrive stakeholders, and develop a final list based on stakeholder feedback for use in evaluating current and emerging data sources.

Chapter 3 summarizes the findings from interviews with roadway geometry and inventory data sources. These sources include commercial roadway database developers; Federal, State, and local transportation agencies that collect and maintain roadway inventory data; transit operating agencies; and commercial roadway data collection firms that are using innovative technologies to collect and process roadway geometry data.

Chapter 4 compares each of the road data items developed in chapter 2 against the roadway data that are currently being collected by commercial and public sources in order to provide a clear picture of specific data gaps.

Chapter 5 analyzes and compares roadway geometry and inventory data sources based on the technical characteristics of each database and on the operational and business practices of each data provider. Key challenges and obstacles to providing data to meet potential near-term IntelliDrive needs are discussed.

Chapter 6 discusses potential options for addressing the data gaps and challenges identified in the previous chapters. Options include alternative institutional structures for database development and maintenance, Federal regulatory and funding strategies, and promising research initiatives.

Three appendices are included to provide additional detail on specific aspects of the trade study. These appendices include: (1) a list of IntelliDrive stakeholders who participated in the identification of roadway data items, (2) a summary of stakeholder comments regarding potential data items needed for IntelliDrive applications, and (3) profiles and summaries of commercial roadway database developers; Federal, State, and local roadway agencies; and firms using innovative roadway data collection technologies that were interviewed in the course of this study.

CHAPTER 2. INTELLIDRIVE DATA NEEDS

PRELIMINARY LIST OF ROADWAY DATA ITEMS

A complicating issue in conducting this trade study is that few, if any, IntelliDrive applications have been defined in sufficient detail to specifically identify what data items or what levels of geospatial accuracy are needed to support them. Both IntelliDrive applications and data requirements are still evolving, and it is likely that early IntelliDrive applications will be driven heavily by data availability.

Recognizing that both data needs and applications will continue to evolve, a preliminary list of roadway geometry and inventory data was developed jointly by U.S. DOT staff and the study team. This initial list was compared against roadway data elements identified in several other similar research studies, including the *Enhanced Digital Mapping Project*, *Model Minimum Inventory of Roadway Elements—MMIRE*, and SHRP2 Project S-03—Roadway Measurement System Evaluation.[1,2]

The combined lists of roadway data items from these sources were then evaluated against an initial set of IntelliDrive application areas that FHWA and other U.S. DOT staff identified as candidates for deployment. These application areas included the following:

- Roadway departure prevention.
- Speed management.
- Intersection safety.
- Commercial vehicle enforcement and operations.
- Transit.

STAKEHOLDER OUTREACH PROCESS

Stakeholder outreach was conducted to ensure that the preliminary list of roadway geometry and inventory data addressed the needs of IntelliDrive stakeholders. Potential stakeholders were identified based on their involvement in the IntelliDrive Coalition, the American Association of State Highway and Transportation Officials (AASHTO) IntelliDrive Technical Working Group, the Crash Avoidance Metrics Partnership (CAMP), and other groups. Representatives from State and local transportation departments, transit agencies, automobile manufacturers, the motor carrier industry, traffic signal and other electronic infrastructure manufacturers and suppliers, traffic management system integrators, university transportation research centers, and other IntelliDrive integrators/developers were included. A list of the organizations represented by potential stakeholders is presented in appendix A.

The study team attempted to recruit one representative from each of the organizations identified on the stakeholder list. For organizations with multiple contacts, the study team initially contacted one person and proceeded to contact other individuals only if the initial contact was unable or unwilling to participate. In some cases, the initial point of contact referred the team to another individual who was more familiar with the technology and data issues associated with IntelliDrive applications or who was more readily available to participate in stakeholder meetings. The stakeholder list was updated accordingly throughout the stakeholder outreach process.

Stakeholder outreach was conducted through three Web meetings, which took place November 18–20, 2009. Meetings with stakeholders were scheduled and coordinated via email and Doodle®, an online collaboration application. Of the 75 stakeholders who received an invitation email, 30 participated in the Web meetings. The preliminary list of roadway data items was sent to all stakeholders for review prior to the meetings. The data items were mapped to a list of potential IntelliDrive applications to facilitate stakeholder responses.

REVISED ROADWAY DATA ITEM LIST

The feedback obtained during the stakeholder meetings was used to revise the preliminary list of roadway geometry and inventory data needs. Appendix B presents a summary of key comments raised by various IntelliDrive stakeholders during the meetings.

Most of the comments and suggestions raised by stakeholders were incorporated into a revised list of roadway geometry and inventory data items. A few recommended data items were left off the revised list because they did not fit within the scope of this study or were combined with similar data items to create a single attribute or feature.[1] The affected data items included:

- **Traffic and railroad crossing signal status.** These two attributes describe the real-time status of a dynamic traffic control device (e.g., is the traffic signal currently red or green?). While these data may be needed for certain IntelliDrive applications, they are too dynamic to be maintained in a roadway geometry database, which contains geospatial features and attributes that are relatively static over time or which change in regular, predictable ways (e.g., reversible high-occupancy vehicle (HOV) lanes). Additionally, traffic signal phase and timing data are currently included as a proposed message layer in the Cooperative Intersection Collision Avoidance System Dedicated Short Range Communication (DSRC) message protocol. Consequently, these two data items were deleted from the revised list.

- **Pavement coefficient of friction.** Pavement coefficient of friction is another measure that changes dynamically, depending on weather conditions, roadway surface type (e.g., concrete, asphalt, gravel), roadway pavement condition, and vehicle speed. While most State DOTs collect data on pavement surface type and condition, none of them specifically maintain coefficient of friction as a roadway inventory item. Consequently, pavement coefficient of friction was excluded from the revised list, and a pavement type attribute was added as a placeholder pending future identification and specification of the key roadway pavement data items (e.g., surface type, condition) needed to calculate a coefficient of friction.

[1] It is important to note that this study focused on roadway geometry and inventory data. The total set of data items that may be required by IntelliDrive applications is much larger and includes data derived from in-vehicle sensors or transmitted in real time from other vehicles or roadway infrastructure (e.g., traffic signals). Neither the preliminary nor revised list of data items are intended to include all of the data that might be needed for IntelliDrive applications.

- **Horizontal and vertical sight distance.** Available sight distance is a measure that is based on a combination of horizontal and vertical alignment of the roadway ahead of a vehicle and any lateral obstructions along the roadside. Consequently, sight distance was combined into a single roadway geometry feature/attribute.

- **Superelevation and roadway cross slope.** The terms *superelevation and roadway cross slope* both describe a measure of roadway slope that is perpendicular to the centerline of the roadway. Although superelevation is typically used in conjunction with a horizontal curve, it is not measured differently nor stored independently from cross slope. Consequently, superelevation was consolidated into the more general roadway cross slope attribute.

Table 1 through table 4 present the revised list of roadway geometry and inventory data items. Data items are grouped into four general categories for presentation purposes: roadway geometry, roadway inventory, intersection characteristics, and other geospatial features. These categories are used throughout the remainder of this report.

Table 1. Roadway geometry attributes.

Feature	Attribute	Attribute Definition
Horizontal alignment	Horizontal curve PC location	Location where curve begins
	Horizontal curve length	Length of curve along arc defined by roadway
	Horizontal curve radius	Radius of curve
Grade	Grade in direction of travel	Percent of slope measured in direction of travel. (Positive (+) for uphill in direction of travel and negative (-) for downhill in direction of travel)
Elevation	*Roadway elevation*	*Elevation of the roadway centerline above a specified geodetic reference point.*
Vertical alignment	Vertical curve PC location	Location where curve begins (including elevation)
	Vertical curve PT location	Location where vertical curve ends (including elevation)
	Vertical curve length	Length of curve along arc defined by roadway
Sight distance	*Available sight distance (stopping, passing)*	*Available sight distance along the roadway in direction of travel*
Cross slope	Roadway cross slope	Percent of slope measured from highpoint of roadway cross section in direction of travel. (Positive (+) slopes toward right side of road and negative (-) slopes towards left side of road)
	Shoulder cross slope	*Cross slope of shoulder. Direction and percent of cross slope measured from the edge of travel lane to edge of pavement*

PC = Point of curvature.
PT = Point of tangency.
Note: Items in italics were added to the initial list based on stakeholder feedback.

Table 2. Roadway inventory attributes.

Feature	Attribute	Attribute Definition
Roadway	Number of through lanes	Number of continuous through lanes on road segment
	Roadway use restrictions	Vehicle restrictions that apply to the entire road segment (e.g., no trucks, HOV/HOT, height or weight limits, HAZMAT, tolled, etc.)
	Roadway surface type	*Type of roadway surface or pavement (e.g., dirt, gravel, asphalt, concrete)*
Lane	Lane number	Integer value indicating which lane in a roadway segment attributes apply (by convention, lanes are counted outward from the center of the roadbed in the direction of travel (e.g., left to right in United States)
	Lane width	Measured width of lane
	Special lane function type	Special lane function type (e.g., left-turn lane, HOV/HOT lane, bicycle lane, reversible lane, bus bay, tolled, etc.)
	Lane pavement marking location	*Location of pavement marking relative to lane in direction of travel (e.g., left, right, inside)*
	Lane pavement marking type	*Type of longitudinal pavement markings (roadway edge, solid centerline, dashed, "diamond" lane)*
Median	Median location	Start and end of median relative to the roadway in the direction of travel
	Median type	Soil, paved (striped), paved (barrier), raised curb, other
	Median width	Average width of median
Shoulder	Shoulder location	Start and end of shoulder relative to the roadway in the direction of travel (including left/right side)
	Shoulder type	Paved, unpaved, composite (part paved, part unpaved), and curb
	Shoulder width	Width of paved portion of shoulder, measured from edge of travel lane to edge of paved surface
	Clear zone width	Measured from edge of travel lane to either a fixed obstacle, or nontraversable slope (> 1:3)
	Special shoulder function type	*Special shoulder use (e.g., queue bypass lanes for HOV or transit, peak-period travel lane)*

See notes at end of table.

Table 2. Roadway inventory attributes—Continued.

Feature	Attribute	Attribute Definition
Sidewalk	Location of sidewalk	Start and end of sidewalk relative to the roadway in the direction of travel (including left/right side)
Ramp	Ramp location	Location of gore point of ramp
	Ramp type	Entry, exit, freeway-to-freeway (in direction of travel)
	Ramp number of lanes	Number of continuous through lanes on ramp
	Ramp merge feature	Acceleration or deceleration lane
	Ramp special lane function type	*Special lane function on ramps (e.g., queue bypass lane for HOV or transit)*
Speed zone	Speed zone location	Start and end of speed zone relative to roadway
	Posted speed limit	Posted speed within speed zone
	Posted advisory speed	Posted advisory speed on curves
	Special speed zone type	Type of special speed zone (e.g., school zone, work zone, differential speed limits for trucks, variable speed limits, by lane, if applicable)
Roadside barrier (guardrail)	*Barrier location*	*Start and end of barrier relative to the roadway in the direction of travel (including left/right side)*
	Barrier type	*Cable, guardrail, concrete barrier, other*

HOT = High-occupancy/toll.
HAZMAT = Hazardous materials.
Note: Items in italics were added to the initial list based on stakeholder feedback.

Table 3. Intersection characteristics.

Feature	Attribute	Attribute Definition
Geometry	Intersection location	Location of center and corners of intersection
	Intersection ID	*Global identifier that indicates the operating agency and unique identification number of the intersection*
	Type of intersection	X-intersection, T-intersection, Y-intersection, roundabout, more than 4 intersecting segments
Approach lane configuration	Number of through lanes	Number of through lanes on approaching road segment
	Lane width	Individual widths for through and turn lanes
	Left-turn prohibition	Yes/no
	U-turn prohibition	*Yes/no*
	Number of left-turn lanes	Number of exclusive left-turn lanes
	Location of left-turn lane	*Location of start of the left-turn lane on approaching road segment*
	Left-turn channelization	Are left-turn lanes physically separated by curb or positive barrier?
	Right-turn prohibition	Yes/no
	Number of right-turn lanes	Number of exclusive right-turn lanes
	Location of right-turn lane	*Location of start of the right-turn lane on approaching road segment*
	Right-turn channelization	Are right-turn lanes physically separated by curb or positive barrier?
	Vehicle paths through intersection	Centerline and route of all available vehicle paths through the intersection
Pavement markings	Location of stop bar	Location of left and right edge of the stop bar on approach
	Location of pedestrian crosswalk	Location of edge of marking nearest to the vehicle
	Location of midblock pedestrian crosswalk	Location of edge of marking nearest to the vehicle
Traffic control	Type of traffic control	Signalized, stop sign, yield sign, none
	Location of traffic signal	Location of traffic signal head
	Traffic signal preemption	*Is traffic signal preemption provided for emergency vehicles at signalized intersection?*
	TSP	*Is TSP provided for emergency vehicles or transit vehicles at signalized intersection?*
	Special traffic control	*Special traffic control for buses, BRT (e.g.,queue jump in right-turn lane), mixed traffic (i.e., light rail transit vehicles and autos)*

BRT = Bus rapid transit.
TSP = Transit signal priority.
Note: Items in italics were added to the initial list based on stakeholder feedback.

Table 4. Other geospatial features.

Feature	Attribute	Attribute Definition
Rail crossings	Railroad crossing location	Position of first rail of first track at at-grade railroad crossing
	Railroad crossing control type	Type of crossing control (e.g., sign, pavement marking, signal, gates)
	Railroad crossing identifier	U.S. DOT inventory crossing number
Bridges/ tunnels	Bridge/tunnel location	Start and end of bridge/tunnel relative to the roadway in direction of travel
	Structure type	Bridge, tunnel traversed by roadway, bridge crossing over roadway
	Overhead clearance	*Actual and posted clearance height of structure crossing over a roadway*
	Restrictions	Height or weight limits
	Bridge identifier	NBI number
Transit facilities	*Transit stop location*	*Location of bus stop*
	Transit stop type	*Type of bus stop, such as in-lane, pulloff lane, counterflow pullout*
Commercial vehicle facilities	*Truck parking facility location*	*Location of truck parking facility (public and private)*
	Truck parking facility capacity	*Number of trucks allowed to park at facility*
	Roadside inspection/ weigh station location	*Location of roadside inspection/weigh stations*
	Runoff lane location	*Location of runoff lane for trucks*
GPS coverage	GPS coverage area location	Boundaries of areas where GPS coverage is enhanced or limited
	GPS coverage area type	Type of GPS coverage (e.g., GPS coverage limited by terrain, structures, or other factors, or enhanced NDGPS coverage available)
Weather monitoring coverage	Weather monitoring coverage area location	Boundaries of areas where local weather monitoring station data are transmitted to motorists
Road condition monitoring coverage	*Road condition monitoring coverage area location*	*Boundaries of areas where real-time information on road conditions is transmitted to motorists*
Traffic monitoring coverage	Traffic monitoring coverage area location	Boundaries of areas where real-time information on local traffic conditions is transmitted to motorists

NDGPS = National Differential Global Positioning System.
Note: Items in italics were added to the initial list based on stakeholder feedback.

CHAPTER 3. ROADWAY GEOMETRY AND INVENTORY DATA SOURCES

This chapter summarizes the findings from the investigation of existing and potential sources of roadway geometry and inventory data and discusses how well the sources satisfy the data needs identified by IntelliDrive stakeholders.

The investigation began with an extensive Web-based search to identify all U.S. commercial roadway database developers, a review of publicly available marketing material and technical documentation provided by those commercial developers, and an email to all State DOTs asking for information about the roadway inventory data they collect and maintain. A series of indepth follow-up interviews were conducted with commercial roadway data developers to obtain additional information about their databases and data collection procedures and to better understand their current business plans with respect to providing additional data needed to support potential IntelliDrive applications. Interviews also were conducted with a selected sample of State DOTs; local highway, public transit, and transportation management agencies; and commercial roadway data collection firms. The purpose of these interviews was to better understand what roadway data are currently being collected by public agencies or what could be collected with emerging technology and to investigate what actions might be needed to encourage public agencies to collect specific data items in support of IntelliDrive applications. Summaries of each of the interviews can be found in appendix C of this report.

The remainder of this chapter is subdivided into three subsections based on the geographical coverage of the data: national, statewide, and local or sub-state. A fourth subsection summarizes the findings regarding emerging data collection technologies.

ALTERNATIVE METHODS FOR STORING AND DISPLAYING ROADWAY DATA

All of the roadway geometry and inventory data required for IntelliDrive applications are georeferenced, meaning they can be linked to a physical location on the earth and can be located and displayed on a map.

Georeferenced data can be stored and displayed using one of the following four methods:

- As a feature of a geospatial roadway network (e.g., a roadway segment or endpoint).
- As an attribute linked to a geospatial roadway network feature.
- As a separate geospatial feature (e.g., point, line, or area).
- As a linear or point feature linked to geospatial roadway network via LRS.

Each of these methods has implications with respect to the locational accuracy, resolution, and ease of integrating data across sources. To better understand these implications, this chapter presents brief descriptions of each data storage method.

Geospatial Roadway Network Features

A geospatial roadway network is a vector-based representation of the physical roadway network. Geospatial roadway networks are comprised of two simple geometric objects—points (which specify locations) and lines (which depict the roadway segments that connect two points).

Both points and lines can include attribute data. Point attributes typically include geographic coordinates such as latitude and longitude (and elevation data, where available), which enable the point to be associated with a physical location on the earth. Point attributes can also contain information about the physical location associated with the point, such as a specific intersection or geographic feature type (e.g., bridge).

Line attributes typically contain information about the physical roadway segment depicted by the line, including items such as road name, number of lanes, surface type, traffic flow (i.e., one- or two-way), and grade or slope.

Roadway segments can be of any arbitrary length, depending on the application needs of the network developer. Typically, a new roadway segment is defined whenever there is a change in a key attribute (e.g., number of lanes). Additionally, roadway networks that support vehicle routing applications define new roadway segments wherever two roads physically intersect (e.g., at-grade intersections or freeway exit and entrance ramps).

Attributes Linked to a Geospatial Roadway Feature

Each roadway segment and endpoint in a geospatial roadway network database has a unique identifier. These unique identifiers can be used to link attribute data stored in other databases to a specific roadway feature for display or analysis purposes. Attribute data that are linked using a feature identifier are assumed to apply to the entire feature. Therefore, if an attribute changes along a roadway segment (e.g., pavement width), the segment must be split wherever the change occurs or the associated pavement width value will be inaccurate over some portion of the segment.

Linking attributes to roadway segments and endpoints using a unique identifier also requires considerable maintenance and updating of the identifiers themselves. For example, whenever a roadway segment is split (e.g., to accommodate a new intersection), the old roadway segment identifier must be retired and three new segment identifiers (plus one new endpoint identifier) must be created. Attributes associated with the old segment must have their segment identifier updated, and new attribute records must be created for each new roadway feature. These changes in feature identifiers must be implemented in all attribute databases linked to the geospatial roadway network using this method.

Other Geospatial Features

Some roadway data may be represented as separate geospatial features distinct from the geospatial roadway network itself. Roadway-related data that are typically depicted as separate geospatial features include bridges, railroad crossings, signs and traffic signals, and points of interest (POIs) (e.g., rest areas, airports, etc.).

These geospatial features can be displayed and linked to the geospatial roadway network based on their geographic coordinates. The primary function of GIS technology is to link data stored in different georeferenced databases based on their location information. However, the accuracy with which data stored in different geospatial databases can be linked depends on how accurately the location is measured in each database. The position of a bridge can appear to be off by several meters or more from a roadway feature if location measurements in the two databases were collected based on different accuracy standards.

Attributes Linked to an LRS

Many roadway attributes maintained by State DOTs are linked to a location on the physical roadway network using an LRS. With an LRS, locations of roadway features such as bridges, guardrails, or signs and changes in roadway attributes such as number of lanes or pavement condition are measured as a linear distance along a defined route from a specific reference point. The reference point could be a physical feature, like an intersection or mile marker signpost, a virtual point, like a State or county boundary, or the starting point of a State numbered route. By specifying the reference point and measured distance, virtually any roadway feature can be located within the accuracy of the distance measurement.

Linear referencing has been used by State DOTs for nearly 40 years and predates the use of GIS technology in most State DOTs by more than 20 years. Indeed, many State DOTs still maintain roadway inventory data on a mainframe computer and have only recently begun migrating these databases into a GIS enterprise environment, which allows the data to be integrated and displayed together with the State DOT’s geospatial roadway network.

Keeping an LRS up to date requires considerable effort. New distance measurements must be taken whenever a road is realigned or a route redefined (e.g., a numbered route is switched to another road). State DOTs have developed elaborate internal procedures to update their LRS under different situations, and these procedures vary from State to State and even from one database to another within a State DOT. Additionally, State DOTs develop and maintain an LRS only for those roads for which they have maintenance or administrative responsibility. Most roads within a State have no associated LRS.

In the following discussion of roadway data sources, information is presented on the primary method of data storage and on any alternative methods used. The terms used to describe each of the four data storage methods are *geospatial roadway endpoint or roadway segment feature*; *linked via roadway feature ID*; *other geospatial feature*; and *linked via LRS*.

NATIONAL-LEVEL DATA SOURCES

National Geospatial Roadway Networks

The investigation identified six geospatial roadway network databases that provide nationwide coverage and include all, or nearly all, public roads. They are ALK Digital Maps™, DeLorme North America Data Set™, Google Maps™, NAVTEQ™ Road Network Database, Tele Atlas® MultiNet®, and Census Bureau TIGER/Line®. Only one of these databases, the Census Bureau TIGER/Line®, is in the public domain. The other five are proprietary databases, developed for specific commercial applications. Table 5 compares each of the roadway network databases with respect to several key database characteristics. Table 6 through table 9 indicate which of the specific roadway data elements identified by IntelliDrive stakeholders are currently included in each roadway network database.

All five of the commercial roadway networks support vehicle routing, with roadway segment attributes identifying one-way streets, overpasses and underpasses, turn restrictions, numbered route identifiers, and stratification by roadway type (e.g., limited access principal routes versus local streets). Most importantly, the commercial roadway networks segment their roadway features at all at-grade intersections and clearly identify those roadway segments that cross but do not physically intersect (e.g., overpasses and underpasses). This data structure, which is essential for vehicle routing, is defined as network topology.

The Census Bureau TIGER/Line® road network does not support vehicle routing directly. The TIGER/Line® database was developed to help the Census Bureau define geographic areas for the purposes of collecting, compiling, and reporting population statistics. Roads are one of several geospatial features used to delineate Census boundaries. Others include rivers, railroads, and State, county, and municipal borders. All of these features are collapsed into a single layer based on planar topology (i.e., linear segments are defined wherever two linear features cross). There are no explicit attributes or data structures in TIGER/Line® that distinguish between roads that cross at-grade and those that cross but do not physically intersect. Nor is there attribute data in TIGER/Line® that identifies one-way verses two-way road segments or restrictions on turning movements. Any or all of these attributes can be added to the TIGER/Line® geometry. Indeed, most of the commercial roadway databases were originally developed from previous versions of TIGER/Line® road databases. However, these enhancements require considerable time and effort, and the required data must be obtained from other nonproprietary sources, such as State and local transportation agencies.

Table 5. National roadway network databases.

Database Developer	ALK®	DeLorme	Google™	NAVTEQ™	Tele Atlas®	Census Bureau
Database Name	ALK Digital Maps™	North America Data Set™	Google Maps™	Road Network Database	MultiNet®	TIGER/ Line®
Coverage Area	United States; Canada	United States; Canada	United States	United States; Canada; Mexico	United States; Canada; Mexico	United States
Locational Accuracy	Equivalent or better than 7.5 m on local streets; 3–5 m on major roads	Equivalent or better than 7.5 m; < 5 m in urban areas	Unspecified	Standard < 15 m absolute; enhanced < 5 m absolute	Standard < 13 m absolute; enhanced < 5 m absolute	7.5 m absolute for sampled points
Datum	NAD83, WGS84	NAD27, NAD83, WGS84	Unspecified (likely WGS84)	WGS84	WGS84	NAD83
Native Projection	Latitude/ longitude	Latitude/ longitude	Latitude/ longitude	Latitude/ longitude	Latitude/ longitude	Latitude/ longitude
Export Format	Shapefile	Multiple: (Geodatabase, Shapefile)	Map data not sold separately from application	Multiple: (GDF, Shapefile, MapInfo TAB)	Multiple: (GDF, Shapefile)	Shapefile
Dual Centerlines	Yes	Yes	Yes	Yes	Yes	Yes
Freeway Ramps	Yes	Yes	Yes	Yes	Yes	Yes
Street Address Information	Street addresses and POIs	Street addresses and POIs	Street addresses and POIs	Street addresses and POIs	Street addresses and POIs	Address ranges
Supports Routing and Navigation	Yes	Yes	Yes	Yes	Yes	No
Update Frequency	Monthly	Twice a year	Unspecified	At least quarterly	At least quarterly	No regular update cycle

1 m = 3.28 ft.
NAD = North American Datum.
WGS = World Geodetic System.

Table 6. Roadway geometry data included in national roadway networks.

Feature	Attribute	Data Storage Method	Geospatial Roadway Networks					
			ALK®	DeLorme	NAVTEQ™	Tele Atlas®	Google™	TIGER/ Line®
Horizontal alignment	Horizontal curve PC location	Segment			F	A		
	Horizontal curve length	Segment ID			F	A		
	Horizontal curve radius	Segment ID			F	A		
Grade	Grade in direction of travel	Segment ID			F	A		
Elevation	Roadway elevation	Endpoint			F	A		
Vertical alignment	Vertical curve PC location							
	Vertical curve PT location							
	Vertical curve length							
Sight distance	Available sight distance (stopping, passing)							
Cross slope	Roadway cross slope							
	Shoulder cross slope							

PC = Point of curvature.
PT = Point of tangency.
Segment = Data item stored as part of feature geometry.
Segment ID = Data item stored as attribute value linked to segment identifier.
Endpoint = Data item stored as part of endpoint coordinate.
A = Data item available for all or most roadway segments.
F = Data item available for only some road segments based on functional class.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 7. Roadway inventory data included in national roadway networks.

Feature	Attribute	Data Storage Method	Geospatial Roadway Networks					
			ALK®	DeLorme	NAVTEQ™	Tele Atlas®	Google™	TIGER/ Line®
Roadway	Number of through lanes	Segment ID			A	F		
	Roadway use restrictions	Segment ID	F		F	F		
	Roadway surface type	Segment ID	A	A	A	A	A	A
Lane	Lane number	Segment ID			F	F		
	Lane width							
	Special lane function type	Segment ID			F	F		
	Lane pavement marking location	Segment ID			F	F		
	Lane pavement marking type	Segment ID			F	F		
Median	Median location	Segment			A	A	A	
	Median type	Segment ID			G			
	Median width							
Shoulder	Shoulder location							
	Shoulder type							
	Shoulder width							
	Clear zone width							
	Special shoulder function type							
Sidewalk	Location of sidewalk	Segment ID			G	G		
Ramp	Ramp location	Segment	A	A	A	A	A	A
	Ramp type	Segment ID	A	A	A	A	A	
	Ramp number of lanes	Segment ID			F	F		
	Ramp merge feature							
	Ramp special lane function type	Segment ID			G			
Speed zone	Speed zone location	Segment ID	F		F	F		
	Posted speed limit	Segment ID	F	F	F	F		
	Posted advisory speed	Segment ID			F	F		
	Special speed zone type	Segment ID	F		F	F		
Roadside barrier (guardrail)	Barrier location							
	Barrier type							

Segment = Data item stored as part of feature geometry.
Segment ID = Data item stored as attribute value linked to segment identifier.
A = Data item available for all or most roadway segments.
F = Data item available for some road segments based on functional class.
G = Data item available for some road segments based on geographical area.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 8. Intersection characteristics included in national roadway networks.

Feature	Attribute	Data Storage Method	Geospatial Roadway Networks					
			ALK®	DeLorme	NAVTEQ™	Tele Atlas®	Google™	TIGER/ Line®
Geometry	Intersection location	Endpoint	A	A	A	A	A	A
	Intersection ID							
	Type of intersection	Endpoint ID	A	A	A	A	A	A
Approach lane configuration	Number of through lanes	Segment ID			G	G		
	Lane width							
	Left-turn prohibition	Segment ID	G	G	G	G	G	
	U-turn prohibition	Segment ID	G	G	G	G	G	
	Number of left-turn lanes	Segment ID			G	G		
	Location of left-turn lane	Segment ID			G	G		
	Left-turn channelization	Segment ID			G	G		
	Right-turn prohibition	Segment ID	G	G	G	G	G	
	Number of right-turn lanes	Segment ID			G	G		
	Location of right-turn lane	Segment ID			G	G		
	Right-turn channelization	Segment ID			G	G		
	Vehicle paths through intersection							
Pavement markings	Location of stop bar							
	Location of pedestrian crosswalk	Other			G	G		
	Location of midblock pedestrian crosswalk	Other			G	G		
Traffic control	Type of traffic control	Other ID			F	F		
	Location of traffic signal	Other			F	F		
	Traffic signal preemption							
	TSP							
	Special traffic control							

TSP = Transit signal priority.
Segment ID = Data item stored as attribute value linked to segment identifier.
Endpoint = Data item stored as part of endpoint coordinate.
Endpoint = Data item stored as attribute value linked to endpoint ID.
Other = Data item stored as other geospatial feature.
Other ID = Data item stored as attribute value linked to other geospatial feature.
A = Data item available for all or most roadway segments.
F = Data item available for some road segments based on functional class.
G = Data item available for some road segments based on geographical area.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 9. Other geospatial features included in national roadway networks.

Feature	Attribute	Data Storage Method	Geospatial Roadway Networks: ALK®	DeLorme	NAVTEQ™	Tele Atlas®	Google™	TIGER/ Line®
Rail crossings	Railroad crossing location	Other	A	A	A	A	A	A
	Railroad crossing control type							
	Railroad crossing identifier							
Bridges/tunnels	Bridge/tunnel location	Other	A	A	A	A		
	Structure type	Other ID			A	A		
	Overhead clearance	Other ID	F	F	F	F		
	Restrictions	Other ID	F		F	F		
	Bridge identifier							
Transit facilities	Transit stop location	Other			G		G	
	Transit stop type	Other ID			G		G	
Commercial vehicle facilities	Truck parking facility location	Segment	F		F	F		
	Truck parking facility capacity							
	Roadside inspection/weigh station location	Segment	F	F	F	F		
	Runoff lane location	Segment	F	F	F	F		
GPS coverage	GPS coverage area location							
	GPS coverage area type							
Weather monitoring coverage	Weather monitoring coverage area location							
Road condition monitoring coverage	Road condition monitoring coverage area location							
Traffic monitoring coverage	Traffic monitoring coverage area location	Other	G		G	G		

Segment = Data item stored as part of feature geometry.
Other = Data item stored as other geospatial feature.
Other ID = Data item stored as attribute value linked to other geospatial feature.
A = Data item available for all or most roadway segments.
F = Data item available for some road segments based on functional class.
G = Data item available for some road segments based on geographical area.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Only two of the commercial developers, NAVTEQ™ and Tele Atlas®, reported that they are planning to enhance their current roadway network databases in order to support IntelliDrive data requirements. Those enhancements include the following:

- Improved locational accuracy of roadway segment geometry from 32.8–49.2 ft (10–15 m) absolute error to 3.28–16.4 ft (1–5 m).
- Explicit measurement of horizontal curvature and grade.
- Enhanced lane information at freeway interchanges and complex urban intersections.
- Enhanced attributes for pavement markings, traffic signs and signals, special speed limits, restricted lanes or roadways, and pedestrian features such as crosswalks, transit stops, and nonmotorized pathways.

While improvements in locational accuracy are being incorporated directly into their core roadway networks, both NAVTEQ™ and Tele Atlas® are developing and marketing their new data attributes as supplemental products to their core roadway navigation database. Measures of roadway curvature and grade are bundled with longitudinal lane markings in an advanced driver assistance system (ADAS) product, while attributes pertaining to pedestrian and transit use are bundled into an Urban Maps™ or Discover Cities™ product.[1]

Neither NAVTEQ™ nor Tele Atlas® currently provides complete nationwide coverage for all ADAS attributes. In general, attribution is more complete on higher functional class roads (e.g., interstates, other freeways, and major through routes) and in larger urban areas. Attribution is less consistent, or missing entirely, on low-volume rural roads and local streets.

Roadway Geometry

All of the national geospatial roadway networks define roadway segments as the "centerline of the travel way." In practice, this means that roads that allow two-way traffic flow without a center median or physical barrier are depicted as a single line feature. Divided highways that are separated by a median or physical barrier are depicted as separate line features—one for each travel direction. Individual travel lanes are only depicted as a separate line feature when they are separated from the main roadway by a physical barrier (i.e., HOV lanes, exit/entrance ramps, or channelized turn lanes). Otherwise, lanes are represented as attributes of the roadway segment (e.g., number of lanes, average lane width).

NAVTEQ™ and Tele Atlas® are currently collecting data on horizontal curvature, grade, and elevation as components of their enhanced ADAS data products. The data are stored as attributes of individual roadway segments, endpoints, and even of individual vertices (shape points) that are used to define the geometry of a roadway segment. NAVTEQ™ currently calculates roadway horizontal curvature and grade only for those roads where it has collected more accurate roadway

[1] Both NAVTEQ and Tele Atlas use the term ADAS to refer to enhancements in their roadway network databases that are intended to support potential IntelliDrive applications. The terms ADAS and IntelliDrive appear to be synonymous. Throughout this report, ADAS will be used to describe enhancements being made by these two commercial database developers to specifically support IntelliDrive.

centerline coordinate information (i.e., freeways and major through routes). Tele Atlas® reports having horizontal curvature, grade, and elevation for all U.S. roads. However, these measures are calculated from the existing digitized road vectors and are only as accurate as the underlying road database.

None of the national roadway networks currently include measures of vertical curvature, cross slope/superelevation, or available sight distance.

Roadway Inventory and Intersection Characteristics

The geographic locations of roadway intersections, ramps, and most medians (over a specified length) are defined implicitly by the way road segments and endpoints are depicted in a roadway network database. Most at-grade intersections are depicted as a point feature, which represents the approximate geographic center of the intersection itself.

Data on posted speed limits, number of lanes, roadway use restrictions, and restrictions on specific turning movements at intersections are maintained by most of the commercial roadway network developers. More detailed ramp information, lane- and intersection-level attributes, sidewalks, pavement markings, and traffic signal characteristics are being collected only by NAVTEQ™ and Tele Atlas® for specific roadway types and/or geographic areas. None of the commercial roadway networks currently include data on roadway shoulders and guardrails or specific attribute data on medians or individual lanes.

Other Geospatial Features

Most commercial roadway network developers currently maintain data on the locations of highway bridges, tunnels, and railroad crossings. These locations are either stored as a separate geospatial feature (e.g., a point, line, or network) or integrated into the roadway network itself as a roadway segment (e.g., a long bridge) or segment endpoint (e.g., a railroad crossing). In general, these features were originally obtained from public data sources (see next chapter), but the locational accuracy has been updated and corrected to better match the geospatial accuracy of the roadway network database.

Those developers with products oriented toward commercial trucks (including NAVTEQ™, Tele Atlas®, and ALK®) also have attribute data on bridge height and weight restrictions, vehicle restrictions on specific roadways, toll roads, and locations of truck rest areas and weigh stations, primarily on higher functional class roads. Attribute data may have been obtained from public data sources, but the commercial database developers have updated and corrected this information using a variety of sources, including ongoing contacts with State and local roadway agencies, error reporting and feedback from their database clients (e.g., trucking companies), and strategic partnerships with specialized industry data sources.

Only NAVTEQ™ and Google™ currently have transit stop locations and typically only in large cities.

National Roadway Inventory Databases

The investigation identified three databases maintained by the U.S. DOT that provide nationwide coverage for some of the roadway attributes identified by IntelliDrive stakeholders. These databases are described in this section.

HPMS

Web site: http://www.fhwa.dot.gov/policy/ohpi/hpms/index.cfm

FHWA's HPMS is a public domain database of roadway condition and performance measures submitted annually by State DOTs in compliance with federally mandated reporting requirements. Several data items identified by IntelliDrive stakeholders are included in the HPMS submission.

HPMS data are used by FHWA to produce its annual *Highway Statistics* report, which summarizes the current status of the Nation's highways. The data also are used extensively in the analyses of highway system condition, performance, and investment needs that make up the biennial *Condition and Performance* reports to Congress.

FHWA requires State DOTs to submit certain information about all public roads located within the State. However, data on non-Federal-aid roads (i.e., roads classified as local or minor rural collector) need only be summarized by functional class. Data on Federal-aid roads, including all roads on the National Highway System (NHS) and other roads functionally classified as major collector or higher, are reported by specific roadway segment. A limited number of data items (universe data) must be reported for all roadway segments. These include number of through lanes, number of HOV lanes, average daily traffic, ramp locations, and number of lanes on each ramp. A more extensive list of roadway attributes (sample data) are reported only for a small, statistically selected sample of roadway segments. Sample data include several of the roadway inventory data items identified by IntelliDrive stakeholders such as lane width, median and shoulder types, and speed limit.

The principal value of HPMS as a source of roadway inventory data is that it provides a standardized and consistent set of specific attribute data across all States. However, many of the data items of interest to IntelliDrive stakeholders, including roadway curvature, median, shoulder, and intersection characteristics, are only reported for sample segments in each State. Moreover, some attributes, such as horizontal curve and grade, are reported not as individual occurrences but as summaries or percentages over the entire length of each sample segment.

Another consideration in using HPMS as a data source for IntelliDrive applications is that HPMS data represents roadway attributes along an "inventory" direction. This is particularly relevant on divided highways (i.e., roads with a median or barrier separating directional travel lanes). The data reported in HPMS on divided highways differ depending on the specific data item. For example, reported number of through lanes and average annual daily traffic represent the sum of both directions, while average lane width and pavement condition represent data collected only in the inventory direction.

Lastly, HPMS does not collect segment-specific data for roads that are not part of the Federal-aid system (i.e., local roads and minor rural collectors). These are, in general, the same roads that commercial roadway network database developers find most difficult to accurately attribute and keep current. These roads comprise approximately 75 percent of the total roadway centerline mileage in the United States, although they carry only 15 percent of total annual vehicle miles traveled.[3]

Since about 2000, information on the location of roadway segments reported in HPMS has been stored using a national LRS developed by FHWA. The national LRS allowed FHWA to display HPMS attribute data on the National Highway Planning Network (NHPN), a relatively inaccurate geospatial roadway network representing higher functional class roads, including those that comprise the NHS. However, State DOTs were required to translate roadway data from their own internal LRS to FHWA's national LRS, which often resulted in reporting errors and loss of locational accuracy, since most State roadway networks are more accurate and current than the NHPN. Consequently, beginning with the 2010 HPMS submission, FHWA will require State DOTs to report HPMS segment locations using their own LRS and geospatial roadway network in lieu of the national LRS. State DOTs also must include their geospatial roadway network and LRS as part of their annual HPMS submission so that FHWA can display HPMS data using the State networks.

NBI

Web site: http://www.fhwa.dot.gov/Bridge/nbi.htm

NBI is a database containing approximately 600,000 of the Nation's bridges subject to the National Bridge Inspection Standards (NBIS), including all bridges that are open to the public and are longer than 20 ft (6.1 m).[4]

Bridge records in NBI are stored as geospatial point features, independent of any specific geospatial roadway network. Each bridge record contains approximately 100 attributes, including information on the bridge's location, structure and material type, age and service, geometric data, navigational data, classification, condition rating, load rating and posting, and appraisal and inspection types and dates. These data are collected, updated, and maintained by State DOTs and are reported to FHWA on an annual basis in compliance with the NBIS. Both geographic coordinates (i.e., latitude and longitude) and LRS measures are collected for bridges located on Federal-aid highways. The LRS measures are being updated to be consistent with new LRS reporting requirements in HPMS.

The NBI *Reporting and Coding Guide* allows each State flexibility in determining what point on the bridge is used to define its location (e.g., beginning of span verses midpoint).[5] Currently, NBI does not require States to report locations for bridges located on non-Federal-aid roads.

Although States submit updates to the NBI annually, many bridge attributes, such as vertical clearances and load capacities, are typically updated only after a bridge inspection. NBIS regulations typically require bridges to be inspected at least once every 2 years, but States may request a waiver to extend the inspection interval on certain bridges to 4 years. Consequently, some attribute data in NBI could be more than 4 years out of date.

HRCI

Web site: http://www.fra.dot.gov/us/content/801

The U.S. DOT's HRCI is a database of all public and private highway-rail crossings, including pedestrian crossings, both at-grade and grade separated (i.e., overpasses and underpasses). Each crossing is identified by a unique crossing inventory number assigned by the Federal Railroad Administration (FRA).

Highway-rail crossing records in HRCI are stored as geospatial point features, independent of any specific geospatial roadway network. Location is stored as geographic coordinates representing the midpoint of the crossing. Each record includes up to 152 attributes, including location, railroad and highway traffic volumes, signal system, and highway and railroad physical characteristics and geometry. These data are collected and maintained jointly by State DOTs and the railroad that owns the track. Previously, there was no regular reporting cycle for HRCI. However, starting October 16, 2010, the Rail Safety Improvement Act of 2008 requires both States and railroads to provide annual updates to HRCI.[6] Additionally, updates to inventory data items are to be reported whenever a physical change occurs at the highway-rail crossing (e.g., installation of a new signal system, significant changes in highway or railroad traffic, addition or abandonment of a crossing track, etc.).

STATE-LEVEL DATA SOURCES

State Geospatial Roadway Networks

State DOTs in all 50 States and the District of Columbia have developed and currently maintain geospatial roadway networks. The State roadway networks are used primarily to display roadway inventory data collected by the State DOT and to integrate data collected by different parts of the agency based on geographic location. A majority of State DOTs are in the process of establishing agency-wide enterprise GIS data warehouses that will enable agency staff to link any geographically referenced database to the roadway network using geospatial coordinates and/or LRS.

The roadway networks developed by State DOTs vary significantly with respect to locational accuracy, feature representation and resolution, completeness, and network connectivity. Over the past decade, many State DOTs have initiated programs to improve the locational accuracy of their roadway network databases, utilizing high resolution (1:10,000 scale or better) digital orthoimagery or GPS tracks collected by roadway inventory vehicles. The geospatial roadway networks produced from these data collection methods have locational accuracies of ±16 ft (5 m) absolute error or better. According to the most recent annual survey of State DOT GIS coordinators, about 60 percent of State DOTs currently have or are developing geospatial roadway networks at this level of locational accuracy.[7]

Improved locational accuracy typically leads to more detailed representation of roadway features. Most of the roadway networks that have been created using high resolution orthoimagery or GPS also include digitized representations of freeway interchange ramps, separate centerlines for each travel direction on divided highways, and dual centerlines for roads separated by a median or physical roadway barrier.

About half of the roadway network databases developed by State DOTs include all public roads. Other State roadway network databases only include those roads that are maintained by the State DOT or that are eligible for Federal highway funding (i.e., roads functionally classified as major collectors or above). Local roads are often not included or are maintained in a separate roadway database that is used only for display purposes and is updated sporadically.

Because State geospatial roadway networks are used primarily for displaying roadway data and not for network analysis or modeling, many of the State networks have not been thoroughly checked for network connectivity. Therefore, the networks are currently not suitable for vehicle routing or navigation. Additionally, many of these databases do not include key attributes required for vehicle navigation such as one-way streets, turn restrictions at intersections, or clear differentiation of overpasses from at-grade intersections.

A few State DOTs have entered into contractual agreements with commercial roadway database developers (primarily NAVTEQ™ or Tele Atlas®) to use a commercial roadway network as the geospatial roadway network for the State. These agreements typically include provisions for data sharing and statewide licenses that allow various State and local public agencies to use the commercial roadway network without paying additional license fees.

State Roadway Inventory Databases

Each State DOT collects and maintains information on the characteristics, condition, and performance of roadways under its jurisdiction. Except for data that are reported to FHWA as part of the annual HPMS submission, there are few, if any, nationwide standards regarding what information is collected, how it is collected, or how it is defined within an agency's roadway inventory database system. Some State DOTs collect and maintain little more than what is required for HPMS submission, while others collect and maintain significantly more data on more roads than required for Federal reporting.

There is also considerable variation in the percent of roads for which State DOTs collect and maintain roadway inventory data. Typically, State DOTs collect and maintain inventory data only on those roads where they have administrative and/or maintenance responsibilities. In most States, State DOTs are responsible for a State highway system composed of interstate, U.S. primary, and State numbered routes (e.g., I-95, US 66, California 1), and the agency delegates responsibility for local roads, collectors, and even some arterials to counties and municipal road agencies. State highway systems typically represent between 10 and 15 percent of all roadway centerline mileage within the State. In a few States, however, the State DOT is responsible for all public roads, except where a local jurisdiction specifically requests administrative responsibility for its roads. In Virginia, for example, the Virginia DOT has administrative and maintenance responsibility for 78 percent of all roadway centerline miles.

Table 10 through table 13 summarize the roadway geometry and inventory data that are currently being collected and maintained by a sample of 16 State DOTs (32 percent of all State DOTs). The information was obtained from responses to an email request sent to all State DOTs and from indepth interviews conducted with State DOTs in California, Florida, Michigan, Virginia, and Washington. The tables distinguish between attributes that the State DOTs collect as part of their internal roadway data collection and those that they are required to collect on selected roadway sample segments for HPMS reporting.

Table 10. Roadway geometry data collected by State DOTs.

Feature	Attribute	CA	FL	HI	KS	MA	MI	MN	NV	NC	OH	OK	PA	SC	VA	WA	WY
Horizontal alignment	Horizontal curve PC location			F							F	F	F			F	F
	Horizontal curve length	H	H	F	H	H	H	H	H	H	H	F	F	F	H	F	F
	Horizontal curve radius	H	H	F	H	F	H	H	H	H	F	F	F	H	H	F	F
Grade	Grade in direction of travel	H	H	F	H	F	H	H	H	H	F	F	F	H	H	F	F
Elevation	Roadway elevation									F							
Vertical alignment	Vertical curve PC location												F			F	F
	Vertical curve PT location												F			F	F
	Vertical curve length												F	F		F	F
Sight distance	Available sight distance (stopping, passing)	H	H	H	F	H	F	H	H	H	H	F	H	H	H	H	F
Cross slope	Roadway cross slope															F	F
	Shoulder cross slope																F

PC = Point of curvature.
PT = Point of tangency.
F = Data item collected for some road segments based on functional class (State highway system).
H = Data item required for HPMS sample segments.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 11. Roadway inventory data collected by State DOTs.

Feature	Attribute	CA	FL	HI	KS	MA	MI	MN	NV	NC	OH	OK	PA	SC	VA	WA	WY
Roadway	Number of through lanes	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Roadway use restrictions		F								F	F	F		F		
	Roadway surface type	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Lane	Lane number																
	Lane width	H	F	F	F	H	F	F	H	H	H	F	F	F	F	H	F
	Special lane function type	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Lane pavement marking location																
	Lane pavement marking type																
Median	Median location	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Median type	F	F	F	F	F	H	F	H	F	F	F	F	F	H	F	F
	Median width	F	F	F	F	F	H	F	H	F	F	F	F	F	H	F	F
Shoulder	Shoulder location	F	F	F	F	F	F	F		F	F	F	F	F	F	F	F
	Shoulder type	F	F	F	F	F	F	F	H	F	F	F	F	F	H	F	F
	Shoulder width	F	F	F	F	F	F	F	H	F	F	F	F	F	H	F	F
	Clear zone width																
	Special shoulder function type		F				F					F					
Sidewalk	Location of sidewalk		F						F								
Ramp	Ramp location	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Ramp type	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Ramp number of lanes	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	Ramp merge feature						F										
	Ramp special lane function type						F										

See notes at end of table.

Table 11. Roadway inventory data collected by State DOTs—Continued.

Feature	Attribute	CA	FL	HI	KS	MA	MI	MN	NV	NC	OH	OK	PA	SC	VA	WA	WY
Speed zone	Speed zone location				F			F				F					F
	Posted speed limit	H	F	F	F	F	F	F	H	F	F	F	H	F	H	F	F
	Posted advisory speed			F	F												F
	Special speed zone type																
Roadside Barrier	Barrier location	F	F	F			F										
	Barrier type	F	F	F			F										

F = Data item collected for some road segments based on functional class (State highway system).
H = Data item required for HPMS sample segments.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 12. Intersection characteristics collected by State DOTs.

Feature	Attribute	CA	FL	HI	KS	MA	MI	MN	NV	NC	OH	OK	PA	SC	VA	WA	WY
Geometry	Intersection location	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**
	Intersection ID																
	Type of intersection	**F**			**F**			**F**								**F**	
Approach lane configuration	Number of through lanes	**F**	**F**	**F**	**F**			**F**				**F**		**F**		**F**	
	Lane width																
	Left-turn prohibition	**H**	**H**	**F**	**F**	**H**	**H**	**H**	**H**	**H**	**H**	**F**	**H**	**H**	**H**	**H**	**H**
	U-turn prohibition			**F**								**F**					
	Number of left-turn lanes	**F**	**F**	**F**	**F**	**H**	**H**	**H**	**H**	**H**	**H**	**F**	**H**	**F**	**H**	**H**	**H**
	Location of left-turn lane	**F**		**F**				**F**				**F**					
	Left-turn channelization	**F**		**F**					**F**			**F**					
	Right-turn prohibition	**H**	**H**	**F**	**F**	**H**	**H**	**H**	**H**	**H**	**H**	**F**	**H**	**H**	**H**	**H**	**H**
	Number of right-turn lanes	**F**	**F**	**F**	**F**	**H**	**H**	**H**	**H**	**H**	**H**	**F**	**H**	**F**	**H**	**H**	**H**
	Location of right-turn lane	**F**		**F**				**F**				**F**					
	Right-turn channelization	**F**		**F**					**F**			**F**					
	Vehicle paths through intersection																
Pavement markings	Location of stop bar																
	Location of pedestrian crosswalk																
	Location of midblock pedestrian crosswalk															**F**	
Traffic control	Type of traffic control	**F**	**H**	**F**	**F**	**H**	**H**	**F**	**H**	**H**	**H**	**F**	**H**	**F**	**H**	**H**	**H**
	Location of traffic signal			**F**				**F**				**F**					
	Traffic signal preemption																
	TSP																
	Special traffic control																

TSP = Transit signal priority.
F = Data item collected for some road segments based on functional class (State highway system).
H = Data item required for HPMS sample segments.
Note: Empty cells indicate the attribute is not included in the roadway network database.

Table 13. Other geospatial features collected by State DOTs.

Feature	Attribute	CA	FL	HI	KS	MA	MI	MN	NV	NC	OH	OK	PA	SC	VA	WA	WY
Railroad crossings	Railroad crossing location	F	F	F	F		F	F	F		F	F			F	F	F
	Railroad crossing control type		F	F	F		F	F	F			F			F	F	F
	Railroad crossing identifier		F	F	F	F	F	F	F		F	F			F	F	F
Bridges/tunnels	Bridge/tunnel location	F	F	F	F	F	F	F	F			F		F	F	F	F
	Structure type	F	F	F	F	F	F	F	F			F		F	F	F	F
	Overhead clearance	F	F	F	F	F	F	F	F			F		F	F	F	F
	Restrictions	F			F	F	F	F	F			F		F	F	F	F
	Bridge identifier	F	F	F	F	F	F	F	F			F		F	F	F	F
Transit facilities	Transit stop location																
	Transit stop type																
Commercial vehicle facilities	Truck parking facility location	F					F										
	Truck parking facility capacity																
	Roadside inspection/weigh station location	F					F								F	F	
	Runoff lane location	F															
GPS coverage	GPS coverage area location																
	GPS coverage area type																
Weather monitoring coverage	Weather monitoring coverage area location				F				F						F	F	
Road condition monitoring coverage	Road condition monitoring coverage area location	F													F	F	
Traffic monitoring coverage	Traffic monitoring coverage area location	F			F										F	F	

F = Data item collected for some road segments based on functional class (State highway system).
Note: Empty cells indicate the attribute is not included in the roadway network database.

Based on the responses received, none of the State DOTs routinely collect inventory data on non-Federal-aid roads (i.e., local and minor rural collectors). Even Virginia, which has administrative and maintenance responsibilities for many local roads, limits most of its roadway data collection to what it describes as “primary routes,” essentially higher functional class roads that include interstate, U.S. primary, and State numbered routes. Data collection on other roads is typically conducted only when needed to support a specific construction or maintenance project.

Information regarding specific roadway geometry and inventory data items collected by State DOTs is summarized in this section.

Roadway Geometry

Approximately half of the State DOTs that responded to the survey and/or interview reported that they are collecting data on horizontal alignment and grade beyond what is required for HPMS sample section reporting. Only about 25 percent of the State DOTs are also collecting data on vertical alignment. Even fewer are collecting data on roadway cross slope, clear zone width, or elevation of specific roadway lanes.

Sight distance is not an attribute that most State DOTs routinely collect as part of their roadway inventory. Sight distance is typically measured as needed on a project-by-project basis to locate roadway pavement markings and signs and is reported as a data element in HPMS only for sample sections and only as a summary measure (i.e., percent of total sample section length that meets the minimum sight distance requirement for passing). Of the State DOTs that responded to the survey, only Michigan DOT reported that they maintain an inventory of passing sight distances for State highway system roads.

Roadway Inventory

Nearly all of the State DOTs that responded indicated that they collect data on the number of lanes, medians, shoulders, ramps, and speed limits as part of their roadway inventory. Data collected includes location, median and shoulder type, widths, and information on special lane use or restrictions (where applicable). State DOTs also collect data on pavement condition, including cracking, rutting, and overall ride quality. Several State DOTs said that they only collect data on paved shoulders, and few indicated that they collect data on special use of ramps or shoulders.

Very few State DOTs collect data on sidewalks or longitudinal pavement markings. Several State DOTs mentioned that pavement markings, guardrails, roadside lighting, and signs are the responsibility of individual State DOT maintenance districts. Inventory data regarding these features may reside within each maintenance district, but the data have not been centralized and, in many cases, may not be available in digital format.

Intersection Characteristics

Relatively few State DOTs collect detailed intersection characteristics other than locations derived from their geospatial roadway network and summary information needed to satisfy HPMS reporting. One reason for this is that, in many States, the State-maintained highway system does not extend into urban areas, where many of the more complex intersections are located.

Likewise, few if any State DOTs currently have a complete inventory of traffic signals, although several mentioned that they have had internal discussions about developing such an inventory.

Other Geospatial Features

Nearly all of the State DOTs reported that they maintain an inventory of highway-railroad grade crossings and highway bridges principally in response to Federal reporting requirements for NBI and HRCI. None of the State DOTs reported that they maintain a statewide database of transit stops, and only a few mentioned that they keep data on truck-related facilities such as weigh stations and truck rest areas. Information is typically limited to those facilities located on interstate and other major routes.

A few State DOTs maintain public traveler advisory Web sites that display information on road and weather conditions, traffic congestion, and highway work zones that could affect travel times and traveler safety. These public Web sites are updated periodically throughout the day, providing information in near-real time.

LOCAL TRANSPORTATION DATA SOURCES

Local Geospatial Roadway Networks

The quality and availability of geospatial roadway networks at a local level are even more varied than at the State level. While a number of county and city governments throughout the United States have GIS departments and are actively developing enterprise data warehouses for their geospatial data, many others have no GIS capabilities whatsoever. Even among those city and county agencies that are actively developing geospatial data, highest priority seems to be focused on cadastral (i.e., land parcel) data and underground utility networks (e.g., water, sewer, and gas pipelines). Local road networks are usually derived from existing road network databases with little modification or enhancement. The most common sources for local road networks are State DOT road networks (for those States that maintain an all-roads network), Census TIGER/Line® files, and commercial road network databases.

Most large- and medium-sized metropolitan planning organizations (MPOs) maintain roadway networks to support their travel-demand forecasting models. These networks are topologically connected to support network analysis and traffic assignment algorithms, but many of them are simple link-node representations (i.e., roadway segments are depicted as straight lines between two intersections, with no intermediate shape points) and therefore are not positionally accurate. Moreover, most networks used for travel-demand modeling include only higher functional class roads; local roads are not explicitly represented.

Local Roadway Inventory Databases

The type of roadway inventory data collected by jurisdictions and transportation agencies below the State level can vary depending on available resources, agency staff technical expertise, and local priorities. Even the small sample of local transportation agencies interviewed for this study showed considerable differences.

For example, although Broward and Palm Beach counties are both part of the same urbanized area (Miami, FL), each county collects roadway data according to its own priorities, with little or no apparent coordination across county lines. Broward County is creating a detailed geospatial inventory of all signalized intersection features, including signs, traffic and pedestrian signals, control boxes, and utility lines. Palm Beach County is compiling an inventory of traffic signal locations but with little or no additional data on signal or intersection characteristics. Both counties are considering using a NAVTEQ™ roadway network that was licensed through Florida DOT as their roadway basemap.

Traffic management centers (TMCs), such as TranStar in Houston, TX, generally do not collect new roadway inventory data themselves. Rather, they utilize data that have been collected by the counties and cities that they serve. TMCs with operational traffic management responsibilities (e.g., controlling traffic signals within their service areas) almost always require a database of traffic signal locations and operating characteristics.

Most public transit operating agencies have compiled an inventory of transit stop locations and routes for fixed-route buses operating on local roadways. Transit operating agencies typically build their bus route databases on whatever roadway network is commonly used within their service region, but the agencies may need to add new road segments to display routes that cross private property, such as shopping malls.

ROADWAY DATA COLLECTION TECHNOLOGY

Existing roadway data sources at the national, State, and local levels provide a baseline for the type and quality of roadway geometry and inventory data that are currently available to support early IntelliDrive applications. However, there also are several emerging data collection technologies that could reduce the cost of collecting certain data items while substantially improving their quality and positional accuracy. Three of the most promising data collection technologies are described here.

IFSAR

IFSAR, utilized by Intermap Technologies, is an innovative data collection system that uses dual synthetic aperture radar technology mounted on an airborne platform to collect high resolution three-dimensional (3-D) imagery quickly over large geographic areas. IFSAR uses a combination of radar frequency bands (e.g., 300 MHz p-band and 8–12 GHz x-band) to acquire images of both “first surface” features (e.g., tree canopies) and “bare earth” features. By postprocessing the raw imagery data, Intermap can create both digital surface models showing vegetation and built structures and digital terrain models showing bare earth elevations with all vegetation and structures removed.

By further processing the imagery data using feature-extraction software, Intermap is able to create 3-D road centerline networks with locational accuracy better than 9.84 ft (3 m) horizontal and 3.28 ft (1 m) vertical.

Intermap has collected IFSAR imagery for all of Western Europe and the contiguous United States (CONUS) and has already created 3-D road layers for most of the Western European countries. It is currently seeking customers to support the data processing needed to create a 3-D road network for the United States.

The primary value of this technology is that it would facilitate the creation of a complete all-road network for CONUS with a consistent level of locational accuracy, both horizontally and vertically. Given this network, it would be possible to calculate horizontal and vertical curvature, roadway elevation, and grade for all roads nationwide, including local roads and low-volume rural roads where accurate curvature and grade data are currently missing.

Because the extracted road network represents the approximate centerline of a roadway, IFSAR technology is not able to capture data that would enable computation of cross slope or superelevation along curves. These data would have to be obtained using other technology.

Feature Extraction and Measurement from Videologs

Using a roadway inventory vehicle to collect videologs of roadway features is not new technology. Many State DOTs have been collecting videologs or photologs for more than two decades. Typically, however, videologs have primarily been used to visualize roadside features and surrounding environment, not as a feature extraction source for collecting road inventory data.

Recent improvements in GPS and inertial measurement unit technology combined with more sophisticated feature identification and measurement software make it more practical and efficient to extract roadway features from videologs and to measure their locations relative to the roadway centerline. Commercial roadway data collection services such as Fugro Roadware, Mandli Communications, and Michael Baker currently have such technology available on their vehicles. The primary limitation is the client's (e.g., State and local transportation agencies) willingness to pay the additional costs for processing the videolog images to collect specific inventory data.

Feature extraction and measurement from videologs can be used to collect many of the roadway inventory data items identified by IntelliDrive stakeholders, including locations and widths of travel lanes, medians, shoulders, sidewalks, and crosswalks; pavement markings; locations of signs and traffic signals; locations of guardrails; beginning and ending locations of bridges and tunnels; and virtually any other feature than can be seen from the window of a moving vehicle.

Mobile LIDAR

Mobile LIDAR is an optical remote sensing technology that measures the properties of scattered light to find the range of and other information about a distant target. LIDAR can produce highly accurate, survey-grade distance measurements (0.394–3.94 inches (10–100 mm)) both horizontally and vertically relative to the mobile platform on which the LIDAR is mounted. Distances to multiple targets can be measured simultaneously from the same mobile vehicle, delivering highly accurate road inventory measurements with a single vehicle pass.

Mobile LIDAR is currently being deployed by some roadway data collection services, such as Mandli Communications and Michael Baker, as a supplement to videologs to provide more accurate location measurements of roadside features as well as measurement of roadway and roadside contours such as roadway, shoulder, and clear zone widths and slopes; locations and heights of signs and traffic signals; bridge and tunnel clearance heights; and offsets and heights of curbs, guardrails, and median barriers.

Processing of mobile LIDAR point clouds to identify specific features requires significant manual effort, and it currently is being marketed as a cost-effective alternative to in-field surveys. However, as data processing software improves, the costs associated with feature extraction and measurement should decrease to the point that mobile LIDAR becomes a practical, cost-effective option for roadway inventory data collection.

CHAPTER 4. SUMMARY OF ROADWAY DATA AVAILABILITY

This chapter examines the current and potential availability of each roadway geometry and inventory data item identified by IntelliDrive stakeholders based on the review of current roadway data sources and emerging data collection technologies. The chapter is divided into four subsections, each corresponding to one of the four general data categories used throughout this report: roadway geometry, roadway inventory, intersection characteristics, and other geospatial features.

Each subsection includes a table that summarizes the relative availability of each roadway data item from current data sources and with extensive deployment of emerging data collection technologies. A comments column provides additional information on current and potential data availability.

ROADWAY GEOMETRY

Table 14 summarizes the current and potential availability of each roadway geometry data item identified by IntelliDrive stakeholders.

Horizontal curvature, grade, and elevation are data items that are currently being collected by two of the commercial roadway network developers, NAVTEQ™ and Tele Atlas®, as part of their ADAS supplement to their core roadway network databases as well as by approximately half of the State DOTs who responded to the survey.

Both NAVTEQ™ and Tele Atlas® derive measures of horizontal curvature (radius and curve length) and grade directly from the geographic coordinates (latitude, longitude, and absolute elevation) of the shape points used to draw their roadway networks. NAVTEQ™ includes measures of curvature and grade only on roadway segments that meet its enhanced locational accuracy standards for ADAS. Tele Atlas® calculates measures of curvature and grade for all roadway segments but acknowledges that there may be significant inaccuracies in these measures for road segments that do not meet its ADAS locational accuracy standards. Both NAVTEQ™ and Tele Atlas® indicated that all of their class 1 and 2 roads are currently ADAS-compliant. These road classes generally correspond to roads functionally classified as interstates, freeways and expressways, and other principal arterials.

Table 14. Availability of roadway geometry data.

Feature	Attribute	Data Availability		
		Current Data Sources	Using Emerging Technology	Comments
Horizontal alignment	Horizontal curve PC location	F	IFSAR	Horizontal alignment data available from commercial databases for major, high-volume roadways
	Horizontal curve length	F	IFSAR	
	Horizontal curve radius	F	IFSAR	
Grade	Grade in direction of travel	F	IFSAR	Elevation and grade data available from commercial databases for major, high-volume roadways
Elevation	Roadway elevation	F	IFSAR	
Vertical alignment	Vertical curve PC location	NA	IFSAR	Vertical curvature not routinely collected in State or national databases
	Vertical curve PT location	NA	IFSAR	
	Vertical curve length	NA	IFSAR	
Sight distance	Available sight distance (stopping, passing)	NA	LIDAR	Sight distance not routinely collected in State or national databases
Cross slope	Roadway cross slope	NA	LIDAR	Cross slope not routinely collected in State or national databases
	Shoulder cross slope	NA	LIDAR	

PC = Point of curvature.
PT = Point of tangency.
F = Data item available for some road segments based on functional class.
NA = Data item not available for most road segments.
IFSAR = Data item could be collected using IFSAR technology.
LIDAR = Data item could be collected using LIDAR technology.

NAVTEQ™, Tele Atlas®, and about 25 percent of the State DOTs reported that they collect vertical curvature on some roads, but the data collected by these sources do not quite match the data needs identified by IntelliDrive stakeholders. Both NAVTEQ™ and Tele Atlas® reported that they measure vertical curvature as the change in slope between shape points along a road segment and measure grade as the average slope (Δelevation/Δ horizontal distance) between the two endpoints of a roadway segment. Both NAVTEQ™ and Tele Atlas® collect vertical curvature data for ADAS-compliant road segments.

Although both NAVTEQ™ and Tele Atlas® plan to expand the number of ADAS-compliant roads in their roadway databases to include class 3 and 4 roads, it is highly unlikely that they will be able to collect enhanced horizontal and vertical alignment data on class 5 (local) roads in the near future. Since local roads comprise nearly 70 percent of total U.S. roadway centerline miles, some other data collection method will have to be utilized to provide accurate horizontal and vertical alignment data for these roads. IFSAR technology, described in the previous chapter, could produce a national 3-D roadway centerline database with consistent levels of horizontal and vertical accuracy for all roads. However, there are at least three unresolved questions concerning IFSAR: (1) Are the levels of accuracy claimed by the technology developer independently verifiable? (2) Do these accuracy levels meet the needs for IntelliDrive applications? (3) Who would pay for the processing of IFSAR data to create a national 3-D roadway centerline database?

None of the commercial roadway database developers and virtually none of the State DOTs currently collect data on roadway or shoulder cross slope. Moreover, none of these data items are currently required for HPMS reporting, even for sample sections. Although it is technologically feasible to collect each of these data items, especially with new mobile LIDAR, it is highly unlikely that these data will be available for IntelliDrive applications in the near future.

Sight distance is another attribute that is not routinely collected by commercial roadway database developers or most State DOTs as part of their roadway inventories. HPMS includes passing sight distance as a sample section data item but defines it as the percent of a sample segment length that allows passing.

ROADWAY INVENTORY

Table 15 summarizes the current and potential availability of each roadway inventory data item identified by IntelliDrive stakeholders.

Data on the number of lanes for each roadway segment and on median and ramp locations along divided highways are currently available from commercial roadway database developers for most roads in their databases.

More specific data on the characteristics of lanes, medians, shoulders, and ramps, including type and special use or restrictions (e.g., HOV, no trucks) are routinely collected by State DOTs as part of their roadway inventories. State DOTs do not typically measure actual lane width on a multilane road. Instead, they compute an average lane width based on the total paved width of the travel way and the number of lanes. None of the commercial roadway database developers and virtually none of the State DOTs currently collect data on clear zone width.

Because most State DOTs only inventory those roads for which they have maintenance responsibilities, roadway inventory data are available primarily for higher functional class roads that are part of the State highway system. HPMS includes many of these attributes as sample section data items. Only the number of lanes on roadways and ramps and designated HOV lanes are required for all HPMS road segments.

Table 15. Availability of roadway inventory data.

Feature	Attribute	Data Availability: Current Data Sources	Data Availability: Using Emerging Technology	Comments
Roadway	Number of through lanes	A	A	Roadway restrictions and surface type collected by most State DOTs for State-maintained roads
	Roadway use restrictions	F	Videolog	
	Roadway surface type	F	Videolog	
Lane	Lane number	G	Videolog	Enhanced lane information available in commercial roadway databases for some freeway interchanges and urban intersections
	Special lane function type	G	Videolog	
	Lane pavement marking location	G	Videolog	
	Lane pavement marking type	G	Videolog	
	Lane width	NA	LIDAR	Measured lane width not routinely collected in State or national databases
Median	Median location	A	A	Median attributes collected by most State DOTs for State-maintained roads
	Median type	F	Videolog	
	Median width	F	LIDAR	
Shoulder	Shoulder location	F	Videolog	Shoulder attributes collected by most State DOTs for State-maintained roads
	Shoulder type	F	Videolog	
	Shoulder width	F	LIDAR	
	Special shoulder function type	F	Videolog	
	Clear zone width	NA	LIDAR	Clear zone data not routinely collected in State or national databases
Sidewalk	Location of sidewalk	NA	Videolog	Sidewalk locations not routinely collected in State or national databases
Ramp	Ramp location	A	A	Ramp locations, type, and number of lanes available in commercial roadway databases
	Ramp type	A	A	
	Ramp number of lanes	A	A	
	Ramp merge feature	NA	Videolog	Ramp characteristics not routinely collected in State or national databases
	Ramp special lane function type	NA	Videolog	

See notes at end of table.

Table 15. Availability of roadway inventory data—Continued.

Feature	Attribute	Data Availability: Current Data Sources	Data Availability: Using Emerging Technology	Comments
Speed zone	Speed zone location	F	Videolog	Speed limits available from commercial databases and State DOTs for major, high-volume roads
	Posted speed limit	F	Videolog	
	Posted advisory speed	NA	Videolog	Special speed zone data not routinely collected in State or national databases
	Special speed zone type	NA	Videolog	
Barrier (guardrail)	Barrier location	G	Videolog	Barrier data not routinely maintained by State DOTs in a centralized database
	Barrier type	G	Videolog	

A = Data item available for all or most road segments.
F = Data item available for some road segments based on functional class.
G = Data item available for some road segments based on geographic area.
NA = Data item not available for most road segments.
IFSAR = Data item could be collected using IFSAR technology.
LIDAR = Data item could be collected using LIDAR technology.
Videolog = Data item could be collected using Videolog technology.

Both commercial roadway databases and State DOTs include posted speed limit as a data item. Speed limit data are likely to be more accurate and current on higher functional class roadways and may be more spotty on local roads that are outside the maintenance responsibility of State DOTs or that are surveyed less frequently by commercial database developers. Data on special speed zones or advisory speeds vary from State to State, and to the extent that many special speed zones are located on local streets (e.g., school zones), these data may not be routinely collected or compiled on a statewide basis.

Data on guardrail locations and type are currently not collected by commercial roadway database developers, and most State DOTs do not maintain centralized inventories of guardrails, signs, pavement markings, or roadside lighting. Instead, inventory and maintenance responsibilities for these roadway features are typically delegated to individual maintenance districts dispersed geographically across the State.

Both NAVTEQ™ and Tele Atlas® collect data on longitudinal pavement markings for those roads with enhanced lane information. Generally, these roads include ADAS-compliant road segments, plus roads that are in selected urban areas and enter complex intersections where additional lane guidance is needed. Most State DOTs do not maintain a centralized inventory of pavement markings.

Data on sidewalk locations are not routinely collected by commercial database developers or State DOTs. One reason is that most State highway system roads are located outside of urban areas and typically do not have sidewalks or do not permit pedestrian traffic (e.g., interstates). Both NAVTEQ™ and Tele Atlas® include some information on sidewalks in their Discover Cities™ and Urban Maps™ supplemental data products, but these products are only available for selected larger U.S. cities.

All of the listed roadway inventory data items can be collected using either videologs or LIDAR technology mounted on mobile roadway data collection vehicles. Many State DOTs are already using such technologies to collect specific data items for their State highway system. However, the data processing costs to extract and inventory each roadway feature make it highly unlikely that these data will be available for all roads without some financial incentive or regulatory mandate.

INTERSECTION CHARACTERISTICS

Table 16 summarizes the current and potential availability of each intersection characteristic data item identified by IntelliDrive stakeholders.

Table 16. Availability of intersection characteristics data.

Feature	Attribute	Data Availability		
		Current Data Sources	Using Emerging Technology	Comments
Geometry	Intersection location	A	A	Intersection location and type available in commercial roadway networks
	Type of intersection	A	A	
	Intersection ID	NA	NA	Nationwide intersection IDs currently not established
Approach lane configuration	Left-turn prohibition	A	A	Turn restrictions available in commercial roadway networks
	Right-turn prohibition	A	A	
	U-turn prohibition	A	A	
	Number of through lanes	G	Videolog	Detailed turn lane characteristics available in commercial roadway databases for some urban intersections
	Number of left-turn lanes	G	Videolog	
	Location of left-turn lane	G	Videolog	
	Left-turn channelization	G	Videolog	
	Number of right-turn lanes	G	Videolog	
	Location of right-turn lane	G	Videolog	
	Right-turn channelization	G	Videolog	
	Lane width	NA	LIDAR	Measured lane width not routinely collected in State or national databases
	Vehicle paths through intersection	NA	GPS Tracks	Vehicle paths not routinely collected in State or national databases

See notes at end of table.

Table 16. Availability of intersection characteristics data—Continued.

Feature	Attribute	Data Availability: Current Data Sources	Data Availability: Using Emerging Technology	Comments
Pavement markings	Location of stop bar	G	LIDAR	Crosswalk locations available in commercial roadway databases for some urban areas
	Location of pedestrian crosswalk	G	LIDAR	
	Location of midblock crosswalk	G	LIDAR	
Traffic control	Type of traffic control	G	Videolog	Traffic control type and location available in commercial roadway networks for most intersections
	Location of traffic signal	G	LIDAR	
	Traffic signal preemption	NA	NA	Traffic signal location and characteristics not routinely collected in State or national databases
	TSP	NA	NA	
	Special traffic control	NA	NA	

TSP = Transit signal priority.
A = Data item available for all or most road segments.
G = Data item available for some road segments based on geographic area.
NA = Data item not available for most road segments.
LIDAR = Data item could be collected using LIDAR technology.
Videolog = Data item could be collected using Videolog technology.
GPS Tracks = Data item could be collected using GPS vehicle tracks.

Data on intersection location and type, as well as restrictions on specific turning movements, are currently available from commercial roadway database developers for most, if not all, roads in their databases. These items are critical to vehicle navigation and routing and are therefore maintained and updated by commercial developers as high-priority data items.

Other lane configuration attributes, including location and number of dedicated turn lanes and lane channelization, are also available from NAVTEQ™ and Tele Atlas® for those intersections where enhanced lane information is provided. Currently, these data items are available for class 1 and 2 roads nationwide and for class 3 and 4 roads (collectors and minor arterials) located in larger cities. Both NAVTEQ™ and Tele Atlas® plan to increase the number of U.S. cities where such enhanced lane data are available. Neither commercial developers nor State DOTs currently collect measured lane widths for turning lanes or allowable vehicle paths through an intersection.

Most State DOTs do not collect detailed data on intersection characteristics beyond what is required for HPMS reporting. HPMS requires only a summary measure of turning movements along a sample section, indicating whether any intersections exist along the sample section, and if so what turning movements, if any, are permitted.

Data on the location of pedestrian crosswalks are available from NAVTEQ™ and Tele Atlas® for selected cities in their Discover Cities™ and Urban Maps™ supplemental data products. As with their extended lane data, both developers plan to increase the number of U.S. cities where such information is available. None of the State DOTs reported that they collect data on crosswalks or other pavement markings in urban areas.

Data on the location and type of traffic control (i.e., sign or traffic signal) at intersections is available from both NAVTEQ™ and Tele Atlas®. The level of detail and locational accuracy of these data varies depending on whether enhanced lane information has been collected for the intersection.

Relatively few of the State DOTs maintain a centralized traffic signal or sign inventory beyond what is required for HPMS reporting. HPMS requires only a total count of the number of intersections along a sample section that are controlled by traffic signals or stop signs.

All of the listed intersection characteristics data items can be collected using either videologs or LIDAR technology mounted on mobile roadway data collection vehicles. However, the data processing costs to extract and inventory each roadway feature make it highly unlikely that these data will be available for all roads without some financial incentive or regulatory mandate.

None of the commercial roadway database developers and few, if any, State DOTs currently collect data on whether the signal supports transit priority or preemption for emergency vehicles. This type of operational data may be collected by specific TMCs that have operational control over traffic signals within their service area, but it is not likely to be available in a roadway database anytime in the foreseeable future.

OTHER GEOSPATIAL FEATURES

Table 17 summarizes the current and potential availability of other geospatial features identified by IntelliDrive stakeholders.

Data on the locations of highway railroad crossings, bridges, and tunnels, along with most of the characteristics of these features required for IntelliDrive applications are currently available in commercial roadway databases and from national inventory databases compiled and maintained by the U.S. DOT. Commercial roadway network database developers, especially those that support commercial trucking customers, update height and weight clearances and commercial vehicle restrictions on a priority basis using a variety of sources, including contacts with State and local transportation agencies, customer feedback, and direct observation by field teams.

Most public transit operating agencies collect and maintain data on their transit stop locations. Both NAVTEQ™ and Google™ have collected transit stop locations from many U.S. transit agencies and have included them as a geospatial feature layer for use with their roadway database.

Several of the commercial roadway databases, including NAVTEQ™, Tele Atlas®, and ALK®, collect data on the locations of truck rest areas and roadside inspection/weigh stations on major truck routes for use with their commercial vehicle data products. Additional data on the characteristics of truck-related facilities (e.g., capacity and amenities at truck stops) are not currently included in these databases. Most State DOTs do not maintain inventory data on commercial vehicle facilities.

Table 17. Availability of other geospatial features.

Feature	Attribute	Data Availability: Current Data Sources	Data Availability: Using Emerging Technology	Comments
Railroad crossings	Railroad crossing location	A	A	Rail crossing data available from commercial databases and U.S. DOT HRCI
	Railroad crossing control type	A	A	
	Railroad crossing identifier	A	A	
Bridges/ tunnels	Bridge/tunnel location	G	Videolog	Bridge location criteria and accuracy varies from State to State
	Structure type	A	A	Bridge characteristics available from commercial databases and FHWA NBI
	Overhead clearance	A	A	
	Restrictions	A	A	
	Bridge identifier	A	A	
Transit facilities	Transit stop location	G	Videolog	Transit stop location available from most public transit operating agencies
	Transit stop type	G	Videolog	
Commercial vehicle facilities	Runoff lane location	F	Videolog	Locations of commercial vehicle facilities available from commercial databases for major, high-volume roads
	Roadside inspection/ weigh station location	F	Videolog	
	Truck parking facility location	F	Videolog	
	Truck parking facility capacity	NA	NA	Commercial vehicle facility characteristics not routinely collected
GPS coverage	GPS coverage area location	G	G	NDGPS coverage available from U.S. Coast Guard Navigation Center
	GPS coverage area type	G	G	
Weather monitoring coverage	Weather monitoring coverage area location	A	A	Nationwide weather monitoring coverage by National Weather Service
Road condition monitoring coverage	Road condition monitoring coverage area location	G	G	Road condition monitoring coverage currently provided by some State DOTs
Traffic monitoring coverage	Traffic monitoring coverage area location	G	G	Traffic monitoring coverage currently provided by some State DOTs and TMCs

A = Data item available for all or most road segments.
F = Data item available for some road segments based on functional class.
G = Data item available for some road segments based on geographic area.
NA = Data item not available for most road segments.
Videolog = Data item could be collected using Videolog technology.
NDGPS = National Differential Global Positioning System.

Geographic features that define coverage areas for specific information services, which may be useful for IntelliDrive applications, currently do not exist on a nationwide basis. Moreover, such coverage area maps may not be particularly informative as part of a roadway database. At least two of the services, weather monitoring and enhanced GPS, have or will soon have ubiquitous coverage throughout the United States. Road condition monitoring is currently being deployed by individual State DOTs for their entire States, and traffic monitoring is currently being deployed as a partnership between commercial roadway databases developers and traffic monitoring services, with traffic updates integrated directly into the roadway database on individual road segments.

Differential GPS coverage is currently available for most of CONUS, Hawaii, Puerto Rico, and coastal Alaska. A GPS receiver equipped with differential GPS capability can improve the accuracy of its positional readings from 32.8 ft (10 m) to less than 3.28 ft (1 m) absolute error. Currently, however, most vehicle-installed and handheld navigation systems are not equipped with differential GPS capability.

The National Differential Global Positioning System (NDGPS) program, which is managed by the U.S. DOT, is expected to add eight additional base station sites to achieve full CONUS coverage. The schedule for construction of these new sites depends on availability of funding. The U.S. Coast Guard Navigation Center maintains a map showing current differential GPS coverage areas.(8) This map could be made available as a geospatial feature for use with a roadway database. No State or nationwide databases were found showing the locations of areas with especially poor GPS coverage, such as natural or urban canyons.

The National Weather Service has developed and maintains the National Digital Forecast Database (NDFD), which provides current and future forecasts of weather conditions throughout the United States.(9) The NDFD is updated on an hourly basis for most attributes and can be accessed and displayed for any U.S. location at a geographic resolution of 3.1 mi (5 km) grids. These data are currently used by many TMCs and State DOTs as the basis for monitoring weather conditions within their service area.

Many of the commercial roadway database developers have established partnerships with traffic monitoring services to provide near-real-time traffic conditions as a supplemental roadway attribute. Traffic monitoring coverage is not consistent nationwide and tends to be concentrated in larger metropolitan areas with correspondingly higher levels of traffic congestion. No State or nationwide databases were found that showed the coverage area boundaries of traffic monitoring services. Moreover, these boundaries appear to be relatively fluid and may not be suitable for display on a static map.

Several State DOTs have developed public traveler information services (e.g., 511) Web sites that provide a variety of information on roadway conditions, work zones, traffic conditions, and roadway weather conditions. Information is updated throughout the day as conditions change.

Although State DOT sites are typically limited to information pertinent to State roads, these sites can provide the framework for additional information provided by local transportation agencies for roads in their service area.

CHAPTER 5. ANALYSIS AND COMPARISON OF ROADWAY DATA SOURCES

This chapter analyzes and compares roadway geometry and inventory data sources based on the technical characteristics of the databases and on the operational and business processes of the data providers. Data sources are stratified by public versus commercial data providers, and where applicable, public sources are further stratified by Federal, State, and local data providers. The final subsection summarizes gaps between data needs for IntelliDrive and availability of sources.

TECHNICAL ANALYSIS

Coverage

Needs for IntelliDrive

Successful deployment of IntelliDrive will require both a geospatial roadway network that provides the location and basic roadway geometry for all public roads and roadway attribute data that can be linked to the geospatial roadway network to support specific IntelliDrive applications. The applications will require complete national coverage.

Data Source Suitability

Commercial Databases: All five of the commercial roadway databases investigated in this study have a geospatial roadway network that includes all (or nearly all) public roads for the entire United States, as well as the southern (populated) Canadian Provinces. The commercial roadway networks include roadway attributes needed for vehicle navigation (one-way streets, turn restrictions, road classification, street name, route numbers, and address ranges).

National Public Databases:

- *TIGER/Line®:* The Census Bureau TIGER/Line® database contains a geospatial roadway network that includes all (or nearly all) public roads for the entire United States, as well as some private roads that lead to occupied housing units. Roadway segments include attributes that identify address ranges and jurisdictional boundaries for defining and aggregating Census geography.

- *HPMS:* HPMS is not a geospatial roadway network. It is a national inventory of roadway condition and performance data compiled and maintained by FHWA from data submitted by State DOTs in response to federally mandated reporting requirements. HPMS includes limited segment-specific attributes for all Federal-aid roads (e.g., number of lanes) and additional data on a sample of road segments selected based on highway functional classification.

- *NBI:* NBI is not a geospatial roadway network. It is a national inventory of bridge locations and characteristics compiled and maintained by FHWA from data submitted by State DOTs in response to federally mandated reporting requirements. NBI includes all bridges with a span greater than 20 ft (6.1 m) that are open to the public.

- *HRCI:* HRCI is not a geospatial roadway network. It is a national inventory of highway-railroad crossings compiled and maintained by the U.S. DOT from data submitted by State DOTs (and railroads) in response to federally mandated reporting requirements. HRCI includes all public and private railroad crossings, both at-grade as well as grade-separated (i.e., railroad bridges over roadways).

Statewide Public Databases: Most State DOTs have developed geospatial roadway networks, primarily to display State roadway inventory data that they collect. State roadway networks rarely extend beyond the State's borders, and there is generally little coordination between States to ensure that the roadway networks between neighboring States are consistent with respect to locational accuracy, feature resolution, and attributes. Additionally, a significant number of State roadway networks exclude roads for which the State DOT has no administrative, maintenance, or Federal reporting responsibilities such as local roads, toll roads administered by a separate authority, and roads on Federal lands.

With the exception of those data items specified by Federal reporting requirements, the roadway attribute data collected and maintained by State DOTs vary considerably from one State to another. In general, State DOTs maintain roadway inventory data only on those roads for which they have administrative or maintenance responsibilities. This represents about 10–15 percent of the total public roadway centerline mileage in most States.

Local Public Databases: Very few local road agencies develop and maintain their own geospatial roadway networks. Local agencies that have their own GIS capability typically use roadway networks developed by the State DOT or the Census TIGER/Line® roadway database, or the agency purchases a road network database from a commercial roadway database developer. Local agencies that require vehicle routing and navigation capabilities (e.g., E911 services) rely almost exclusively on commercial roadway data sources.

Data collection at the local level is extremely variable, with most local agencies collecting little, if any, roadway attribute data. Local data collection rarely extends beyond the jurisdictional or administrative service area boundaries of the local roadway agency.

Network Connectivity

Needs for IntelliDrive

Several of the key roadway attributes required for IntelliDrive applications (e.g., locations of intersections, entrance and exit ramps on freeway interchanges, and the identification of overpasses or underpasses where road segments cross but do not intersect at-grade) are most efficiently represented through the structure of the roadway database itself. Geospatial roadway databases that incorporate the basic network structure into the design of the database are defined as having network connectivity or network topology. At a minimum, this means that roadway segments always end wherever one road physically intersects another (e.g., at-grade intersections, freeway on- and off-ramps) and that road segments that cross but do not physically intersect (e.g., overpasses) do not end at the crossover point. Network connectivity is also a prerequisite for vehicle navigation and routing.

Data Source Suitability

Commercial Databases: All of the commercial roadway databases currently have the necessary network connectivity as well as additional roadway attribute data (e.g., identification of one-way roads and turn restrictions) needed to fully support vehicle routing and navigation.

National Public Databases:

- *TIGER/Line®:* The TIGER/Line® database is structured using planar topology, which means that all line segments (roads, rivers, railroads, etc.) end wherever they cross any other line segment even if they do not physically intersect. The TIGER/Line® database could potentially be enhanced to support IntelliDrive applications but would require a significant amount of effort to identify overpasses and underpasses, one-way streets, and additional administratively defined prohibited and permitted vehicle movements.

- *HPMS, NBI, and HRCI:* These databases are not geospatial roadway networks, and network connectivity is not applicable.

Statewide Public Databases: Most State geospatial roadway networks currently lack network connectivity. This is because State roadway networks have been developed primarily to display roadway inventory data and only need to support one or more LRS consisting of defined routes and linear measurements along those routes. Like the TIGER/Line® roadway database, State geospatial roadway networks could be enhanced to support IntelliDrive applications, but such an enhancement would require significant effort to identify and correct missing network connections. Most State DOTs currently do not have the available resources nor the perceived need to undertake such an activity.

Local Public Databases: Very few local road agencies develop and maintain their own geospatial roadway network.

Feature Resolution

Needs for IntelliDrive

IntelliDrive stakeholders and prior research have indicated that geospatial roadway networks should have sufficient feature resolution to distinguish between individual travel lanes on a roadway and to provide lane-level attribute information (e.g., lane width, pavement markings, cross slope).

Data Source Suitability

None of the current geospatial roadway networks, either public domain or commercial, provide lane-level feature resolution for all roads. Virtually all of the current roadway networks represent roadway segments as the approximate centerline of the travel way or paved surface. This means that two-way roads with no center median or physical barrier are depicted as a single line in the roadway database, representing the approximate centerline of the paved surface. Divided highways with an unpaved median or physical barrier separating travel directions are typically depicted by two lines, with each line representing the approximate midpoint of all through lanes in each travel direction. Individual lanes are typically represented only when they are separated from the general travel lanes by a physical barrier or median (e.g., HOV lanes with their own on- and off-ramps or channelized turn lanes separated by a curb). The actual number of through lanes associated with a roadway segment is an attribute of the roadway segment. The following provides some additional information for each data source.

Commercial Databases:

- *ALK®:* Roadway segments depicted as centerline of the travel way.
- *DeLorme:* Roadway segments depicted as centerline of the travel way.
- *Google™:* Roadway segments depicted as centerline of the travel way.
- *NAVTEQ™ and Tele Atlas®:* NAVTEQ™ and Tele Atlas® also depict roadway segments as centerlines of the travel way. However, both NAVTEQ™ and Tele Atlas® offer enhanced lane information for certain roadway segments—specifically, freeway interchanges and complex intersections with dedicated turn lanes. The enhanced lane information does not explicitly provide lane-level feature resolution. Instead, information is provided to enable drivers to navigate to the correct lane on a roadway segment in sufficient time to enter a turning lane. Enhanced lane information is available for all major highway interchanges and for arterial intersections in approximately 36 cities. Additional cities are being added at a rate of about 10 per year.

National Public Databases:

- *TIGER/Line®:* Roadway segments depicted as centerline of the travel way.
- *HPMS, NBI, and HRCI:* These databases are not geospatial roadway networks, and feature resolution is not applicable.

Statewide Public Databases: Most State DOTs currently have geospatial roadway networks that depict roadway segments as the centerline of the travel way. However, a few State DOTs have not significantly enhanced their roadway networks in more than a decade. Their geospatial roadway networks depict roadway segments as the centerline of the entire roadway right-of-way. This means that divided highways are represented by a single roadway centerline located approximately in the median of the divided highway and freeway interchanges are represented as a simple intersection point.

Local Public Databases: Very few local road agencies develop and maintain their own geospatial roadway network.

Geospatial Accuracy

Needs for IntelliDrive

Potential IntelliDrive applications require a level of geospatial accuracy in the roadway network database so that a vehicle can unambiguously locate what roadway it is traveling on, where on the roadway it is relative to specific roadway features (e.g., a curve, steep grade, or intersection), and ideally, what lane of the roadway it is in. Currently, standard GPS locational accuracy is approximately 32.8 ft (10 m) absolute (circular error) and approximately 3.28 ft (1 m) with differential correction (as provided through the NDGPS program). This suggests that geospatial roadway networks necessary to support IntelliDrive should have a geospatial accuracy of no worse than 3.28 ft (1 m) absolute error.

Data Source Suitability

Current geospatial roadway networks have a geospatial accuracy of approximately 16.4–49.2 ft (5–15 m) absolute error, depending on how and when they were constructed. Most current geospatial roadway networks were initially digitized from digital orthoimagery. The corresponding accuracy of the roadway centerline depends on both the resolution of the source imagery and the accuracy of the digitizing technician to manually trace the centerline of the roadway from the imagery.

An alternative method is to drive each road in a GPS-equipped vehicle (with differential correction) and trace the vehicle's GPS position (as recorded every 1–5 s) to create or correct the position of the digitized roadway centerline vector. This method should be more accurate than manual digitizing from orthoimagery but is also subject to errors caused by forced lane changes along a roadway and by temporary loss of GPS signal due to urban canyons, tree cover, etc.

A third method, which has the potential to improve overall geospatial accuracy and produce centerline vectors for individual lanes, is to collect GPS tracks of a large number of vehicles traveling the same roadway over time. Using statistical averaging techniques, these GPS tracks can be aggregated to generate the centerlines of individual lanes along the roadway traversed by the vehicles.

Specific accuracies are presented for each geospatial roadway network data source.

Commercial Databases:

- *ALK®:* 3.28–9.84 ft (1–3 m) (absolute error) on most major roads, no worse than 24.6 ft (7.5 m) on other roads.
- *DeLorme:* 3.28–16.4 ft (1–5 m) in most urban areas, no worse than 24.6 ft (7.5 m) on other roads.
- *Google™:* Unknown accuracy, appears to be no worse than 24.6 ft (7.5 m) on most roads.
- *NAVTEQ™:* 3.28–16.4 ft (1–5 m) on all ADAS-compliant roads, 16.4–49.2 ft (5–15 m) on other roads.
- *Tele Atlas®:* 3.28–16.4 ft (1–5 m) on all ADAS-compliant roads, 16.4–42.6 ft (5–13 m) on other roads.

National Public Databases:

- *TIGER/Line®:* 24.6 ft (7.5 m) maximum absolute error, nationwide. The Census Bureau established this as its standard for acceptable positional error for all roadway geometry submitted by TIGER/Line® enhancement contractors and public agencies.

- *HPMS, NBI, and HRCI:* The locational accuracies of roadway features in these national inventories are variable, depending on the data collection methods and accuracy criteria utilized by each State DOT that submitted the data.

Statewide Public Databases: The roadway networks developed by State DOTs vary significantly with respect to locational accuracy. Over the past decade, many State DOTs have initiated programs to improve the locational accuracy of their roadway network databases, utilizing high resolution (i.e., 1:10,000 scale or better) digital orthoimagery or GPS tracks collected by roadway inventory vehicles. The geospatial roadway networks produced from these efforts have locational accuracies of 16.4–32.8 ft (5–10 m) absolute error or better. About 60 percent of the State DOTs currently have or are developing geospatial roadway networks at this level of locational accuracy.

Local Public Databases: Very few local road agencies develop and maintain their own geospatial roadway network.

Attributes

Needs for IntelliDrive

The tables in chapters 3 and 4 provided detailed information on the specific roadway geometry and inventory attributes identified by IntelliDrive stakeholders with respect to availability by data source and to current and potential availability given emerging data collection technologies. This chapter provides more general observations regarding the consistency, measurement accuracies, and timeliness of roadway attribute data on a nationwide basis.

Data Source Suitability

Commercial Databases: All of the commercial roadway databases provide consistent feature and attribute definitions, attribute domains, measurement methods, and verification procedures across their entire roadway database.

Commercial roadway network developers also take a proactive role in verifying and updating the roadway inventory data included in their databases. Commercial database developers rely on multiple sources, including ongoing contact with State DOTs and local roadway agencies, feedback and error reporting from database customers, and in some cases, field teams that independently verify attribute changes reported from other sources.

National Public Databases:

- *TIGER/Line®:* The TIGER/Line® database provides consistent and well-defined feature and attribute definitions, attribute domains, and measurement methods. However, other than the geospatial representation of the roadway network and locations of certain roadway features (intersections, freeway ramps, and railroad crossings), it does not include any of the roadway attributes identified by IntelliDrive stakeholders.

- *HPMS, NBI, and HRCI:* These national inventory databases provide consistent feature and attribute definitions, attribute domains, and measurement methods. However, other than consistency checks on domain values, little if any of the data currently submitted by State DOTs to the national inventory databases is independently verified by the U.S. DOT for accuracy. Additionally, although each of the national inventory databases requires an annual submittal, attributes for specific features may be updated much less frequently. For example, bridge inspections are required every 2 years (4 years under certain conditions). Consequently, changes in some bridge attributes (e.g., clearance height) may not be reflected in NBI for up to 4 years after they occur.

Statewide Public Databases: Roadway attribute data maintained by State DOTs vary considerably from one agency to another with respect to attribute definitions, domain values, positional accuracy and resolution, data collection methods, and frequency of updates. Other than those data collection and reporting standards associated with the national inventory databases, there are no federally mandated standards for collecting and maintaining any of the roadway geometry or inventory data items identified by IntelliDrive stakeholders. Consequently, compilation of roadway attributes from individual State DOTs would require either the promulgation of additional national standards for data collection and reporting or substantial effort to document and reconcile differences across all contributing agencies.

Local Public Databases: Roadway attribute data collected and maintained by local roadway agencies vary even more than among State DOTs with respect to attribute definitions, domain values, positional accuracy and resolution, data collection methods, and frequency of updates. At the local level, there are no federally mandated standards for collecting and maintaining any of the roadway geometry or inventory data items identified by IntelliDrive stakeholders.

Data Format and Size

Needs for IntelliDrive

Roadway geometry and inventory data to support IntelliDrive applications must be stored in a format that can be read and utilized by a vehicle's on-board processors and can be efficiently transmitted and updated for specific (small) geographic areas and attributes.

Data Source Suitability

Nearly all of the geospatial roadway networks can be exchanged in one or more standard commercial GIS formats such as ESRI shapefiles, geodatabase files, or MapInfo TAB files. These files can be translated, with relatively little loss of information, into most commercial GIS software packages. However, transmitting and merging geographic subsets of the database requires additional processing by the receiving GIS software.

Commercial Databases: Standard distribution formats used by commercial database developers are as follows:

- *ALK®:* Shapefile.
- *DeLorme:* Shapefile, geodatabase.
- *Google™:* Google™ does not distribute its Google Maps™ roadway network as a separate commercial product.
- *NAVTEQ™:* Shapefile, TAB file.
- *Tele Atlas®:* Shapefile.

NAVTEQ™ and Tele Atlas® also distribute their roadway geometry and attribute data using GDF, a European geographic data format that has become the international de facto exchange standard for navigation databases. While this ultimately may not be the most efficient format for transmitting roadway data needed for IntelliDrive applications, it has proven to be an operationally practical format for in-vehicle roadway navigation databases.

National Public Databases:

- *TIGER/Line®:* Shapefile.
- *HPMS:* HPMS databases are collected and distributed as standard ASCII files, with each data record representing a roadway segment. Each record includes fields for a route identifier and beginning and ending mile point measurements needed to link the record to a State geospatial roadway network using a State DOT-specified LRS.
- *NBI and HRCI:* Both of these national inventory databases are distributed as geospatial point features in shapefile format.

Statewide Public Databases: State geospatial roadway networks are typically stored and distributed as a geospatial database using the format of the predominant GIS software used by the agency (generally shapefile or geodatabase format). Roadway attribute data are usually linked to the geospatial roadway network using one or more LRS developed and maintained by the State DOT.

Transmittal of roadway attribute data stored using an LRS is significantly more complex than the transmittal of a geospatial feature database. It requires the receiving geospatial roadway network to have the route identifiers and linear measures for each LRS used to link a roadway attribute to the network. Additionally, because State DOTs continually update their LRS, these updates also need to be transmitted on a regular basis.

Local Public Databases: Very few local roadway agencies develop and maintain their own geospatial roadway network.

Methods and Frequency of Updates

Needs for IntelliDrive

IntelliDrive applications will require that roadway attribute updates that are critical to vehicle safety (e.g., bridge height and weight clearances, one-way street designations, turn prohibitions) be transmitted and incorporated into the vehicle roadway database soon after they are implemented. Failure to do so will, at best, undermine driver confidence in specific IntelliDrive applications and, in the worst case, contribute to a safety-related incident.

Data Source Suitability

None of the geospatial roadway networks or roadway inventory databases investigated in this study are updated and disseminated in real time.

Commercial Databases: Commercial roadway databases obtain updates on a continual basis from multiple sources, including regular contact with State DOTs and local road agencies, feedback from database users reporting corrections and changes in attribute information, data from field teams, and automated customer-generated content such a GPS tracks from vehicles and personal navigation devices (PNDs). Data from these multiple sources are verified, cross-checked, and reconciled with conflicting data and incorporated into a master internal roadway database.

Commercial database customers can obtain published updates at regular intervals ranging from as frequently as once a month to once a year, depending on the needs of the customer and volume of demand. Current publication frequencies of commercial roadway databases are as follows:

- *ALK®:* Quarterly release of complete roadway network; monthly maintenance updates for some commercial customers.
- *DeLorme:* Annual release of complete roadway database; semiannual release for some commercial customers.
- *Google™:* Google™ does not distribute its Google Maps™ roadway network as a separate commercial product.
- *NAVTEQ™:* Release of complete roadway network at least quarterly.
- *Tele Atlas®:* Release of complete roadway network at least quarterly.

National Public Databases:

- *TIGER/Line®:* A new version of the TIGER/Line® database was published annually during the TIGER/Line® accuracy enhancement program. The Census Bureau plans to continue to publish updates on an annual cycle, subject to available funding.
- *HPMS, NBI, and HRCI:* The national inventory databases receive updates from State DOTs on an annual basis, but some of the data items reported by the States are based on periodic inspections or data collection activities that take place on 2-, 3-, or 4-year cycles.

> Additionally, there is often a significant lag between the time that data are submitted to the U.S. DOT by the States and the time the data are actually published. The lag time for HPMS data, for example, has historically been 6–9 months.

Statewide Public Databases: Other than those data items that are submitted annually to the U.S. DOT in compliance with Federal reporting requirements, most State DOTs have no regular schedule for collecting or disseminating roadway attribute data. Generally, roadway data collection efforts are determined by available funding and other programmatic priorities that divert staff and resources.

Local Public Databases: Roadway data collection among local roadway agencies is even more variable than among State DOTs. Resources are typically more scarce, and there are no specifically mandated roadway data collection requirements for local agencies. Many local data collection initiatives are one-time efforts with no specific plans for updates once the initial data are collected.

MAINTENANCE AND OPERATIONS ANALYSIS

Data Collection and Updating Technologies

Needs for IntelliDrive

Ideally, roadway geometry and inventory data used in support of IntelliDrive applications should be collected using methods that are consistent, meet the required levels of positional and measurement accuracy, and are amenable to efficient updating.

Alternative Data Collection Technologies

Most of the sources of roadway geometry and inventory data investigated in this study use similar technologies for collecting and updating their databases. The method currently used for most primary roadway data collection is to drive each road using a vehicle equipped with a differential GPS recorder and various data capture technologies such as videolog cameras, pavement condition measurement equipment, vehicle telemetry recorders, and increasingly, mobile LIDAR. By synchronizing all of the on-board data measurements to the vehicle location, it is possible to collect large volumes of roadway data simultaneously with one pass of the vehicle along the roadway.

In theory, nearly all of the roadway inventory data items identified by IntelliDrive stakeholders could be captured and measured using mobile data collection vehicles. In practice, however, the level of effort currently required to manually process videolog or mobile LIDAR imagery in order to identify, locate, and obtain key measurements of specific roadway features typically forces the sponsors of these data collection efforts to prioritize what features they extract and measure as well as what roads they collect data on.

A second data collection method that is useful in capturing basic roadway alignment and some roadway features (e.g., number of lanes, bridge and median locations, pavement markings) is airborne imagery. The primary advantage of airborne imagery is that it can capture data over large areas more quickly and at a lower overall cost per area than mobile roadway vehicles.

Additionally, the collection of airborne imagery is often conducted as a cooperative project that is jointly funded by several State and Federal agencies, further lowering the cost to each agency.

Airborne imagery, specifically orthophotography, is the original source for most of the geospatial roadway networks currently in use, both public and commercial. It continues to be a major source for updating and correcting geospatial roadway network databases with respect to general alignment and incorporation of new roadways, particularly among several commercial roadway database developers. One reason for this is that a significant amount of orthoimagery is in the public domain, making it a free data source that commercial developers can use to improve their products.

An emerging data collection technology closely related to airborne orthoimagery is the use of IFSAR imagery to obtain reasonably high-accuracy (3.28–9.84 ft (1–3 m) absolute, 0.984–3.28 ft (0.3–1 m) relative error) 3-D measurements of roadway centerline alignment and elevation. While potentially less accurate than alignment measurements collected using mobile LIDAR, IFSAR has the benefit of producing a consistent measurement of curvature and grade for all roads over large geographic areas (i.e., entire States or even CONUS). This approach could be used to collect roadway geometry measures on low-volume local roads, where mobile roadway vehicles are not likely to be deployed.

A third data collection method is to collect and process GPS vehicle tracks from users of in-vehicle navigation devices and PNDs. By collecting large numbers of GPS tracks over the same roadways, it is possible to calculate the centerlines of individual lanes, locations of new roads, locations of stop bars at intersections, paths of vehicles through intersections, and average speeds on roadways more accurately than could be obtained from a single pass of a roadway data collection vehicle. This technology is not able to collect all of the roadway attribute data identified by IntelliDrive stakeholders and will produce measurements with varying levels of error depending on the number of GPS tracks collected. In other words, measurements will be more accurate on higher volume roads with larger numbers of vehicles contributing GPS track information and less accurate on low-volume rural and local roads, where fewer GPS tracks are collected. However, GPS track data can also provide an historical record of changes in roadway traffic conditions over time (e.g., vehicle speeds, lane use) that could be used to develop behavioral profiles for specific roadway segments.

Data Source Suitability

Commercial Databases: The principal data collection and updating methods used by commercial roadway database developers are as follows:

- *ALK®:* Airborne orthoimagery, user-generated GPS vehicle tracks.
- *DeLorme:* Airborne orthoimagery.
- *Google™:* Airborne orthoimagery, roadway videolog imagery.
- *NAVTEQ™:* Airborne orthoimagery, roadway videolog imagery.

- *Tele Atlas®:* Airborne orthoimagery, roadway videolog imagery, user-generated GPS vehicle tracks.

National Public Databases:

- *TIGER/Line®:* Airborne orthoimagery.

- *HPMS, NBI, and HRCI:* National inventory databases are compiled from data submitted by State DOTs. No primary data collection is conducted by the U.S. DOT for these databases.

Statewide Public Databases: State DOTs collect roadway data using a variety of data collection technologies, including airborne orthoimagery and mobile roadway data collection vehicles equipped with differential GPS, videolog cameras, and pavement condition measurement equipment. Historically, much of the mobile roadway data collection has been in support of pavement condition monitoring. More recently, however, a number of State DOTs have initiated statewide data collection of roadway features (e.g., signs, guardrails, pavement markings) and are utilizing mobile roadway vehicles with video cameras and mobile LIDAR.

Local Public Databases: Local roadway agencies generally collect little or no roadway data on a regular basis. Any data that are collected at the local level are often done in cooperation with State DOT data collection activities.

Work Flow Processes

Needs for IntelliDrive

Roadway data to support IntelliDrive applications need to come from stable, reliable data sources with well-defined processes for data collection, storage, updating, quality control, and dissemination.

Data Source Suitability

In general, work flow processes are more clearly defined and better integrated among the commercial roadway database developers than among public agency sources. The reason for this is that, for commercial database developers, the roadway database is a marketable product that represents a primary source of income. The better the product, the higher the market share and greater the revenue. For public agencies, data collection is conducted either in response to a statutory reporting requirement or to support specific internal applications.

Commercial Databases: All of the commercial roadway database developers have established work flow procedures for collecting, verifying, updating, and disseminating each of the data items included in their roadway network databases. The specific processes differ slightly for each database developer.

Each of the commercial roadway database developers employs an in-house staff of GIS technicians to input, verify, and edit geospatial and attribute data received from various primary sources. These sources include publicly obtained roadway vector and orthoimagery, updates from State DOTs and local roadway agencies, error reports from database users, and other user-generated content such as GPS vehicle tracks. The new data are checked, verified, reconciled against other data sources, and incorporated into the master roadway network database on a continuing basis. On a periodic basis, a copy of the master roadway network is produced and published as a new version of the commercial database.

In addition to in-house database technicians, some commercial database developers deploy local field staff who work with State and local transportation agencies throughout the United States to obtain updated information on new road construction, changes in roadway alignments or traffic regulations, and temporary road closings due to construction. The local field staff also use mobile roadway data collection vehicles to verify changes reported from alternative sources and to collect new attribute data (e.g., street names, number of lanes, sign messages) that may not have been provided.

Methods used by commercial database developers to collect, verify, and update roadway databases are as follows:

- *ALK®:* Ongoing contact with State and local roadway agencies, public domain data sources, feedback from database customers, user-generated content (GPS vehicle tracks).

- *DeLorme:* Ongoing contact with State and local roadway agencies, public domain data sources, feedback from database customers.

- *Google™:* Ongoing contact with State and local roadway agencies, public domain data sources, feedback from database customers, mobile field teams. (Note: this information is unverified.)

- *NAVTEQ™:* Ongoing contact with State and local roadway agencies, public domain data sources, feedback from database customers, mobile field teams.

- *Tele Atlas®:* Ongoing contact with State and local roadway agencies, public domain data sources, feedback from database customers, mobile field teams, user-generated content (GPS vehicle tracks).

National Public Databases:

- *TIGER/Line®:* The Census Bureau maintains the TIGER/Line® database with an in-house staff of GIS technicians, who respond to feedback from users regarding errors in feature location, address ranges, and other attribute values (e.g., wrong street name). Additional feedback is provided by Census takers for both the decennial Census and the annual sample of respondents for the American Community Survey. Major updates and enhancements to the TIGER/Line® database are conducted through outside contracts.

- *HPMS, NBI, and HRCI:* National inventory databases are compiled from data submitted by individual State DOTs subject to a standard data reporting format. U.S. DOT staff conduct consistency checks to ensure that attributes values are within acceptable domain ranges and that summary statistics are reasonable (e.g., Interstates represent 0.5–1.5 percent of total road mileage in the State). However, the U.S. DOT does not conduct independent verification of attributes reported by State DOTs for specific road segments.

Statewide Public Databases: Among State DOTs, collection of specific roadway data items has historically been compartmentalized, with each operating division collecting the data it needs for its own internal applications (e.g., the Traffic Division collects traffic counts, the Pavement Division collects pavement data, and individual maintenance districts collect roadside features (guardrails, shoulders, signs) on roads within their geographic area of responsibility). The result has been an assortment of "legacy" databases scattered throughout the agency, using different data formats, storage media, data collection and updating procedures, quality control standards, and location referencing methods.

Over the past two decades, many State DOTs have tried to develop enterprise data repositories to facilitate data sharing across organizational units, using geographic location as the common identifier for roadway features and attributes. The success of these efforts has been mixed. In general, most State DOTs have been successful in developing a statewide geospatial roadway network and one or more LRS methods to enable them to display roadway inventory data stored in different legacy databases on the roadway network. However, relatively few State DOTs have successfully implemented agency-wide standards for data collection, including database documentation, quality control/quality assurance criteria, update or reverification frequency, or even storage media. As a result, roadway data collection at many State DOTs remains highly decentralized with minimal agency-wide coordination of data collection processes.

With respect to data collection for Federal reporting, many State DOTs have established separate groups within their organizational structure whose sole purpose is to compile and/or collect data for HPMS reporting. HPMS data items are compiled from databases maintained by individual organizational units, translated into the formats required for HPMS reporting, and submitted to FHWA on an annual basis. Some HPMS sample data items, such as roadway curvature, passing sight distance, or number of signalized intersections, are collected only for the designated HPMS sample sections and are not used by any other organizational unit within the agency.

Local Public Databases: Local roadway agencies collect roadway data on a sporadic basis, if at all. Work flow processes for data collection, verification, and updating are extremely limited or nonexistent.

Business Models

Needs for IntelliDrive

Ideally, roadway geometry and inventory data sources should recognize IntelliDrive stakeholders as potential customers and develop either new data products or enhancements to their current data products to address specific IntelliDrive application needs. At a minimum, the business models should have the flexibility to accommodate new data collection required for IntelliDrive.

Data Source Suitability

There is a clear dichotomy between public and commercial data sources with respect to who is viewed as the primary customer for the roadway data that they collect. This fundamental difference in business models between the public and private sector significantly influences how much each data source is likely to support IntelliDrive.

Commercial Databases: For commercial roadway database developers, the roadway data are either the primary product or are an integral part of the product or service that the commercial developer sells. The content and quality (i.e., geospatial accuracy, frequency of updates) of the data are tailored to meet the perceived needs of the target market. Details of each product are as follows:

- *ALK®:* ALK®'s primary markets are the commercial transportation industry and personal navigation applications for mobile phones. Many enhancements to ALK®'s roadway network database are focused on data items of interest to commercial trucking, including height and weight limits on bridges, roadway restrictions, and truck-based services and POIs. ALK® also has implemented practices to ensure that key data items are updated and disseminated quickly to commercial customers. ALK® currently does not plan to develop roadway map databases specifically for the IntelliDrive application market. However, ALK Digital Maps™ could be extended to incorporate new roadway attributes should a supporting business case for this market materialize.

- *DeLorme:* DeLorme's primary markets are outdoor recreational and natural resource exploration. To serve this market, DeLorme has created a basic roadway map database, primarily from publicly available sources, and has focused its supplementary data enhancement on identifying and locating off-road features such as hiking trails, campsites, back country topography, and natural POIs. Given its current market niche, DeLorme currently does not plan to develop a roadway database with additional attributes and enhanced geospatial accuracy necessary to support IntelliDrive applications.

- *Google™:* Google™'s target market for Google Maps™ appears to be location-based services marketing to Internet and mobile phone users. Google Maps™ and the associated roadway map database that Google™ recently developed are provided as free services to users of Google™'s Web site and search engine. Google™ has supplemented the Google Maps™ roadway database with visual enhancements like "Street View," additional public domain data like transit stops, and expanding its POI database. All of these enhancements seem to be directed at making Google Maps™ the most popular Internet map search site, which in turn, increases the volume of searches for location-based businesses through Google™. At the time this report was written, Google™ did not appear to have any interest in marketing Google Maps™ as a separate product or in enhancing Google Maps™ to meet the requirements for IntelliDrive applications.

- *NAVTEQ™ and Tele Atlas®:* The principal markets for NAVTEQ™ and Tele Atlas® are vehicle and equipment manufacturers for in-vehicle navigation systems, manufacturers of PNDs like Garmin or TomTom, mobile phone manufacturers like Nokia, and public agencies and commercial clients who want a geospatially accurate and routable roadway network for various applications. Both developers place a high priority on updating navigation-related data items such as new streets, changes in one-way streets, etc. and employ large, geographically dispersed field staffs to proactively identify and verify roadway changes from multiple sources. Both NAVTEQ™ and Tele Atlas® approach IntelliDrive as a potential new market area and already have begun making enhancements to their current roadway data products in anticipation of supporting future IntelliDrive requirements.

National Public Databases:

- *TIGER/Line®:* The Census Bureau developed the TIGER/Line® database to enable it to define and update nationwide Census geography (e.g., Census Blocks, Block Groups, and Tracts) consistently and efficiently based on physical linear features such as roads, railroads, and rivers. Additionally, the TIGER/Line® road network was developed to help Census-takers locate housing units based on address ranges. The widespread popularity and use of the TIGER/Line® database for other GIS applications is recognized and encouraged by the Census Bureau. However, the collection and incorporation of new attributes into the TIGER/Line® database goes beyond the Census Bureau's mission and would have to be supported entirely by outside resources.

- *HPMS, NBI, and HRCI:* National data inventories exist to respond to Federal statutory requirements for periodic reports to Congress on critical elements of the Nation's transportation infrastructure. The national inventory databases provide a consistent, well-defined set of selected roadway attributes, some of which may satisfy IntelliDrive application needs. However, Federal reporting requirements rely almost entirely on State DOTs for data accuracy and quality control. Federal agencies conduct little or no independent verification of the accuracy of individual data items reported by the States. Additionally, the frequency with which Federal inventory databases are updated is not compatible with IntelliDrive requirements for most data items.

Statewide Public Databases: State DOTs collect roadway data for one of two reasons: (1) to meet federally mandated reporting requirements or (2) to support internal business needs for roadway construction, maintenance, or operations. Data collected by State DOTs in response to Federal reporting requirements are typically not utilized directly by the State DOT for its own business needs. In contrast, data that are used to support specific agency operational or maintenance needs are often collected, stored, updated, and administered by individual organizational units, with little or no coordination among organizational units.

Local Public Databases: Local roadway agencies generally collect little or no roadway data on a regular basis. Any data that are collected at the local level vary considerably from one agency to another, even within the same State.

CHALLENGES AND OBSTACLES TO PROVIDING ROADWAY GEOMETRY AND INVENTORY DATA FOR INTELLIDRIVE APPLICATIONS

The trade study identified several current data sources and promising new data collection technologies that can produce most of the roadway geometry and inventory data items identified by stakeholders as necessary or highly desirable for potential IntelliDrive applications. However, the study also identified a number of current data gaps and challenges that must be addressed in order to provide the necessary data coverage, level of detail, and timeliness of updates to support IntelliDrive applications on a nationwide, operational basis. These data gaps and challenges are summarized in this section.

Variability in Coverage for Roadway Data

The investigation of current sources of roadway geometry and inventory data revealed a clear and consistent hierarchy for collecting roadway data based on highway functional classification and geography. In general, the highest quality and most extensive data are available for the highest functional class roads—interstates, freeways and other limited access highways, and other principal arterials. These roads account for approximately 5 percent of the total roadway centerline miles in the United States but carry more than 50 percent of total annual vehicle miles of travel (VMT).[3]

In contrast, data on local roads (including minor rural collectors) are currently limited to basic roadway geometry and navigation information (e.g., turn restrictions, intersection locations) provided in commercial roadway network databases. Local roads account for over 75 percent of total roadway centerline miles but carry just over 15 percent of total annual VMT.

There are currently few, if any, incentives for either commercial roadway database developers or public transportation agencies to significantly expand their data collection on local roads. For commercial database developers, it is a matter of economics. The overwhelming majority of customers for roadway navigation data are traveling on nonlocal roads and want current and accurate data for those roads. Consequently, roadway database developers have traditionally focused their data collection activities on updating nonlocal roads. In order for them to provide equivalent levels of data collection on all local roads, they would have to expand their field staffs significantly. Similarly, because local roads are not eligible for most Federal-aid road funding, there are few incentives for State DOTs to collect and maintain roadway inventory data on these roads. Even HPMS requires only limited summary information on non-Federal-aid roads.

The administrative and maintenance responsibilities for local roads typically fall on local governments (counties, cities, or towns). The amount of data collected by these local agencies varies significantly, with no standards and little guidance provided about what data should be collected, data definitions, data formats, or even storage media. Some agencies collect extensive, high-quality data that could be used directly to populate a roadway database; other agencies collect no roadway data at all or maintain their data as paper records. Given this wide variation in local road data, it may actually be more efficient to implement a nationwide data collection effort for key local road data than to try to coordinate and standardize roadway data collection across more than 3,000 counties and 20,000 cities and towns.

Given the realities of current roadway inventory data collection in the United States, IntelliDrive stakeholders need to address the following two questions:

- What is the absolute minimum roadway geometry and inventory data that is required on all U.S. roads in order to implement early IntelliDrive applications?
- Can early IntelliDrive deployments function successfully if some roadway inventory data are only provided for higher functional class roads?

If the answers to these questions indicate that additional data need to be collected for local roads before early IntelliDrive applications can be deployed, then a major, nationwide data collection effort may need to be undertaken to acquire the minimum necessary roadway data items.

Resolution of Roadway Features

IntelliDrive stakeholders identified several roadway attributes that they would like to have for individual lanes, including lane width, cross slope, posted speeds, and longitudinal pavement markings. However, none of the current geospatial roadway networks, public domain or commercial, provide lane-level feature resolution, except where lanes are separated by a physical barrier or unpaved median.

Two of the commercial roadway database developers, NAVTEQ™ and Tele Atlas®, offer "enhanced lane information" for certain types of roadways—specifically, freeway interchanges and complex intersections with dedicated turn lanes in selected urban areas. This enhanced lane information does not produce separate geospatial features for each lane but does include additional data items associated with the roadway segment to identify specific lanes on the roadway segment and relevant attributes associated with each identified lane. Current lane-level attributes include turn restrictions and pavement markings but not the specific location of the lane centerline itself.

Both NAVTEQ™ and Tele Atlas® are collecting and incorporating enhanced lane information into their roadway geometry databases in preparation to support future ADAS applications. IntelliDrive stakeholders and application developers need to evaluate whether the architecture for lane-level data offered in these commercial databases can meet the requirements for proposed IntelliDrive applications or whether new geospatial roadway networks will have to be built to provide lane-level feature resolution.

Current Availability of Specific Roadway Attributes

Although nearly all of the roadway data items identified by IntelliDrive stakeholders could be collected using current or emerging data collection methods, many of these items are not currently being collected by commercial roadway database developers or public agencies as part of routine data collection activities. Specific data items currently not being collected include the following:

Roadway Geometry:

- Vertical curvature (points of curvature and tangency, curve length).
- Available sight distance (passing and stopping).
- Cross slope/superelevation (roadway, lane, and shoulder).

Roadway Inventory:

- Clear zone width.
- Barrier and guardrail locations and characteristics.

- Sidewalk locations.
- Lane-level characteristics (width, function type, posted speeds).

Intersection Characteristics:

- Unique intersection ID.
- Detailed intersection geometry (location of corners, width of turn lanes).
- Pavement markings (crosswalks, bicycle lanes, stop bars).
- Vehicle paths through intersection.
- Traffic signal characteristics (priority and preemption, precise location of signal head).

Other Geospatial Features:

- Commercial vehicle facility characteristics (parking area capacity).

In the absence of new mandated reporting requirements or incentives, it is unlikely that these roadway data items will be collected by public agencies or commercial database developers. IntelliDrive stakeholders need to determine which of these data items are essential for specific applications and then identify strategies for collecting and maintaining each essential data item.

Data Standards

Many of the roadway geometry and inventory data items that are currently being collected do not have well-defined or widely applied standards for feature and attribute definitions, attribute domains and values, data formats, or positional accuracy. The only standards that currently exist on a nationwide basis are those promulgated by the U.S. DOT for the national roadway inventory databases (HPMS, NBI, and HRCI) and the exchange standard for roadway network databases as embodied in GDF, utilized by NAVTEQ™ and Tele Atlas®.

Roadway inventory data that are collected by State DOTs or local road agencies for their own internal applications but are not required by any of the national inventory databases can vary significantly with respect to definitions, attribute values, etc. from one agency to another. The level of effort required to assemble and reconcile data from these multiple sources is likely to be substantial.

For those data items where nationwide standards do exist, the current standards may not be sufficient to satisfy the requirements for IntelliDrive applications. For example, HPMS requires data on median, shoulder, and intersection characteristics to be reported only for selected sample sections and data on roadway curvature and grade to be collected only for broad ranges of values over the entire roadway segment rather than as specific measurements.

Data standards need to be developed to ensure that current and new roadway geometry and inventory data sources meet the needs of proposed IntelliDrive applications. The development of

IntelliDrive data standards needs to be a cooperative effort involving IntelliDrive application developers and roadway database developers in both the public and private sectors.

Database Maintenance and Updating

IntelliDrive applications will require that updates to roadway data items be incorporated into the master roadway database quickly and accurately and be transmitted efficiently to in-vehicle databases.

Current reporting requirements and procedures for national inventory databases do not meet basic IntelliDrive requirements for accurate and timely updates. State DOTs are required to submit updates for national inventory data items once a year but may actually update attribute values associated with a specific feature according to an inspection schedule that is less frequent (e.g., 2–4 years for bridges). Furthermore, since the U.S. DOT does not conduct independent verification of data submitted by States DOTs, data errors are incorporated into the inventory database.

Commercial roadway database developers take a much more proactive approach to data updates, utilizing a variety of sources in addition to State DOT reports, including feedback from database customers and reports from field teams. Commercial master roadway databases are updated on a continuing basis, and changes in key roadway attributes are incorporated as soon as they are received and verified.

Regardless of how a roadway geometry and inventory database is initially developed, a long-term home must be found for it that will provide the database maintenance, updating, and verification functions necessary to meet IntelliDrive application requirements. IntelliDrive stakeholders need to determine whether these database maintenance functions can be achieved within a public agency structure such as the U.S. DOT or through a long-term maintenance contract with a commercial database firm or if overall responsibility for developing and maintaining IntelliDrive roadway geometry and inventory databases should rest entirely with the private sector.

CHAPTER 6. RECOMMENDATIONS AND OPTIONS TO ADDRESS DATA GAPS

This chapter summarizes options and recommendations for developing and maintaining the roadway geometry and inventory databases needed to support future IntelliDrive applications. The first subsection deals with refining and standardizing the roadway data requirements. The second discusses options for building a roadway geometry database. The third discusses regulatory options to support the initiative, and the final subsection lists research needs.

REFINE AND STANDARDIZE INTELLIDRIVE ROADWAY DATA REQUIREMENTS

An issue encountered throughout this study is the inconsistency in roadway feature and attribute definitions, attribute domain values, positional and attribute measurement accuracies, and update frequencies for many of the identified roadway attributes across roadway data collection organizations. This issue underscores the need for development of data standards for roadway geometry and inventory data to support IntelliDrive applications. The standards development process needs to be collaborative, with participation from key stakeholder groups, including, at a minimum, IntelliDrive application developers; Federal, State, and local transportation agencies that collect roadway data; and commercial roadway database developers.

Key issues that should to be addressed through standards development include the following:

- What roadway geometry and inventory data should be provided using a geospatial roadway database versus other data delivery methods such as signal phase and timing data transmitted to a vehicle as it approaches an intersection or vehicle on-board sensor measurements?
- Which roadway features and attributes are essential for specific IntelliDrive applications and which are desirable? Which features and attributes are required for all road segments versus specific types of environments (e.g., complex intersections)?
- What level of feature resolution is needed? (e.g., How should lane-specific attributes, such as lane width or use restrictions, be represented in a roadway database?)
- How can feature and attribute definitions be unambiguously defined? (e.g., What does vertical curvature or available sight distance mean? Where does a bridge begin and end?).
- What are the units of measurement and required accuracy for attributes (e.g., lane and pavement width, curve length and radius, or cross slope)?
- What is the acceptable maximum absolute positional error for specific roadway features? Can this accuracy be collected using current data collection methods?
- How frequently are updates needed? Which attributes must be kept current to ensure safety? How quickly must updates be incorporated into the on-board roadway database?

- Are the standards that emerge from this process mandatory or voluntary? (i.e., Should standards for data definitions, measurement, and positional accuracies be incorporated into Federal reporting requirements?)

The standards development process for IntelliDrive roadway data will be highly technical in nature, time-consuming, and iterative. It will require significant commitments of time and energy from specific stakeholder representatives. Early phases of the process will involve education and information sharing on such topics as geospatial data structures, roadway data collection methods, and IntelliDrive applications and processes. Later phases will involve preparation of standards specification documents and convincing other members of the stakeholder communities that the standards are both necessary and beneficial.

The U.S. DOT can play several roles in the development of standards, including active participation as a Federal stakeholder, the sponsor and facilitator of meetings and workshops related to standards development, and ultimately, a champion for standards that emerge from the development process.

OPTIONS FOR BUILDING A ROADWAY GEOMETRY AND INVENTORY DATABASE

While the development and promulgation of data standards are important steps in building a roadway geometry and inventory database for IntelliDrive applications, the ultimate goal is to create a geospatial data product containing the roadway geometry and inventory data items that are needed to support nationwide deployment of specific IntelliDrive applications. Additionally, once the initial database is developed, organizational structures and procedures must be in place to keep the data current and to disseminate updated information efficiently to IntelliDrive-equipped vehicles throughout the United States.

There are several possible options for building and maintaining an IntelliDrive Roadway Geometry and Inventory Database. These options are discussed along with each option's potential strengths and weaknesses.

Option 1

The first option is a public sector development initiative using public domain data and managed by a Federal agency with authority (and adequate resources) to build and maintain the database.

Under this option, a public sector agency (presumably the U.S. DOT or one of its operating agencies) would develop a national geospatial roadway network database containing many or all of the data items needed to support IntelliDrive applications and make it available as a public domain data product similar to the Census Bureau's TIGER/Line® database.

Developing a public domain roadway database would be extremely costly and time-consuming.[1] However, it also would provide the U.S. DOT with the greatest amount of control over data content, accuracy, and accessibility by all stakeholders and would enable the U.S. DOT or other

[1] For example, the Census Bureau's TIGER and Master Address File accuracy update program took 6 years and cost the Census Bureau in excess of $200 million to complete.

stakeholders to add new data content without concerns about proprietary restrictions on derivative products.

Development of a national geospatial roadway basemap would need to begin from an existing public domain database. This could be either the most recent Census TIGER/Line® road network or possibly a nationwide all-road geospatial database purchased from a commercial roadway developer. The Bureau of Transportation Statistics (BTS) negotiated a similar purchase nearly 10 years ago with Geographic Data Technologies to acquire a slightly out-of-date (18-month-old) roadway network database with limited attribute information and place it in the public domain. The primary benefit of using a public domain version of a commercial network over the Census TIGER/Line® network is that the commercial network would require relatively little additional processing to achieve network connectivity.

Once the base roadway network is acquired, roadway attribute data would have to be collected or compiled from public sources such as State DOTs, local roadway agencies, other Federal agencies, etc. Each new roadway attribute would require resources either for primary data collection or for compiling, verifying, and reconciling attribute data. Development and population of a public sector roadway network database would provide a platform for integrating and enhancing roadway data contained in national inventories such as HPMS, NBI, and HRCI and may facilitate the establishment of a national geospatial data repository for transportation data.

Option 2

The second option is a public sector roadway database that is maintained by a private sector contractor under the sponsorship (and funding) of a public agency.

One of the limitations of the public sector model is that State and national geospatial roadway networks and roadway inventory databases are not maintained or updated in a timely manner. The national inventory databases such as HPMS receive updates from State DOTs on an annual basis, but some of the data elements are based on periodic inspections or data collection that take place on 2-, 3-, or 4-year cycles. One way to overcome this would be through a long-term contract with a commercial database firm to update and maintain the roadway database, with the U.S. DOT sponsoring (and funding) the effort.

An important yet currently unanswerable question is whether any commercial roadway database developer would be willing to accept a contract to maintain and update a public domain roadway database that potentially competes against its own proprietary product. If so, how would the developer differentiate its own product from the public domain product, and would these differences still enable the public domain database to meet IntelliDrive application needs? Finally, how costly would such a maintenance agreement be?

Option 3

The final option is a private sector model where current (and possibly new) roadway database developers compete to market commercial databases to IntelliDrive application developers.

Given the current status of roadway data collection in the United States, a third option is the development of a roadway geometry and inventory database built upon commercial roadway databases. In general, work flow processes such as data collection, storage, updating, quality control, and dissemination are more clearly defined and better integrated among commercial roadway database developers than among public agency sources. In this private sector model, current (and possibly new) roadway database developers would compete to market their own commercial databases to IntelliDrive application developers.

The results of the trade study indicate that commercial developers such as NAVTEQ™ and Tele Atlas® would be strong candidates for this option. Both the NAVTEQ™ and Tele Atlas® databases currently provide basic nationwide geometry for all roads with enhanced positional accuracy and attribute data on higher functional class roads intended specifically for use in IntelliDrive applications. Furthermore, both firms have conducted internal research and development efforts to explore data collection and updating and transmission methods, as well internal and external data communication and processing protocols, and both seem to understand and appreciate the challenges of creating data that need to interface with computers rather than people. Additionally, NAVTEQ™ and Tele Atlas® have the necessary field staff in place to collect and update their roadway data in a timely and efficient manner. Finally, NAVTEQ™ and Tele Atlas® both reported current business plans in place to support IntelliDrive application needs.

INSTITUTIONAL AND REGULATORY OPTIONS

This trade study revealed that State and local roadway management agencies are very reluctant to increase their data collection activities without financial incentives or regulatory mandates. It is recommended that the U.S. DOT implement one or more of the following institutional and regulatory options to encourage new data collection activities among State and local roadway management agencies to better support IntelliDrive data needs.

Option 1

One option is to monitor and participate in ongoing national roadway data sharing initiatives.

A major national data-sharing initiative known as Transportation for the Nation (TFTN) is currently underway. Its purpose is to create a public domain national geospatial roadway layer from the "best available" data collected by all levels of government. The effort is being supported by the National States Geographic Information Council, the U.S. Geological Survey (USGS), the Census Bureau, and the U.S. DOT. The initiative follows the same approach as the previously successful Imagery for the Nation. At a minimum, this effort should be monitored by IntelliDrive to determine what data items, if any, might be included in TFTN that could be used for IntelliDrive applications. Through active participation, IntelliDrive representatives might be able to add new data items from the IntelliDrive roadway data list or be able to identify additional local data sources for specific attributes.

Additionally, TFTN could prove to be a strong ally for both the development and promulgation of roadway data standards and the development of a public sector roadway database.

Option 2

Another option is to consider the availability of local roadway data as a selection criterion for future IntelliDrive demonstration grants.

It is likely that early IntelliDrive deployments will involve operational demonstrations in specific geographic areas and that Federal funding grants will be awarded to local jurisdictions to help support equipment purchases, project oversight, and demonstration evaluation activities. In awarding future IntelliDrive demonstration grants, the U.S. DOT should include the availability and quality of local roadway data as either a prerequisite or an important criterion for selection. This provides an incentive for State and/or local agencies to collect roadway data to support IntelliDrive deployment but does so without regulatory mandate.

RESEARCH INITIATIVES

The study identified several roadway geometry or inventory data items that were not being collected extensively enough to be useful for nationwide IntelliDrive applications. This suggests that one or more research efforts may need to be undertaken to investigate the feasibility and practicality of collecting specific data items using existing or emerging technologies and new methods for data integration and standardization across multiple data sources. The following federally sponsored research projects are recommended to help move forward the development of a roadway database to support IntelliDrive applications.

Project 1

Investigate and test the accuracy of IFSAR technology to develop a 3-D roadway centerline network.

The use of IFSAR technology to develop a 3-D nationwide roadway centerline database could potentially produce an accurate and consistent database of horizontal and vertical roadway curvature, grade, and elevation for all U.S. roads, including local roads. The cost to process the already collected IFSAR imagery is likely to be substantially less than any other current data collection method. However, before any decision is made to proceed with this technology, the following research should be undertaken: (1) verify the horizontal and vertical accuracy levels claimed by the technology developer, (2) evaluate if these accuracy levels meet IntelliDrive application requirements, and (3) examine the costs and use limitations to acquire the 3-D roadway centerline database and place it in the public domain.

Project 2

Examine the feasibility and costs of using mobile LIDAR to collect selected roadway geometry and inventory data.

Some roadway geometry data, including roadway cross slope, lane, shoulder, and clear zone width cannot be collected using IFSAR technology and cannot be measured accurately from videologs. Research should be undertaken to examine the costs and feasibility of collecting and processing multiple roadway data items using mobile LIDAR, either by itself or in combination with videolog feature extraction. The study could explore use of the technology in several roadway environments (e.g., urban, rural high-volume freeway, rural low-volume road, mountainous verses flat terrain) in order to develop a cost profile for collecting key roadway data items on a per-mile basis.

Project 3

Coordinate IntelliDrive roadway data research with safety research activities currently underway through SHRP2.

SHRP2 is currently sponsoring a naturalistic driver behavior study, which will explore the relationships between driver behavior and roadway environment in contributing to vehicle crashes. The study is being conducted at six study area locations and will include the collection of detailed roadway inventory data similar to that identified by IntelliDrive stakeholders at each of the six sites. The data collection activities undertaken at these sites should provide considerable insight into the availability of specific roadway data items, the costs of collecting new data, and the relevance of the data for vehicle crash avoidance. The IntelliDrive program should coordinate closely with this research effort, sharing information on data collection technologies, roadway database standards, and even support for specific data collection activities (e.g., processing of IFSAR imagery).

Project 4

Work with State DOTs to demonstrate the potential benefits of collecting specific additional roadway data items in their business process.

The trade study revealed that few State DOTs have successfully implemented agency-wide standards for data collection such as database documentation, quality control/quality assurance criteria, update or reverification frequency, or even storage media. The IntelliDrive Program could sponsor projects with specific State DOTs to demonstrate the benefits and costs to implementing agency-wide standards for roadway data collection.

Project 5

Expand research done through NCHRP 08-70—Target-Setting Methods and Data Management to Support Performance-Based Resource Allocation by Transportation Agencies to develop a data governance model for IntelliDrive.

NCHRP 08-70 is developing recommended data management and governance techniques for the application of performance measures in State DOTs. It also is identifying the ways data management systems and organizational units within a State DOT can be used to ensure the use of accurate, timely, high-quality data for decisionmaking purposes. Many of the concepts such as data stewardship and data governance maturity models would be relevant to the development of a data management process to support IntelliDrive.

APPENDIX A. INTELLIDRIVE STAKEHOLDER LIST

Table 18. IntelliDrive stakeholder list.

Stakeholder Group	Agency/Organization Invited	Participated in Web Meeting
State DOTs	AASHTO	X
	Arizona DOT	
	California DOT (Caltrans)	X
	Florida DOT	X
	Georgia DOT	
	Idaho Transportation Department	X
	Maryland DOT	
	Michigan DOT	
	Minnesota DOT	X
	New York State DOT	
	Texas DOT	X
	Utah DOT	
	Virginia DOT	X
	Washington State DOT	
Local Transportation Agencies	Metropolitan Transportation Commission, CA	
	Road Commission for Oakland County, MI	
	City of Los Angeles, CA	
	City of Austin, TX	
	Maricopa County, AZ	
	Monterey County, CA	
	Palm Beach County, FL	X
	Montgomery County, MD	
Transit Agencies	APTA	
	Veolia Transportation	
	MTA New York City Transit	
	Lynx (Orlando, Florida)	
	Utah Transit Authority	
	Lane Transit District	

Table 18. IntelliDrive stakeholder list—Continued.

Stakeholder Group	Agency/Organization Invited	Participated in Web Meeting
Traffic Signal and Other Electronic Infrastructure Manufacturers	NEMA	X
	Qualcomm	
	Peoplenet	
	XATA Corporation	
Traffic Management System Integrators	Iteris	
	TransCore	X
	Verizon	
	Econolite Control Products, Inc.	
	HNTB	
Other	International Bridge, Tunnel, and Turnpike Association	
	Strategic Highway Research Program	X
	Transport Canada	X
	Noblis	X
Automobile Manufacturers (CAMP)	Association of International Automobile Manufacturers	
	Center for Automotive Research (CAR)	X
	BMW	
	Chrysler	
	Daimler	
	Ford	
	General Motors	
	Honda	
	Mercedes-Benz	
	Nissan	
	Subaru	X
	Toyota	
	Volkswagen	
	VW Group (Audi)	
Motor Carrier Industry	American Transportation Research Institute	X
	Scania Trucks	
	Truck Manufacturers Association	
	Volvo Technology—North America	X

Table 18. IntelliDrive stakeholder list—Continued.

Stakeholder Group	Agency/Organization Invited	Participated in Web Meeting
University Transportation Centers	University of Minnesota	
	CTRE—Iowa State University	X
	California PATH Berkeley	X
	Virginia Transportation Research Council	X
	Western Transportation Institute—Montana State University	
	Michigan Tech Research Institute	X
	University of Michigan Transportation Research Institute	
	Virginia Tech University	
IntelliDrive Integrators/ Developers	Delphi Electronics & Safety	
	Denso International America, Inc.	
	Intrass	X
	Kapsch Group	
	OmniAir Consortium	
	Mixon/Hill, Inc.	X
	G4 Apps Inc.	X
	Applied Computer Technologies, Inc.	
	Intelligent Transportation Society of America	
	Vehicle Infrastructure Integration (VII) Consortium	X
	Institute of Transportation Engineers	
Federal Agencies	National Highway Traffic Safety Administration	
	Federal Transit Administration	X
	Federal Motor Carrier Safety Administration	
	FHWA	X
	U.S. DOT	

APPENDIX B. SUMMARY OF STAKEHOLDER FEEDBACK

This appendix summarizes stakeholder feedback from the Web meetings on roadway geometry and inventory information needs.

ROADWAY GEOMETRY DATA

The following comments were received from stakeholders regarding the roadway geometry data elements:

- Stakeholders generally agreed that information on basic roadway geometry and curvature are critical data elements in the short term.

- Additional data elements include sight distance for passing and stopping and slope of the road for braking purposes.

- One stakeholder observed that the data elements related to vertical alignment appeared to focus on curves only. Many urban areas have elevated roadways or multilevel bridges, and it would be necessary to distinguish between vehicles traveling on the elevated portion of the roadway and cars traveling underneath the road, where the GPS signal could potentially be blocked. It is important to capture this third dimension (i.e., the z measurement). Additional research is needed in this area.

ROADWAY INVENTORY DATA

The following comments were received from stakeholders regarding the roadway inventory data elements:

- One stakeholder suggested that speed zone data should be provided at the lane level. For example, Canada has many locations where there might be variable lane speeds across a single segment of road.

- Additional data elements include locations of the edge of travel lanes; locations of bicycle paths/lanes; guardrail information; overpass height restrictions; locations of runaway truck lanes, particularly in mountainous areas; restricted lane use for trucks and transit vehicles on freeways; and pavement condition data and pavement coefficient of friction, particularly during inclement weather conditions.

- High-occupancy/toll (HOT) is listed as a lane use restriction type, but additional information is needed on whether a lane is tolled and the type of toll in place (e.g., variable, fixed, based on time of day, etc.).

- For HOV lanes, the presence of lane barriers (e.g., continuous flow HOV lane or barrier separated) should be included as part of the lane geometry.

- Data elements needed for transit applications should also be considered. Transit-related data include transit stop locations, hard shoulder running for buses, and type of transit stop (e.g., in-lane, pulloff lane, contraflow pullout stops for buses). Transit stop type is important because it impacts how a transit vehicle merges into traffic. Other transit data include queue jump and transit signal priority (TSP). These data are highly dynamic with respect to whether TSP is engaged, route schedule considerations, etc.

- Stakeholders suggested that obtaining speed zone data would not be easy, as there is no one-stop data source that includes posted speed information. The same applies for reduced speeds in work zones, particularly when the work zone is in place for a year or more.

INTERSECTION CHARACTERISTICS

The following comments were received from stakeholders regarding intersection-related data elements:

- Stakeholders generally agreed that the location of stop-controlled intersections is a high-priority data element for intersections.

- Additional detail is needed to identify the location of the intersection (i.e., locating each of the four corners of the intersection), as well as the location of the stop bar on the approach.

- Stakeholders suggested that the location of the start of a left- or right-turn lane would be more relevant than the length of the turn lane. This would provide information on the transition from regular travel lanes to an intersection location.

- In order to implement the intersection-related applications, one stakeholder suggested that a linkage between the signal control status and lane configuration would be needed. It is important to provide mapping between lanes and the signal phase they are matched with. Information on pedestrian protection controls also would be needed.

- One stakeholder suggested that vehicle path and centerline data would be more efficient and relevant for collision applications at intersections, rather than the data elements that are listed. This would involve drawing vectors through the intersection to represent potential vehicle paths. If vehicle paths are predefined, it is possible to then provide information regarding warnings or near collisions. Detailed intersection configuration data may be needed to calculate vehicle paths, however.

- One stakeholder suggested that data elements for intersection-related applications should capture normal operations as opposed to unexpected conditions.

OTHER GEOSPATIAL FEATURES

The following comments were received from stakeholders regarding other geospatial data elements:

- Stakeholders suggested that the start and end location of bridges would be more pertinent than bridge length.

- Additional data elements for commercial vehicle applications include the location of truck parking facilities; facility capacity and availability of truck parking; right-of-way information for wireless inspection applications; posted and actual vertical clearance of overpasses; weight restrictions for bridges; and locations of commercial vehicle restricted zones in suburban/urban areas.

- Information related to border crossings would also be useful for commercial vehicle applications. Data elements could include border wait times, whether particular lanes are fast/normal lanes, inspection regimes, and other relevant factors.

- Information on the movement of dangerous goods and hazardous materials through an area is also important, particularly for disseminating information to first responders in case of an emergency.

- Railroad crossing data elements are applicable for all IntelliDrive applications, not just those related to commercial vehicles. One stakeholder suggested that railroad crossing control status also would be an important data element. One stakeholder pointed out that at some locations, railroad crossing status may not be available, particularly in rural areas where there may be unregulated crossings that have no control type.

- Stakeholders generally agreed that knowledge of locations where real-time traffic information is available would be useful, particularly to commercial freight operators for route diversion based on congestion. The locations of road condition coverage also would be useful.

APPENDIX C. ROADWAY DATA SOURCE PROFILES

COMMERCIAL ROADWAY NETWORKS

Interviews were conducted with four of the five commercial developers of roadway networks databases that provide nationwide all-road coverage for vehicle routing, navigation, and location-based services.[1] The purpose of the interviews was threefold: (1) to accurately identify what roadway geometry and inventory data items are currently included in each developer's roadway network database, (2) to learn more about developers' internal procedures for updating and enhancing their databases, and (3) to explore each developer's current business plans for creating a national roadway database to support IntelliDrive applications.

The four commercial database developers interviewed were ALK® Technologies, Inc., DeLorme, NAVTEQ™, and Tele Atlas®. Brief profiles of each firm and summaries of their responses to interview questions are presented here.

ALK® Technologies, Inc.

Web site: http://www.alk.com/

ALK® is a privately held information technology company specializing in transportation and logistics software solutions and the development of roadway map data. The company was founded in 1979 and is headquartered in Princeton, NJ.

ALK®'s PC*MILER® business solutions provide industry-standard PC*MILER® mileages, routes and maps via back-office and Web-based solutions deployment. First introduced in 1986, PC*MILER® components are used today throughout the freight transportation industry for routing, scheduling, rating, driver pay, toll and fuel calculations, and fuel tax filing and auditing purposes.

ALK®'s CoPilot® business provides GPS navigation solutions to the consumer and business markets worldwide. In 1990, ALK® launched a back-office trip-generating service for the consumer market and then expanded its consumer-related offerings with a series of desktop trip-planning products. In 1997, ALK® launched its CoPilot® GPS navigation business and in 2002 expanded into the European market with the launch of CoPilot Live® turn-by-turn navigation for Pocket PCs and Windows Mobile smartphones. Today, CoPilot Live® provides GPS navigation solutions for Android, iPhone, and iPad. ALK® provides CoPilot® solutions for a variety of onboard computers, PNDs, handheld devices, and smartphones.

ALK®'s map business has historically bundled ALK Digital Maps™ with both PC*MILER® and CoPilot® solutions. Originally optimized to function within just ALK® software solutions, ALK Digital Maps™ is now available for licensing to third parties.

[1] Despite numerous attempts, no one contacted at Google responded to requests for information about their development of a roadway map database. Consequently, all information in this report pertaining to Google Maps™ has been derived from Google's Web site or from secondary sources.

1. What is the source of your roadway network?

ALK Digital Maps™ is derived from the U.S. Census TIGER/Line®, U.S. Postal Service, Statistics Canada roadway data, and Canada Post information. ALK® processes millions of GPS tracks from its consumer and commercial customers and utilizes a variety of satellite and aerial imagery for validation purposes. ALK® developed and utilizes a proprietary GIS network editing system to enhance ALK Digital Maps™ to meet the specific needs of the North American commercial trucking, transportation, and logistics industries. As such, the roadway data has been topologically connected and attributed to support turn-by-turn commercial vehicle routing (e.g., identification of one-way streets, turn restrictions, bridge height, weight, truck prohibited roads, HAZMAT restrictions, etc.).

2. How are roadway geometry and inventory data items updated?

ALK® uses a variety of public and private sources for updating its roadway database. The company has developed relationships with thousands of Federal, State, and local government agencies and combines information gathered from public sources with detailed feedback from its large base of consumer and commercial customers. ALK® has implemented an electronic GPS track collection and processing system that helps to identify and accurately position new roads, interstate on- and off-ramps, traffic patterns, real-time speeds, and travel times. Additionally, ALK® customers routinely identify map improvements by phone, fax, and email and by submitting GPS log files to ALK®.

ALK® actively works with Federal, State, and local agencies to obtain updates of roadway information (e.g., new roads, changes in attributes, etc.). Additionally, ALK® has created an ALK MapSure™ service for its CoPilot Live® (version 8) North American customers, which enables them to report missing addresses and changes in roadway attributes to ALK® and to receive a map update that incorporates these changes within 45 days.

The locational accuracy of the roadway geometry varies depending on a variety of factors including road type, data source, and whether or not GPS tracks have been submitted for a particular segment. The majority of ALK Digital Maps™ data have a positional accuracy of 3.28–9.84 ft (1–3 m).

3. How long, typically, is the lag time between when a change in a roadway feature or attribute is identified and when it becomes available to your database customers?

ALK®'s master roadway database is updated continually as corrections, enhancements, and changes are obtained from various sources. A new "snapshot" of the entire roadway database is built weekly for internal use.

ALK® releases updates of its roadway data on different schedules depending on the product and specific customer requirements. CoPilot Live® mobile navigation customers can download maintenance updates (user-reported updates) monthly and can obtain a full map update quarterly. Updates for PC*MILER® customers are handled on a case-by-case basis, depending on individual requirements. For some customers, ALK® is moving toward providing near-real-time updates. In emergency situations, like a bridge collapse, ALK® can issue map data overrides in a matter of hours.

4. Who are your principal customers for roadway data?

ALK®'s principal customers for roadway data have been its PC*MILER® and CoPilot® product customers. PC*MILER® sells primarily to the commercial trucking, transportation, and logistics industries. CoPilot® sells to general consumers, business fleets, telematics solution providers, commercial truck manufacturers, and manufacturers of smartphones and handsets.

5. Are you planning to develop a roadway database that would support IntelliDrive applications?

ALK® currently does not plan to develop roadway map databases specifically for the IntelliDrive application market. However, ALK Digital Maps™ could be extended to incorporate new roadway attributes should a supporting business case for this market materialize.

6. Do you collect and maintain roadway features that serve specialized markets, such as commercial vehicles or pedestrians?

Yes. To support ALK's PC*MILER® business solution, ALK Digital Maps™ incorporates a large number of truck-specific attributes, including bridge clearances; size and weight restrictions; designated, restricted, and prohibited truck routes; HAZMAT routes and restrictions; and toll roads and toll costs by vehicle class and direction. Truck-specific POIs, including truck stops, State weigh stations, and certified automated truck scales; major freight destinations, including military installations, intermodal terminals, and railroad freight stations; and standard point location codes for freight billing also are actively maintained.

To support ALK®'s CoPilot® GPS navigation solution, ALK Digital Maps™ are enhanced with height, weight, and bridge clearance information, scenic route designations, fuel locations, campgrounds, and other consumer-oriented POIs. For CoPilot® business customers, ALK Digital Maps™ are enhanced with depot locations and other business facilities, business-designated through roads, and branded POIs from major commercial chains, customers, and advertising partners.

7. What impact do you think that "free" navigation data such as Google Maps™ or OpenStreetMap, will have on market share and profitability of your roadway map data?

ALK® does not think that Google™'s recent development of a roadway database will impact its market share for its transportation industry customers. Among business customers, quality is paramount, and ALK® believes that with its 25-year history of serving this market, they can deliver a superior quality product. Neither Google Maps™ nor OpenStreetMap currently are able to support transportation and logistics customers, and ALK® believes that they each have a long way to go in order to become viable within that market.

In the general consumer market, the new entries may cut into ALK®'s market share, but ALK® believes that the total number of customers will increase as the overall market for GPS navigation solutions continues to expand due to a combination of growing public awareness, price reduction, and the availability of digital map products on the market. This customer growth will help ALK® to improve and update its core map data and enhance its customer offerings. ALK® also believes that there are numerous emerging options to further monetize its existing investment in map data within the consumer market.

DeLorme

Web site: http://www.delorme.com/

DeLorme is a commercial map maker founded in 1976 and headquartered in Yarmouth, ME. It produces a variety of products serving both the general public and commercial customers, including paper maps, atlases and gazetteers, GIS and navigation software, GPS receivers, and geospatial data. DeLorme produces and markets several software products for the general consumer, including Street Atlas USA®, a route planning and navigation software package for use with computers, wireless devices, and GPS receivers; Topo USA™, GPS mapping, route planning, and navigation software oriented toward offroad exploration and the outdoor recreation market with extensive information on hiking trails, campgrounds, topography, land cover, etc.; and XMap®, a full-function GIS software package.

DeLorme has developed a number of geospatial databases that can be used with its mapping, routing, and GPS navigation software. These databases are also sold separately for use with other GIS software packages. The DeLorme Base Map, World is a worldwide topographic data set with a horizontal accuracy of ±164 ft (50 m) and a consistent level of detail and resolution for all features worldwide. Transportation features, including roads and railroads, are topologically connected to support routing and navigation. Elevation data are based on the Shuttle Radar Terrain Model, which uses point elevation measurements taken at 3 arc-second intervals (approximately every 196.8–295.2 ft (60–90 m), depending on latitude).

The DeLorme North America Data Set™ contains an all-roads database for the United States and Canada. The roads layer, along with other geospatial features (e.g., railroads, airports, hydrography, place names, and State, county, and urban area boundaries) are part of the Reference Base Map data set. Elevation data, along with hiking trails, land cover, public land boundaries, and more detailed hydrographic data, are included in the Topographic Data Set, which is oriented toward the offroad market. The elevation data were derived from USGS digital elevation model data, which uses point elevation measures posted every 32.8 ft (10 m). Elevation data are not explicitly integrated into the roads layer. Additional roadway attribute data, including highway functional classification, one-way streets, bridge heights on major roads, some road signage, and designation of overpasses and underpasses, are part of the Routing Data Set.

1. What is the source of your roadway network?

Most of the geospatial data in the North America Data Set™ were originally compiled from public data sources, including the Census TIGER/Line® files, USGS National Map data, Statistics Canada, and other State and local data sources. DeLorme has enhanced the locational accuracy of the source data by redigitizing the line work using "best available" orthoimagery data obtained from USGS and other publicly available State and local sources.

2. How are roadway geometry and inventory data items updated?

DeLorme relies most heavily on publicly available secondary data sources to update its roadway geometry database. The primary sources for updating are orthoimagery databases that have been collected under national programs such as the National Digital Orthoimagery Program or by State and local agencies.

DeLorme also obtains updated data from State and local agencies but does not have any formal or exclusive data-sharing agreements with specific agencies. DeLorme also provides a reporting capability, both on its Web site and with each software product, that enables users to report errors or submit revisions to its databases.

DeLorme has no external field staff or roadway inventory vehicles and therefore does not conduct its own independent verification of information received from its update sources.

3. How long, typically, is the lag time between when a change in a roadway feature or attribute is identified and when it becomes available to your database customers?

Roadway data are updated on a continuing basis, but DeLorme releases an annual update of its North America roadway data in conjunction with its Street Atlas USA® product. A small subset of commercial customers can update twice a year.

4. Who are your principal customers for roadway data?

DeLorme believes that its comparative strength and market niche is in producing maps and geospatial data for rural areas. The corporate slogan is “where the pavement ends,” and its most lucrative customer markets are related to outdoor recreation (hiking, backcountry camping, hunting and fishing, offroad vehicles) and oil and gas exploration. The Topographic Data Set is specifically oriented toward these markets with geospatial layers showing elevation, natural features, and land cover, and its PND product line has been designed specifically for rugged, outdoor use.

5. Are you planning to develop a roadway database that would support IntelliDrive applications?

DeLorme currently does not plan to develop a roadway database with the additional roadway attributes and enhanced geospatial accuracy necessary to support IntelliDrive applications. Given its relatively small size and absence of a nationwide field staff, DeLorme does not believe that it can compete profitably against larger international firms like NAVTEQ™ or Tele Atlas® in serving the IntelliDrive market.

6. Do you collect and maintain roadway features that serve specialized markets, such as commercial vehicles or pedestrians?

In addition to serving the rural, offroad market, DeLorme includes some data on bridge height and weight restrictions (derived from FHWA’s NBI) and on truck roadside weigh and inspection stations. However, commercial trucking does not represent a major customer for DeLorme roadway data.

7. What impact do you think that “free” navigation data such as Google Maps™ or OpenStreetMap, will have on market share and profitability of your roadway map data?

DeLorme does not see Google™’s recent development of a roadway database as a serious competitor for its customers. Street Atlas USA® operates as a stand-alone trip planner in addition to supporting its product line of GPS PNDs, and the North America Data Set™ includes many more geospatial features than Google Maps™. DeLorme believes that Google™’s widespread visibility and ease of access to mapping will increase public awareness of mapping products and could potentially enlarge the market for such products as Street Atlas and Topo USA™.

NAVTEQ™

Web site: http://www.NAVTEQ.com/

NAVTEQ™ is a major provider of digital map data for automotive in-vehicle navigation systems, mobile navigation devices, and Internet mapping applications both in North America and worldwide. The Chicago-based company was founded in 1985 and has more than 4,700 employees located in over 200 offices across 46 countries. In 2008, NAVTEQ™ was acquired by and operates as a wholly owned subsidiary of Nokia Corporation, a Finland-based company that is one of the largest cell phone manufacturers worldwide.

NAVTEQ™'s North American roadway network data are used in a variety of in-vehicle navigation systems, portable GPS navigation devices, wireless navigation applications for most cell phone manufacturers, and Internet mapping services. NAVTEQ™ has also been an ongoing participant in research related to roadway data for IntelliDrive applications.

To support current vehicle routing and navigation applications, NAVTEQ™ roadway databases are fully connected topologically and include roadway attributes needed for correct vehicle routing, including one-way streets, turn prohibitions, and restrictions on use of certain lanes (e.g., HOV/HOT lanes). NAVTEQ™ roadway data also include posted speed limits, number of lanes, bridge and tunnel locations, railroad crossings, and locations of medians. NAVTEQ™ is also collecting and incorporating detailed lane attributes at complex intersections, including location and number of turn lanes, ramp transition lanes, lane-level restrictions and temporal qualifiers (where applicable), and location of traffic control signals and signs. These enhancements currently are available for all controlled access highways and in selected North American cities. Additional cities will be added in the future.

NAVTEQ™ data are published in several formats, including GDF, two common GIS data formats—ESRI shapefiles and MapInfo Table format—and a Relational Data Format.

1. What is the source of your roadway network?

NAVTEQ™ leverages a combination of sources and technologies for both collection and verification of roadway data. While some public domain geospatial data were used as a foundation, NAVTEQ™ uses a total of 80,000 sources to build and update its roadway map data. NAVTEQ™ employs over 1,000 geographic analysts who drive the roads to validate the quality of sources and to collect over 260 attributes based on direct observation and a global specification.

NAVTEQ™'s quality control and quality assurance procedures have established a maximum locational error of 16.4–49.2 ft (5–15 m). However, NAVTEQ™ also has worked closely with industry leaders to help define new requirements for increased locational accuracy requirements for ADAS applications. NAVTEQ™ is currently upgrading accuracy standards to a maximum of 16.4 ft (5 m) absolute error and 3.28 ft (1 m) relative error and employing these standards for future roadway data updates. NAVTEQ™ has completed this enhancement for all controlled access highways and approximately 80 percent of secondary roads in North America; additional coverage will be added in the future based on input from customers developing ADAS applications.

2. How are roadway geometry and inventory data items updated?

NAVTEQ™'s primary means of updating its roadway data is through its extensive field staff. Local field staff maintain ongoing relationships with State and local transportation agencies to obtain information on roadway changes (e.g., new roads, road closings, designation of one-way streets). Additionally, NAVTEQ™'s fleet of roadway inventory vehicles resurvey roads on a regular, multiyear schedule.

NAVTEQ™ also maintains a Map Reporter page on its Web site through which users may report errors or changes in current NAVTEQ™ maps.

3. How are roadway geometry attributes that change frequently, such a horizontal curves and grades, represented in your roadway network?

Roadway curvature and slope data are stored as attributes of nodes and shape points for those roadway segments that have enhanced locational accuracy to support ADAS applications. Horizontal curvature is represented by a measure of curvature and heading at shape points along the curve. Slope is represented by both absolute elevation and gradient at shape points along the road segment where slope is present.

4. How long, typically, is the lag time between when a change in roadway feature or attribute is identified and when it becomes available to your database users?

Roadway geometry and attribute data are updated continually by NAVTEQ™, and new public releases are currently published four times a year.

5. Do you envision that the roadway database developed to support IntelliDrive applications would be a separate product from your current vehicle navigation database?

NAVTEQ™ has developed its roadway database to support a variety of customers and use cases, including ADAS. IntelliDrive applications will most likely use both basic roadway geometry and attributes currently used for navigation, as well as the increased locational accuracy and advanced attributes such as measures of roadway curvature and slope.

IntelliDrive applications would need to integrate the roadway database into a vehicle's on-board computer system. NAVTEQ™ has proposed utilizing its Map and Positioning Engine (MPE™) map, which integrates the essential roadway geometry and critical attribute data required for IntelliDrive applications. This simplified map can be updated more efficiently and installed in an MPE™ that can deliver the necessary data for a defined range ahead of the vehicle (i.e., the electronic horizon) directly to the controller-area network (CAN) bus on each vehicle. The MPE™ architecture combines GPS, dead reckoning, MPE™ map, and the electronic horizon into a single low-cost, compact device that is always on and can be installed in all vehicles whether or not they have supplemental navigation systems.

6. How would updates to roadway data be transmitted to end users?

To support IntelliDrive applications, updates to key roadway data would need to be provided more often than quarterly and would need to be provided automatically, rather than dependent on the end user to download them. One option would be to transmit updates for specific geographic areas (e.g., a 1-mi^2 (2.59-km^2) tile) directly to the MPE™ for vehicles entering the area using DSRC or some other wireless communications technology. The updating process would be automatic and would require no action by the driver.

7. Do you see any limitations in the type of data that can be maintained in a roadway geometry and inventory database?

Roadway map data provide important road-based information that can be combined with data provided by other sensors to support specific IntelliDrive applications. Map data provides the longer range "over the horizon" view of upcoming roadway conditions and potential hazards that cannot be detected by in-vehicle stability sensors (e.g., gyroscopes, wheel slip detectors) or near field vehicle-mounted sensors (e.g., radar, LIDAR, or video).

Additionally, roadway map data are best at providing information that stays relatively constant over time, such as roadway curvature and grades or locations of fixed roadway features such as signs, guardrails, or traffic lights. Map data are not well suited to provide information that is highly dynamic or irregular, such as the current phase of a traffic signal or railroad crossing gate or roadway weather or traffic conditions. This type of information needs to be communicated directly to the vehicle through some form of wireless technology.

8. Do you collect and maintain roadway features that serve specialized markets, such as commercial vehicles or pedestrians?

NAVTEQ™ has developed a set of roadway attributes that enable routing and guidance specific to large trucks, which it markets as a supplemental database to its core roadway data file (NAVTEQ Transport™). Additional attributes include physical restrictions such as bridge height and weight clearances, legal restrictions such as truck speed limits, turn restrictions, and signs oriented toward large vehicles such as crosswinds or steep grades.

NAVTEQ™ also has developed NAVTEQ Discover Cities™, which includes pedestrian-oriented data items such as transit (bus and rail) stops, crosswalks, pedestrian- and bicycle-only pathways, and time-of-day restrictions on access to specific POIs. Discover Cities™ is currently available for about 30 North American cities, and NAVTEQ™ plans to expand to new cities every year, focusing on the major metropolitan areas.

9. What do you see as the most significant obstacles to the commercial development and deployment of roadway map databases to serve IntelliDrive applications?

There is currently little in the way of specific guidance or standards on what roadway data will be needed to support IntelliDrive applications, so commercial roadway developers are proceeding cautiously to incorporate attributes that seem to be important but also are practical to collect given current technology.

Tele Atlas®

Web site: http://www.teleatlas.com/index.htm

Tele Atlas® is a major provider of digital map data for automotive in-vehicle navigation systems, PNDs, and Internet-based mapping applications, both in North America and worldwide. It currently provides roadway map coverage for more than 200 countries and territories and has offices in 27 countries around the world. Tele Atlas®'s North American headquarters is located in Lebanon, NH.

Tele Atlas® was founded in 1984 in the Netherlands. In 2000, it acquired ETAK, an early developer of in-vehicle navigation systems and navigation-based roadway data, and in 2004, it acquired Geographic Data Technologies, a U.S. digital mapping firm founded by Don Cooke in 1980. Through these two acquisitions, Tele Atlas® became a major competitor in the U.S. digital roadway map database market. In 2008, Tele Atlas® was acquired by TomTom, another Netherlands-based company that produces PNDs.

Tele Atlas®'s North American roadway network data are used in navigation systems installed in certain new vehicles for auto manufacturers like BMW and Ford, in products developed by original equipment manufacturers (OEMs) like DENSO, for various PNDs including Blaupunkt, Navman, Pioneer, and TomTom, and for automotive traffic reporting services such as INRIX. Tele Atlas® data are also used as roadway basemaps by several State transportation and emergency management agencies, including New York and Washington.

Tele Atlas® map data are published in several formats, including GDF and ESRI shapefiles. The map data are updated on a continuous basis, with new public releases published four times per year.

1. What is the source of your roadway network?

The Tele Atlas® U.S. roadway network was originally derived from public data sources, including the Census TIGER/Line® files and USGS topographic maps. Since the early 1990s, the network has been updated and substantially enhanced through a variety of procedures, including use of high-resolution orthoimagery, GPS-equipped vehicles operated by Tele Atlas® staff, updates from State and local data sources, and through feedback from Tele Atlas® map users. With its acquisition by TomTom, Tele Atlas® gained exclusive access to vehicle-based GPS tracks collected through TomTom's MapShare program, whereby vehicles using TomTom PNDs are anonymously tracked as probes based on GPS coordinates.

Current quality control and quality assurance procedures developed for Tele Atlas® navigation applications have defined a maximum locational error of 42.6 ft (13 m). However, in anticipation of increased locational accuracy requirements for ADAS applications, Tele Atlas® is enhancing accuracy standards to a maximum of 16.4 ft (5 m) absolute error and 3.28 ft (1 m) relative error.

2. How are roadway geometry and inventory data items updated?

Tele Atlas® plans to continue to use all of the previously mentioned sources for updating and enhancing its roadway database but will substantially increase its use of "community input" or "user-generated content" as a major source for updating and enhancing its roadway geometry data. There currently are over 30 million TomTom PNDs in service worldwide. Compiling the GPS vehicle tracks recorded by all TomTom users in the United States and Canada can generate traces of roadway mileage equivalent to covering the entire North American road network once a day; in Europe it is equivalent to covering the European road network four times per day. By developing efficient procedures to process and summarize this vast amount of vehicle track data, Tele Atlas® expects to be able to extract more accurate location information on roadway lane centerlines, turning lanes, intersection stop locations, and the location of new roads (e.g., multiple tracks that seem to leave the existing roadway network).

GPS vehicle tracks can also provide information on average speeds (e.g., greater distances between successive GPS points indicate higher speeds). By developing more sophisticated data processing methods, it may be possible to create driver-based speed profiles, with both average and ranges of speed, over specific roadway segments. With this information, it may even be possible to develop IntelliDrive applications that specifically account for individual driving behavior (e.g., someone who typically drives faster than average may be able to adjust their speed or curve departure warning to activate only when their speed exceeds the 80^{th} percentile of all drivers using that section of road).

Tele Atlas® has reduced, but not eliminated, its use of roadway inventory vehicles driven by in-house staff. These vehicles will continue to be used to verify new roads and to provide updates to roadway attributes that cannot be extracted from GPS vehicle tracks.

Tele Atlas® maintains contacts with many State and local agencies to obtain updates for local roadway geometry and attribute data. However, there is considerable variation in the quality, frequency, and type of data that these agencies provide. Most often, this information is used to identify areas that need to be investigated or revisited by Tele Atlas® rather than used directly to update roadway attributes.

3. How are roadway geometry attributes that change frequently, such a horizontal curves and grades, represented in your roadway network?

The coordinates of all endpoints and intermediate shape points used to draw a roadway segment include latitude, longitude, and elevation. Measures of curves and grades are calculated from these point measures. When the calculated measure is constant over the entire segment, a single value is assigned at each endpoint. However, when the calculated measure changes more than a specified threshold amount across the segment, additional intermediate values are included based on linear distances measured from the beginning of the segment.

4. How long, typically, is the lag time between when a change in roadway feature or attribute is identified and when it becomes available to your database users?

For changes that reflect construction of new roadways, information is typically known well in advance of when the roadway is actually opened to traffic, and the new feature and attributes are already incorporated into the roadway database. However, since Tele Atlas® currently releases an update four times a year, it is possible that some changes may not appear in their published database for up to 3 months after they occur.

In preparation for future ADAS applications, Tele Atlas® has established a goal of incorporating changes into the roadway database within 48 hours of receiving and verifying the change.

5. Do you envision that the roadway database developed to support IntelliDrive applications would be a separate product from your current vehicle navigation database?

Both vehicle navigation and ADAS applications would use the same basic roadway geometry. However, the specific roadway attributes and how they are represented could be very different. For example, data for ADAS applications will need to be interpreted by in-vehicle processors and therefore must be more precise in how they are defined and in their domain values. Additionally, some attributes that are very important for routing and navigation (e.g., street name, POI) are unnecessary for ADAS applications.

The primary customers for vehicle routing and navigation data are the end users (i.e., buyers of vehicle navigation systems and PNDs). The primary customers for ADAS data are the automobile manufacturers and OEM developers. This potential market has a much smaller number of potential customers, but each product sale would be substantial (e.g., license to install data in each new vehicle).

6. How would updates to roadway data be transmitted to end users?

Tele Atlas® sees this as a critical question that needs to be resolved. Periodic releases of complete replacement databases, as is presently done for navigation data, will not meet the needs for safety-related ADAS applications. Most likely, methods to transmit updates for portions of the database based on geographic location will be used. For example, using G4/G5 wireless or DSRC technology, updates to map data for a defined geographic area could be broadcast and received by any vehicle passing within transmission range. Vehicles with updated maps would simply ignore the transmission, while those with outdated maps would read and incorporate the updates into their databases. The technology, communications protocols, and data standards needed to make this work are critical but beyond the scope of this study.

7. Do you see any limitations in the type of data that can be maintained in a roadway geometry and inventory database?

Map databases are effective in providing data that is relatively static or that changes in predictable ways over time (e.g., the directionality of reversible highway lanes by time of day). Map databases should not be expected to deliver highly dynamic data that changes on irregular schedules (e.g., traffic signal status, congestion-based tolls) or data that is dependent on several highly variable conditions (e.g., pavement coefficient of friction or passing sight distance).

Map databases are a complement to, rather than substitute for, on-board vehicle sensors and intelligent roadway infrastructure (e.g., traffic signals or traffic message signs) that use DSRC to transmit their current status.

8. Do you collect and maintain roadway features that serve specialized markets, such as commercial vehicles or pedestrians?

Tele Atlas® produces a Logistics® product, which supplements its core roadway map database with additional attributes needed to select safe and efficient routes for large trucks. Attributes included in the Tele Atlas® Logistics® database include height, weight, and length restrictions, truck-specific speed limits, designated truck routes, cargo type restrictions, etc. Current POI data also include some information on locations of truck stops, weigh stations, etc., but Tele Atlas® is planning to develop a more comprehensive database of truck-specific locations.

Tele Atlas® also is developing an Urban Maps™ enhancement product oriented toward pedestrian travel in larger urban areas. To date, most of the cities for which Tele Atlas® Urban Maps™ have been developed are located in Europe.

9. What do you see as the most significant obstacles to the commercial development and deployment of roadway map databases to serve IntelliDrive applications?

Currently, the financial risks to developing roadway map data to support IntelliDrive applications rest with the commercial map database developers. At least, the following three components of risk need to be better resolved:

- **Standards:** Acceptable standards for locational accuracy, feature, and attribute content and definition need to be established. These standards must reflect both the minimal needs of IntelliDrive applications and practical expectations for data collection, maintenance, and updating. Once established, these standards need to remain stable so that database developers are not chasing a moving target.

- **Liability:** The locational and temporal accuracy of specific data items cannot be guaranteed by a database developer; too many things change too often for a map database to remain perfectly accurate all the time. Map database developers need to be indemnified against liability claims that inaccurate or out-of-date map data contributed to a vehicle crash.

- **Marketability:** The potential market for a roadway database to support IntelliDrive applications is likely to be limited to a few high-volume customers (e.g., auto manufacturers and OEMs). Initially, at least, the costs of collection and maintenance of ADAS data items will have to be cross-subsidized by profits from sales of navigation data. If the market for commercial navigation data is reduced due to availability of free navigation data and applications (e.g., Google Maps™ or OpenStreetMap), the price for ADAS data may have to increase significantly.

STATE DEPARTMENTS OF TRANSPORTATION

California DOT

The California Department of Transportation (Caltrans) is responsible for designing, constructing, operating, and maintaining more than 50,000 mi (80,500 km) of California's State highway system, which includes freeways, highways, expressways, toll roads, and rights-of-way. Caltrans provides additional services within the State, such as intercity rail, permitting for public-use airports and special-use hospital heliports, and working with local agencies. The organization is subdivided into 12 geographic districts, each having jurisdictional responsibility for State highways within the county or group of counties encompassed within that district. In 2007–08, the Caltrans annual budget totaled $14.1 billion.

1. What roadway features and attributes does your agency collect and maintain?

For roadway inventory, Caltrans maintains a georeferenced database on lanes, including number of lanes, lane use restrictions (limited to HOV lanes), and special lane function type (limited to bicycle accessibility). Median- and shoulder-related attributes include location, type, and width for highways only. For ramps, Caltrans maintains a georeferenced inventory of ramp location and type. Pavement condition data are maintained for highways only and are collected annually through measurement.

For intersection characteristics, Caltrans maintains data on intersection location and type, number of through lanes, left- and right-turn lane configuration, location, and channelization, and type of traffic control. These data are available for highways only.

For other geospatial features, georeferenced data are available for barrier systems on highways, including beginning and ending locations, type, and location (roadside/median). These data are updated based on construction drawings for new projects. Rail crossing data are limited to crossing locations on highways. Data for bridges/tunnels includes beginning location, structure length (from which ending location could be determined), vertical under clearance if over a highway or railroad, design load, and bridge unique identifier. Georeferenced data on commercial vehicle facilities includes location of major truck-stop plazas and commercial vehicle enforcement facilities. These data were derived from a database of National Association of Truck Stop Operators member truck stops and from the California Highway Patrol report, *1997 Weigh Station Inventory of Needs*. Data are updated as needed to reflect the current status of these facilities. Coverage areas for roadway and traffic condition monitoring could be obtained from geocoded point data for existing and proposed detection stations, dynamic message signs (DMS), closed-circuit television (CCTV), highway advisory radio, and road weather information systems.

Caltrans does not maintain an inventory of roadway geometry data.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

Caltrans maintains a roadway basemap representing State highway routes, highway ramps, and functionally classified roads. The basemap is referenced based on the Caltrans postmile system (for linkage to other Caltrans databases) and a section identifier (for linkage to the HPMS database).

3. Does your agency have any specific data sharing agreements or contracts with commercial roadway database vendors (e.g., providing regular updates to NAVTEQ™ or Tele Atlas®)?

Caltrans previously had a contract in place with Tele Atlas® to provide street and highway layer updates, but the contract is no longer in place.

4. How often is the data updated, and how are these updates collected?

The roadway basemap is updated annually with postmile updates or other significant changes. The updates are digitized based on the Caltrans County Map Series. The accuracy is sub-32.8 ft (10 m).

5. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

For roadway inventory, Caltrans is considering collecting data on sidewalk location and number of lanes on ramps. There are no plans to collect other attributes.

6. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

Caltrans indicated new data collection activities could be initiated by a Federal requirement attached to funding, a new State law, or direction from the governor's office.

7. What do you see as the most significant obstacles in terms of providing data to support the development and deployment of IntelliDrive?

Caltrans cited the following as potential obstacles in providing data to support IntelliDrive: liability, accuracy limitations, cost, scope (local roads as well as highways), and the time deltas for collecting and disseminating data revisions as the built environment changes.

Florida DOT

The Florida Department of Transportation (FDOT) is a decentralized agency responsible for designing, constructing, maintaining, and regulating public transportation in the State of Florida. Florida has 12,093 centerline miles of roads in its State highway system, representing approximately 10 percent of the 121,387 public roadway centerline miles. The majority of these other roads (92,136 mi (148,338 km)) are local streets.

FDOT is organized into seven geographic districts plus Florida's Turnpike Enterprise. In 2009–10, FDOT's annual budget totaled $6.5 billion.

1. What roadway features and attributes does your agency collect and maintain?

FDOT maintains a Roadway Characteristics Inventory (RCI), which is a database of inventory information related to the State highway system and other Federal-aid roads. Data collection to support RCI is the responsibility of the District Planning and Maintenance Offices. Many of the roadway features and attributes that support IntelliDrive applications are available in RCI.

FDOT maintains limited data on roadway geometry, primarily to support HPMS reporting. Attributes related to horizontal alignment include horizontal curve central angle (delta), horizontal degree of curvature, and horizontal point of intersection. Data on sight distance is defined for two-lane rural roads as the percent of an HPMS sample segment with a passing sight distance of 1,500 ft (457.5 m) or more. Grade on HPMS samples is defined as the total roadway length within each sample that falls into each grade classification ranging from A through F, depending on percent of grade.

For roadway inventory, FDOT maintains the following attributes related to lanes: number of lanes, total travel surface width, lane use restrictions, and auxiliary lane function type. Median attributes in RCI include median type and width. The location of the median relative to a vehicle could be inferred from the RCI data. FDOT collects all of the attributes related to shoulders: location, type, width, and special shoulder function type. Lane, median, and shoulder data are collected for all functionally classified roads on the State highway system. Sidewalk width and offset distance are collected for all nonlimited access urban State highways up to 1 mi (1.6 km) outside designated urban boundaries. The maximum posted speed limit is also collected for State roads and non-State HPMS samples. For pavement condition data, FDOT collects international roughness index (IRI) data on State and NHS roads as well as on non-State HPMS samples on principal arterials and rural minor arterials, which are maintained in the RCI database and updated annually after March 15. HPMS now requires IRI (including bridges), cracking, and faulting data, but they are only required for the HPMS submittal and will not be included in RCI.

For intersection characteristics, FDOT maintains limited data on intersection locations for all roads on the State highway system and for major crossroads on other HPMS samples. The number of exclusive left- and right-turn lanes on the State highway system could be inferred from a count of auxiliary lanes adjacent to intersections.

For other geospatial features, FDOT maintains railroad crossing location and National Railroad Grade Crossing Numbers for all at-grade crossings on all Federal-aid roads. The crossing location is defined as the point where the centerline of the roadway crosses the center of the railroad crossing. Guardrail and bridge inventory data are collected and maintained by the Maintenance Office. FDOT does not collect data on transit-stop locations, although bus bays are coded as a type of auxiliary lane in RCI. FDOT also collects data on the type and location of permanent and nonpermanent traffic monitoring sites with embedded loops.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

FDOT maintains an RCI/GIS basemap, which was developed in-house. The basemap includes the State highway system, other roads functionally classified above local, NHS and Strategic Intermodal System roads, and local roads that are important to FDOT. RCI data are linked to the basemap through an LRS that includes a roadway ID and beginning and ending mile points. The locational accuracy is in compliance with national mapping standards (sub-6.56 ft (2 m) for 95 percent of all roads).

FDOT has recently entered into a 3-year agreement with NAVTEQ™ for a roadway basemap, and all public agencies in the State have access to it. FDOT also has an agreement with Florida’s Department of Revenue to collect, share, and maintain aerial imagery (public record and public domain).

3. How often is the data updated, and how are these updates collected?

Maintenance of the RCI/GIS basemap is continuous. The basemap coordinator works with appropriate staff from district offices to make corrections to the basemap and to ensure compatibility between the RCI and basemap roadway ID lengths and alignments is maintained. Updates to the basemap are obtained from FDOT/Department of Revenue submeter aerial photos.

For the RCI database itself, most data are maintained by the Planning Office, although some attributes are collected and maintained by the Maintenance Office and the Traffic Engineering and Operations Office.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

The State Materials Office wants to change the road conditions survey from windshield-based to mobile mapping. Videologs are still collected by the Planning Office every 2 years. Within the current economy, FDOT does not expect to initiate any new data collection programs.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

FDOT indicated that a new data collection activity would be initiated only if the benefit-to-cost ratio made sense. Other reasons would be new Federal requirement or State mandate.

Michigan DOT

The Michigan Department of Transportation (MDOT) is responsible for overseeing and maintaining more than 9,700 mi (15,617 km) of State highway system as well as administering other State transportation programs, including airports, intercity passenger services, rail freight, local public transit services, and nonmotorized transportation. The State highway system comprises approximately 8 percent of Michigan's 121,667 total roadway centerline miles. The State DOT is divided into seven geographic regions (Metro, Grand, University, Bay, Southwest, North, and Superior), with several Transportation Service Centers located in each region. As part of their asset management program, MDOT has developed an integrated decision support tool called the Transportation Management System, which is an enterprise database management system with the following components: bridge, congestion, intermodal, pavement, public transportation, and safety. MDOT's budget for fiscal year 2010 totaled $3.3 billion.

1. What roadway features and attributes does your agency collect and maintain?

MDOT maintains limited data on roadway geometry, with the exception of sight distance. It has a comprehensive inventory of passing sight distance for all roadways on the State highway system.

For roadway inventory, MDOT maintains an inventory of number of lanes for all Federal-aid roads and lane widths for all roadways on the State highway system. MDOT maintains data on shoulder location, type, width, and special shoulder function type. For ramps, inventory data includes location, type, number of lanes, merge feature, and special lane function type. Speed zone data are limited to the predominant speed within a section. Pavement condition data are collected only for new projects. Pavement marking data (location and type of longitudinal markings) are maintained as part of operational project files but are generally not shared. With the exception of project-related data (pavement condition and pavement markings), most roadway inventory data are updated annually through windshield surveys or aerial photography.

With regards to intersection characteristics, MDOT has a comprehensive inventory of intersection locations for all roads included in the State highway system. Officials indicated that data on intersection geometry, lane configuration, and pavement markings could be obtained from construction plans for each intersection but that the data has not been geocoded.

With regards to other geospatial features, MDOT has a comprehensive guardrail inventory that includes data on guardrail beginning/ending locations, type of guardrail, and type of end treatment. For rail crossings, MDOT has an inventory of railroad crossing locations and National Railroad Grade Crossing Numbers. MDOT collects data on more than 12,500 bridges through its Bridge Management System. The bridge inventory is organized into the following types of data: (1) inventory data such as location, dimensions, material, design, capacity, route, etc.; (2) inspection data such as examination date, bridge condition findings, extent and severity of bridge element deterioration, etc.; and (3) maintenance history. MDOT does not maintain a statewide database on transit facilities, but it does have an inventory of State-owned rest areas and roadside inspection/weigh station locations. Real-time traffic monitoring is limited to urban areas with intelligent transportation systems (ITS) coverage, although MDOT is collecting some probe data through NAVTEQ™.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

The Michigan Geographic Framework is a statewide basemap that includes features such as roads, rivers, lakes, streams, railroads, political jurisdiction boundaries, power lines, pipelines, and other features. The Framework has an accuracy of better than 6.56 ft (2 m). The roadway network is referenced based on an enhanced LRS that was derived from the Michigan Accident Location Index. The LRS consists of a physical reference number, beginning mile point, and ending mile point.

MDOT also has a 3-year software and imagery licensing agreement with Microsoft Bing Maps for Enterprise to collect, share, and maintain aerial photography. The aerial images will be collected at a 12-inch (304.8-mm) resolution covering one-fifth of the State each year for the next 3 years, for a total of approximately 34,000 mi^2 (88,060 km^2).

3. How often is the data updated, and how are these updates collected?

Maintenance of the Michigan Geographic Framework is the responsibility of the Center for Shared Solutions and Technology Partnerships, which maintains the actual basemap, works to incorporate GIS updates from agency partners, and serves as a clearinghouse for GIS shapefiles, metadata, documentation, training, and support. Updates are the responsibility of agency partners, who provide updated map and attribute information via their business applications, which then signal changes that need to be made to the map.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

MDOT indicated that there is an interest in collecting more detailed roadway inventory data, although no specific plans are in place.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

MDOT has initiated new data collection activities based on Federal mandate and internal staff requests. These activities include collection of data on Americans with Disabilities Act (ADA) ramps, guardrail inventory, retroreflectivity, and roadway features needed to support the SafetyAnalyst software tool. The department is in the process of incorporating GPS into the maintenance system in order to better track the condition of assets such as culverts and roadways.

6. What do you see as the most significant obstacles in terms of providing data to support the development and deployment of IntelliDrive?

MDOT did not provide input on significant obstacles in terms of providing data to support IntelliDrive.

Virginia DOT

There are approximately 74,000 mi (119,140 km) of public roads in the Commonwealth of Virginia. The Virginia Department of Transportation (VDOT) is responsible for the administration and maintenance of about 58,000 mi (93,380 km), or 78 percent, of these roads, including local roads within most counties and incorporated cities.

1. What roadway features and attributes does your agency collect and maintain?

Most of VDOT's roadway data are maintained centrally in the Highway Traffic Records Information System (HTRIS), a mainframe-based system written in ADABase. VDOT is in the process of converting to a new Oracle-based roadway database management system. VDOT anticipates that migration to the new system will be completed by the end of 2011. Some progress has already been made; pavement data has been fully migrated to the new system. Specific IntelliDrive data items collected and maintained by VDOT include the following:

- **Roadway Geometry:** VDOT is not currently collecting data on horizontal or vertical curvature or grade, although there has been some discussion about collecting these data for higher functional class roadways. VDOT currently has a contract with Fugro Roadware to collect videologs and pavement condition on primary State highways (interstates, U.S. primary, and State signed routes classified as principal arterials). VDOT is hoping to expand this contract to begin collecting data on secondary roads (State and county signed routes designed as minor arterials). Some roadway geometry data could be extracted by additional postprocessing of the videolog data, but this is not currently part of the contract. No data are collected on roadway elevation, cross slopes, or clear zones.

- **Roadway Inventory:** VDOT collects and maintains data on the number of lanes, overall roadway width, lane use restrictions (e.g., HOV), locations of freeway ramps, medians, and (paved) shoulders. Additional information on roadbed characteristics may be maintained by VDOT's pavement division. Most of VDOT's roadway inventory data are collected and maintained only for primary State highways. Data needed to satisfy more detailed HPMS sample data requirements are typically collected only for specified sample sections. VDOT tries to identify whether roadway sections have a sidewalk but does not specifically identify the beginning or end of each sidewalk.

  In Virginia, speed limits are set by default at 55 mi/h for primary highways and 25 mi/h for secondary and local roads. Local governments must request waivers from the Transportation Commissioner to change the posted speed limits to any other speeds. However, there is no automatic process for recording approved waivers, so the accuracy of speed zone data is unknown.

  Data on pavement markings, guardrails, and signs are maintained by individual residencies. (VDOT maintenance activities are distributed among approximately 40 geographic areas known as residencies.) There are no central repository or standards for these data; each residency collects and maintains whatever data it needs to accomplish its work.

- **Intersection Characteristics:** VDOT maintains minimal data on urban intersections or pedestrian features such as crosswalks. VDOT does not currently have a complete statewide inventory of traffic signal locations, although there has been some discussion about creating one. VDOT's ITS Office does maintain a statewide database of ITS devices (e.g., variable message signs, ramp meters, traffic cameras, etc.)

- **Other Features**: VDOT maintains data on railroad crossings, including sign and signal type, in support of the U.S. DOT's HRIC. Likewise, VDOT maintains data on highway bridges and tunnels in support of FHWA's NBI. Locations of truck weigh stations are only maintained along interstate routes. VDOT does not maintain data on public transit stops. This information may be maintained by the Virginia Department of Rail and Public Transportation.

  VDOT maintains a public Web site (www.511virginia.org) that provides information on road conditions, weather, traffic incidents, and work zones throughout the State. Information on this site is updated continuously in near-real time.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

VDOT's State geospatial roadway database was digitized from high-resolution orthoimagery that was coordinated through the Virginia Geographic Information Network (VGIN) and covers the entire State. This orthoimagery serves as the foundation for virtually all of Virginia's geospatial data layers. The roadway database includes all 58,000 mi (93,380 km) of roadways for which VDOT has administrative and maintenance responsibility. The only roads for which VDOT does not have administrative and maintenance responsibility are roads located on Federal facilities (e.g., military installations, national parks) and local roads in certain counties (Arlington and

Henrico counties) or incorporated cities (e.g., City of Alexandria) that have elected to maintain these roads themselves.

The roadway database geometry is updated and maintained by VGIN and VDOT under a Memorandum of Understanding. Updates come from various sources including counties, local jurisdictions, and E911 agencies.

HTRIS inventory data are linked to the roadway network database through an LRS that is maintained by VDOT staff. The LRS supports data in both directions along a roadway, even if the roadway is represented by only one centerline in the database.

3. Does your agency have any specific data sharing agreements or contracts with commercial roadway database vendors (e.g., providing regular updates to NAVTEQ™ or Tele Atlas®)?

VDOT reports that some local municipalities share data with commercial roadway vendors. However, the status of these agreements was unclear. VDOT referred the inquiry to VGIN for further information.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

A committee has recently been established within VDOT to explore the feasibility and cost of collecting additional inventory data statewide. Several years ago, VDOT conducted a research project to inventory all roadway features (signs, culverts, curbs, drainage basins, etc.) in three counties. However, the large number of data items and high cost to collect and maintain these data precluded VDOT from expanding the effort statewide.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

VDOT reports that the initiation of new data collection activities is dependent on items required to address VDOT needs. VDOT specifically mentioned pavement issues.

VDOT also noted that there is a perception that a centralized collection of data items (e.g., guardrail locations) leads to an increasing efficiency. Although officials did not know if this would realistically help with the day-to-day operations, it may help with the analysis of data and statistics, leading to better budgeting and tracking and a greater justification for maintenance. Thus, in general, there is a greater call for more sophisticated statistical data. However, like many State DOTs, VDOT currently is unable to initiate additional data collection due to budget constraints.

6. How likely is it that your agency would be willing or able to collect new or additional data to support IntelliDrive applications (e.g., collect cross slope or expand collection of horizontal curvature to all public roads)?

VDOT focuses on the maintenance of current infrastructure and the safety of its motoring public. To the extent that IntelliDrive applications support these two overarching goals, there is the opportunity for policy to support IntelliDrive. Policy begets funding, and with sufficient funding, VDOT would be willing to collect additional data to support IntelliDrive applications.

Washington State DOT

There are approximately 83,500 mi (134,435 km) of roads in the State of Washington, of which about 19,000 mi (30,590 km) are Federal-aid roads. However, the Washington State Department of Transportation (WSDOT) is administratively responsible for a State highway system comprising only about 7,000 mi (11,270 km) (8.4 percent) of State and U.S. signed routes.

1. What roadway features and attributes does your agency collect and maintain?

Most of WSDOT's business databases currently are stored on a mainframe computer and are not spatially enabled. There currently are at least 14 mainframe databases covering everything from accounting records to highway construction and roadway inventory. The Transportation Information Planning Support (TRIPS) database stores roadway inventory, traffic, and collision data. Information from this database is sent once a year to WSDOT's GIS group in order to build spatial data layers. These layers are made available through WSDOT's GIS workbench, an internal GIS application.

In 2009, WSDOT conducted a critical assessment of all mainframe systems in order to develop justification for replacing these systems. The TRIPS database received high priority for migrating or replacing with a spatially enabled database. However, given current budget constraints, all database migration has been deferred.

Specific IntelliDrive data items collected and maintained by WSDOT are as follows:

- **Roadway Geometry:** WSDOT derives horizontal and vertical alignment and grade from construction drawings on a project-by-project basis. Coverage is relatively complete for all mainline routes on the State highway system. However, data are only reported on the increasing milepost direction of travel. Superelevation is available for some but not all routes. WSDOT does not collect or maintain data on roadway cross slope, clear zone width, or roadway elevation.

- **Roadway Inventory:** The TRIPS system maintains data on number of lanes, special lane types, total roadway width, medians, (paved) shoulders, and ramps. The WSDOT Traffic Office maintains an inventory of signs and signals, including speed limits and stop signs.

  WSDOT's GIS and Roadway Data Office has also begun collecting an inventory of fixed objects (signs, guardrails, culverts, etc.) located along the roadway and clear zone. The inventory is being done manually by WSDOT crews walking the shoulder of each State highway with a survey-grade GPS unit. At the time of this report, crews have inventoried about 40 percent of the 7,000 mi (11,270 km) of State highway, collecting information on approximately 425,000 features.

  WSDOT does not maintain statewide inventory data on pavement markings, sidewalk locations, or pavement coefficients of friction. Sidewalk data may have been collected for selected ADA projects in smaller urban areas, but the data are very limited and not linked spatially to WSDOT's roadway inventory data. Pavement markings are the responsibility of WSDOT's maintenance areas, and the data have not been consolidated. WSDOT is currently conducting a test project to survey pavement edge location using survey-grade GPS technology installed on pavement striping vehicles.

- **Intersection Characteristics:** Intersection location and type can be derived from WSDOT's geospatial roadway network. Turn lanes at intersections can also be inferred from the total roadway width and the number of identified through lanes, but data on lane channelization and pavement markings are not readily available. Data are maintained on the location of traffic signals but not on signal characteristics.

- **Other Geospatial Features:** WSDOT collects and maintains information on railroad crossing locations and FRA crossing number. Bridge locations, structure types, and identifiers are maintained in the TRIPS database. Additional data on height and weight restrictions are maintained separately by WSDOT's Bridge Office. Locations of official State truck weigh and inspection stations are also maintained. WSDOT does not collect information on transit facilities.

  WSDOT maintains a public Web site (www.wsdot.wa.gov) containing information on weather conditions, status of mountain passes, roadway construction and maintenance, traffic congestion and incidents, and roadway traffic cameras. This information is updated regularly through the day.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

WSDOT currently uses a geospatial roadway network basemap that includes the 7,000 centerline miles of State highways. The basemap was originally digitized from 1:24,000 scale orthoimagery. Several years ago, WSDOT funded a project to obtain GPS measurements along all State highways and used this to improve both the spatial accuracy of the base map and the LRS that links roadway data to the base map. The current locational accuracy of the WSDOT roadway basemap is 3.28–9.84 ft (1–3 m).

TRIPS and other roadway data can be displayed on the WSDOT roadway basemap using WSDOT's 24K LRS. The LRS measure was derived by converting engineering station measurements on construction drawings into accumulated route measures using State route mileposts. WSDOT also has created a more accurate LRS based on its GPS measurement, but that LRS is not currently used with mainframe databases because the mainframe data are referenced to a single (inventory) direction, whereas the GPS LRS includes bidirectional measurements.

WSDOT also has a project underway to create an all-roads geospatial data layer that will serve as the transportation framework for the entire State, including county and local governments and E911 agencies. The Washington Transportation Framework Project (WaTrans) database is being developed by assembling the "best available" data from each county and stitching it together to create as seamless statewide road network. This project has been ongoing for several years, and by October 2010, only 16 of 39 counties will be completed. In order to meet FHWA's 2010 HPMS requirements for a roadway network covering all Federal-aid roads (approximately 28,000 centerline miles), WSDOT is attempting to fill the gaps in county data by converting WSDOT's CAD data into geospatial road layers and adding LRS measures to the new data.

3. Does your agency have any specific data sharing agreements or contracts with commercial roadway database vendors (e.g., providing regular updates to NAVTEQ™ or Tele Atlas®)?

WSDOT currently has a data sharing agreement with Tele Atlas® to provide roadway geometry and geocoding for those counties where local roadway data are not available. In addition, the Washington State Patrol purchased a Tele Atlas® road network for Statewide use in the E911 program for routing applications. That contract ran through August 2010, but WSDOT expected to renew the contract to provide an interim roadway network until WaTrans is fully operational.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

Data collection for the Roadside Features Inventory Program is currently about 40 percent complete. The initial data collection effort should be finished within the next 5 years.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

A major goal of WSDOT is to increase safety while controlling costs. WSDOT has been working with the University of California-Davis to investigate the costs and efficiencies of using mobile LIDAR for collecting and updating roadway inventory and geometry information. However, no decision has been made on actual deployment. The research project is scheduled to be completed by September 2011.

6. How likely is it that your agency would be willing or able to collect new or additional data to support IntelliDrive applications (e.g., collect cross slope or expand collection of horizontal curvature to all public roads)?

At the current time, WSDOT does not see any way to support IntelliDrive applications with the available personnel and budget. In order to do this, WSDOT would need financial incentives. WSDOT sees costs and people as the largest barriers to the expansion of data collection efforts. The department already feels a great deal of pressure to consolidate the workforce and complete current tasks with reduced budgets.

LOCAL TRANSPORTATION AGENCIES

Two local transportation agencies and one TMC were interviewed as part of the trade study to identify what, if any, roadway geometry and inventory data they collect, maintain, or use in support of their current transit operations.

The agencies interviewed were Broward and Palm Beach counties, both in south Florida, and TranStar, the TMC serving the Houston metropolitan area. Brief profiles of each agency and summaries of their responses to interview questions are presented in this section.

Broward County

Broward County is responsible for providing government services at the county level in South Florida. As one of three counties that comprise the South Florida metropolitan area, Broward

County is the second most populated county in the State, with a resident population of more than 1.7 million. The major metropolitan area is Fort Lauderdale. As a home-rule government, Broward County provides a broad range of services, including property assessments, tax collections, law enforcement and fire rescue protection, maintenance of streets, highways, bridges, and traffic signals, parks, libraries, airports, a seaport, a convention center, water and sewer systems, transportation, environmental protection, urban planning, economic development, and other community and human services.

1. What roadway features and attributes does your agency collect and maintain?

Broward County's Engineering Department surveying group is currently conducting a GPS inventory of all signalized intersections in the county. The inventory is 95 percent complete and currently in the quality assurance and quality control phase. The inventory is limited to within 100 ft (30.5 m) for each direction of the intersection, and the locational accuracy ranges from sub-1 ft (0.305 m) to sub-3.28 ft (1 m).

As part of the GPS inventory, Broward County is developing a geospatial database of intersection characteristics and selected attributes. Current attributes include intersection location, identification number, and location of physical assets such as traffic signal poles, pedestrian signal poles, street light poles, regulatory signs, school zone flashers, signal controller cabinets, service points, pull boxes, interconnect, fiber optic cable, and Florida Power and Light connection feeds. Only the location and type of physical assets are being inventoried; attributes such as intersection configuration and pavement marking data are not included. Type of traffic control is inventoried only if an electronic field device is present (e.g., traffic signal, flashing signal, etc.). Attributes such as turn prohibitions, posted speed limit, or school zone speed limits within the vicinity of the intersection are captured as part of the sign inventory, although sign type is coded based on general descriptions rather than specific *Manual on Uniform Traffic Control Devices* codes.

Broward County does not maintain data on roadway geometry. For roadway inventory, Broward County maintains a limited inventory of sidewalk locations, posted speed limits, and special speed zones. For other geospatial features, Broward County Transit maintains a GIS inventory of bus-stop locations.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

Intersection characteristics are maintained in a geospatial database with locations referenced in the State Plane Florida East coordinate system. The County is currently maintaining its own street data but is beginning to move towards a commercial roadway database (NAVTEQ™) that has been purchased by FDOT and is available through a multiagency use agreement. The NAVTEQ™ database provides locationally accurate and attributed street-level data, and participating agencies agree to provide updates such as new streets or changes in traffic regulations to NAVTEQ™. FDOT will support the contract for a 3-year period, and Broward County Sheriff's Office has committed to using E911 funds to cover the costs of the NAVTEQ™ updates if the State chooses not to continue the contract.

3. How often is the data updated, and how are these updates collected?

Broward County updates the intersection characteristics data as needed on a quarterly basis (e.g., when new mast arms are installed). Updates are collected using Trimble GPS with an external antenna that collects data for 30–40 s.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

Broward County plans to collect data for ongoing maintenance purposes only and does not have plans to collect additional attributes.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

Broward County indicated that new data collection activities could be initiated based on internal staff requests. Commonly requested maps and GIS data sets are maintained on the County's Web site (www.broward.org). In terms of data collection to support IntelliDrive applications, Broward County indicated that new Federal or State mandates would be required.

Palm Beach County

Palm Beach County is responsible for providing government services at the county level in South Florida. Palm Beach is the third most populated county in the State, with a resident population of over 1.3 million. Palm Beach is one of three counties that comprise the South Florida metropolitan area, with major cities including West Palm Beach and Boca Raton. The county government provides a broad range of services, including property assessments, tax collections, law enforcement and fire rescue protection, maintenance of streets, highways, bridges, and traffic signals, parks, libraries, airports, a seaport, a convention center, water and sewer systems, transportation, environmental protection, urban planning, economic development, and other community and human services.

1. What roadway features and attributes does your agency collect and maintain?

Palm Beach County does not maintain data on roadway geometry. It is possible to obtain this information from design/CAD files available for the last 20 years, but the data have not been inventoried or coded into a geospatial database.

Palm Beach County maintains a roadway inventory of public roads that are maintained by the county. It does not include city- or State-maintained roadways. The database includes centerline location, posted speed limit, and number of lanes. The county mandates standard lane widths of 11–12 ft (3.35–3.66 m), depending on roadway classification. For lane use restrictions, the county indicated that some portions of I-95 have truck restrictions in place and that FDOT may maintain a detailed inventory of these locations. The county has a listing of bridges and other locations with weight limits in place, but the information has not been geocoded. The county has the information for special lane function type, but it has not been geocoded. A bike consultant is currently conducting an inventory of the locations of bicycle lanes. The county has a limited inventory of sidewalk locations. In terms of ramp-based attributes, the county has identified and geocoded the ramp locations, but the database is incomplete. However, officials indicated that a geospatial database could be easily developed based on aerials. The county indicated that speed zone location information could be derived based on the segmentation in the roadway inventory (i.e., segment breaks are typically based on changes in speed limit). School zone locations with flashers have been identified as part of the county's signal inventory, but detailed information on the posted speed limit and hours of operation has not been recorded. Palm Beach County has not conducted a detailed sign inventory, although equipment is available to the county to measure the retroreflectivity of signs, if needed.

For intersection characteristics, Palm Beach County maintains an inventory of intersection locations, but the attribute is defined as the intersection of two roadway centerlines (i.e., the location of the center of the intersection is not survey accurate). The type of intersection could be extrapolated based on the number of segments coming into the node. Data on lane configuration and pavement markings could be developed based on design/CAD drawings for county-maintained roads.

Palm Beach County is conducting a signal inventory of all locations with an electronic device of any type (traffic signal, flashing light, school zone locations equipped with flashers, fire station signal, etc.). The inventory is 80–90 percent complete. The inventory is being conducted for fire/rescue routing purposes and includes location attributes only. No other physical assets are included. For traffic signal phasing/timing plan and status, the county has an advanced traffic management system (ATMS) in development. ATMS will include 1,000 signals, more than 600 of which will be connected to a central office. Rather than having traffic signal preemption between the emergency vehicle and a transmitter at the intersection, preemption will be coordinated from the central office through ATMS.

For other geospatial features, Palm Beach County indicated that it does do not have a geospatial database of rail crossing locations and type, but that such an inventory could be developed easily based on aerials. This information will likely be inventoried soon for fire/rescue routing purposes. The County has a point layer of bridge locations. Other bridge attributes are available but are not inventoried in GIS. In terms of structure type, Palm Beach County suggested that drawbridges be considered an additional type. Drawbridge status could impact routing for both private vehicles and fire/rescue. In terms of transit data, the county maintains a GIS inventory of bus-stop locations (including school buses), route served, type of stop, and bus-stop shelter type/shelter assets. Boundaries of road condition monitoring coverage may be available through the countywide emergency operations center.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

Roadway data that has been geocoded is maintained in a geospatial database with locations referenced in the State Plane Florida East coordinate system. Many of the attributes required for IntelliDrive could be developed based on aerial photographs/parcel maps available through the property appraisal office. Maps are available for the last 10 years and are tied into survey control points, making them accurate to within six inches.

The county currently maintains its own street data but is beginning to move toward a commercial roadway database (NAVTEQ™) that has been purchased by FDOT and is available through a multiagency use agreement. The NAVTEQ™ database provides locationally accurate and attributed street-level data, and participating agencies agree to provide updates, such as new streets or changes in traffic regulations, to NAVTEQ™.

3. How often is the data updated, and how are these updates collected?

Data updates are conducted as needed.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

Data such as railroad location and type of crossing will likely be inventoried soon for fire/rescue routing purposes. However, there are no plans to begin collecting additional data unless it is specifically requested or could be used for fire/rescue routing.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

Significant effort is required to initiate, collect, and maintain new data. New data collection would likely require a mandate, unless such activity is seen as beneficial and cost effective to the county. For example, the signal inventory was initiated to support more efficient routing of fire/rescue vehicles because of the significant public safety benefits associated with having these data.

6. What do you see as the most significant obstacles in terms of providing data to support the development and deployment of IntelliDrive?

Palm Beach County suggested that vehicle-to-infrastructure communications would be difficult at the local level due to data limitations and quality of available data. Vehicle-to-vehicle communications might be better in this regard.

Houston TranStar

Houston TranStar is a partnership of four government agencies that provide transportation management and emergency management services for the greater Houston, TX, area. TranStar partner agencies include the Texas DOT, Harris County, the Metropolitan Transit Authority of Harris County (METRO), and the City of Houston. Transportation management capabilities include more than 600 regional CCTV cameras, toll tag readers, DMS, synchronized traffic signals, highway advisory radio, ramp meters, and smart sensor technology.

1. What roadway features and attributes does your agency collect and maintain?

For roadway inventory, data on roadway centerlines, number of lanes, special lane function type, ramp locations, and posted speed limits are available as part of the region’s basemap. The City of Houston maintains a georeferenced database that contains data on sidewalks and pavement conditions; however, it is not available for public use.

For intersection characteristics, the City of Houston maintains a georeferenced database on intersection location and type of traffic control.

For other geospatial features, TranStar indicated that METRO maintains a GIS shapefile of transit stop locations, including Park and Ride, transit centers, bus stops, and light rail stations. TranStar maintains a number of real-time condition maps on its Web site (www.houstontranstar.org), including real-time traffic conditions; incidents/road closures; road flood warning system, which includes 40 sensors to detect flooded roadways, stream flow, wind, and ice; Doppler radar imagery and satellite weather maps; current ozone levels; Galveston Island-Port Bolivar Ferry information, including current wait times and CCTV images; and a new real-time Web-based hurricane evacuation status map, which is based on smart sensor technology to monitor traffic flow from evacuation zones and during contraflow operations.

Real-time traffic conditions are monitored using toll tag reader locations, which collect vehicle probe data for estimating travel times and speeds. The toll tag reader locations are geocoded, and current speeds are displayed on the map in real time. For incident locations, coverage currently is limited to freeways and locations are geocoded based on the nearest cross street. TranStar has a project in progress to expand real-time coverage to major arterials in the region.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

The Southeast Texas Addressing and Referencing Map (STAR*Map) is a digital basemap and database that is maintained by the Houston-Galveston Area Council and the Geographic Data Committee, of which TranStar is an active participant. STAR*Map contains all of the roads for 13 counties in the Houston area, including Harris, Fort Bend, Colorado, Matagorda, Walker, Brazoria, Waller, Montgomery, Wharton, Galveston, Liberty, Austin, and Chambers counties. The basemap includes more than 1.7 million parcel addresses, roadway centerlines, block address information, street names, street types, census geography, and other feature attributes.

3. How often is the data updated, and how are these updates collected?

Updates to STAR*Map are conducted every three months based on data received from Centerpoint Energy, Fort Bend Engineers Office, Alterra Technology, and 911 systems in each county.

4. For any data that currently is not maintained by the agency, are there any plans to begin collecting these data in the next 5 years?

There are many projects that would require additional data collection that TranStar is interested in initiating, but TranStar has been limited by budgetary restraints.

5. What are the primary reasons that would cause your agency to initiate a new data collection activity (e.g., new Federal requirement, internal staff request, State mandate)?

The availability of Federal funding would enable TranStar to initiate a new data collection activity.

6. What do you see as the most significant obstacles in terms of providing data to support the development and deployment of IntelliDrive?

TranStar noted staffing and maintenance of data as primary obstacles in providing data to support IntelliDrive.

PUBLIC TRANSIT OPERATORS

Three public transit agencies were interviewed as part of the trade study to identify what, if any, roadway geometry and inventory data they collect, maintain, or use in support of their current transit operations, as well as what specific IntelliDrive applications they considered to be most beneficial for transit in the near future. Each of the three interviewed transit agencies is an active participant in the IntelliDrive for Transit working group, and the three were selected in coordination with FHWA and Federal Transit Administration staff based on the agencies' knowledge and experience with IntelliDrive activities.

The three agencies interviewed were LYNX Transit, serving Orlando, FL; LTD, serving Lane County and the cities of Eugene and Springfield, OR; and NYCT, the primary public transit operator for New York City, NY. Brief profiles of each transit agency and summaries of their responses to interview questions are presented in this section.

LYNX Transit

LYNX (officially known as the Central Florida Regional Transportation Authority) is responsible for coordinating public transportation services for a three-county region that includes Orange, Osceola, and Seminole counties and the city of Orlando, FL, serving a resident population of over 1.8 million. Some LNYX bus routes also extend into neighboring Polk, Volusia, and Lake counties.

LYNX directly operates a fleet of over 238 buses on 65 fixed routes. In 2008, it provided over 26 million bus trips and over 166 million revenue passenger miles. Its annual operating budget was nearly $109 million, with approximately 20 percent covered from fare-box revenues. Its 2008 capital budget was nearly $26 million.(10)

1. What roadway features and attributes does your agency collect and maintain yourself?

LYNX maintains a geospatial database of transit-stop locations and selected attributes. Current attributes include stop amenities (e.g., bus shelter), routes served, and other notable characteristics (e.g., pulloff lane). Future attributes may include information on ADA accessibility (e.g., curb cuts, warning signals for visually impaired), but these attributes have not yet been finalized. The locational accuracy of the stop information is 3.28 ft (1 m) or better, as measured at the transit-stop sign. Both NAVTEQ™ and Google™ have made inquiries about incorporating LYNX transit-stop locations in their databases, but currently neither database developer has actually done so.

LYNX also maintains two separate databases on transit routes—one for use with their proprietary scheduling software and one for use in displaying and mapping using GIS software. The routes are built on an existing commercial roadway basemap (NAVTEQ™) and are supplemented with some additional digitized road segments where routes cross private property (e.g., through shopping malls).

LYNX has also compiled a regional database of transit and emergency facility locations (e.g., shelters, schools, fire and police stations, hospitals) for the six-county area. Basic location and attribute information has been standardized, and this database is available to counties and emergency management agencies that require multicounty data.

LYNX does not maintain or utilize data on sidewalk locations, crosswalks, traffic signal locations, etc. There is currently no signal priority for transit vehicles in the LYNX service area. LYNX staff believe that data on signal locations, sidewalks, etc., are probably maintained either by individual counties or by FDOT.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

LYNX uses a commercial roadway database (NAVTEQ™) that has been purchased by FDOT and is available through a multiagency use agreement. The NAVTEQ™ database provides locationally accurate and attributed street-level data, and participating agencies agree to provide updates, such as new streets or changes in traffic regulations, to NAVTEQ™.

3. Does your agency currently use any other roadway features or attributes that are developed and maintained by another agency or commercial source?

LYNX does not routinely use any other geospatial roadway features or attributes beyond what is available in the NAVTEQ™ roadway database.

4. What specific IntelliDrive for Transit applications do you foresee being developed and deployed in the next 5 years?

LYNX sees itself primarily as a provider of IntelliDrive information rather than as an early user. The potential safety benefits associated with IntelliDrive seem less relevant for transit because of low vehicle speeds and urban environments. Most of the transit-related benefits would be in vehicle-to-vehicle applications where transit vehicles could serve as regular probes for traffic and weather conditions or where a transit vehicle would broadcast its location and upcoming maneuver (e.g., left turn) to other nearby vehicles.

One potential long-term transit use might be in dynamic routing for paratransit or route diversion services to avoid congestion.

5. What do you see as the most significant obstacles to the development and deployment of IntelliDrive for Transit applications?

The major barriers are likely to be uncertainty of funding, both for implementing and maintaining IntelliDrive applications, and the “chicken and egg” dilemma, in which no agency wants to spend scarce resources to purchase equipment unless they know there is (or will be) a critical mass of similarly equipped vehicles that are able to share data and communicate with one another.

Another concern, especially to transit maintenance, is the increasing amount of on-board, single-purpose electronic equipment, which takes up space, drains vehicle power, and increases vehicle maintenance costs and downtime. There is a need for applications that can utilize existing on-board equipment or can share resources with other applications. (e.g., multiple communications requirements, GPS, DSRC, 3G).

LTD

LTD is the public transportation provider for Lane County, OR, which includes the cities of Eugene and Springfield. It provides fixed-route bus and demand-response service to a resident population of approximately 272,000.

LTD directly operates a fleet of 96 buses on 43 fixed routes. In fiscal year 2008–09, it provided over 11.7 million bus trips and over 4.7 million revenue passenger miles. Its annual operating budget was $33.1 million, with approximately 23 percent covered from fare-box revenues. Its 2008 capital budget was $11.4 million.[(10)]

1. What roadway features and attributes does your agency collect and maintain yourself?

LTD maintains a geospatial database of bus-stop locations and selected attributes. Current attributes include stop amenities (e.g., bus shelter) and pedestrian accessibility (e.g., sidewalks, curb cuts) in the vicinity of each bus stop. The locational accuracy is consistent with that of the underlying roadway network database, which appears to be in the range of 3.28 to 9.84 ft (1 to 5 m) absolute accuracy.

LTD does not maintain its own databases on sidewalk or signal locations. However, the City of Eugene maintains a database of traffic signal locations and selected attributes (e.g., signals with priority overrides, pedestrian crossing phases). Other databases of signal locations also may be maintained by the City of Springfield and Oregon DOT.

LTD also maintains a geospatial database of transit routes, built on the roadway basemap database maintained for Lane County. LTD has implemented an automated vehicle location system, which allows it to track the location of its bus fleet in real time.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

LTD uses a roadway network database that was developed and is maintained by the Lane Council of Governments, which serves as the geospatial roadway basemap for the entire county.

3. Does your agency currently use any other roadway features or attributes that are developed and maintained by another agency or commercial source?

LTD does not routinely use any other geospatial roadway features or attributes for its transit operations. Updates to some bus-stop attributes may utilize data collected by individual jurisdictions.

4. What specific IntelliDrive for Transit applications do you foresee being developed and deployed in the next 5 years?

The primary IntelliDrive application that LTD sees as useful is TSP on specific routes such as bus rapid transit (BRT). However, implementation of TSP requires negotiation and cooperation between the transit agency and the local jurisdiction that has responsibility for managing the traffic signals on issues such as the length of time a signal can be extended to allow a bus to pass through the intersection.

LTD sees applications such as curve departure warning being generally of lower priority for transit but believes there may be some benefit for this application on its more rural routes.

5. What do you see as the most significant obstacles to the development and deployment of IntelliDrive for Transit applications?

The current primary barrier is cost. LTD currently is planning a 20 percent cut in service due to existing budget constraints, and there is no funding available to purchase necessary in-vehicle equipment to support new applications such as IntelliDrive. Hopefully, this is only a short-term problem.

For any sort of new, innovative application, there needs to be a minimum number of early adopters who can demonstrate the benefits of the application to encourage more widespread adoption. The key is to minimize the risk for these early adopters.

MTA NYCT

NYCT is a division of New York City’s MTA and is responsible for operating a majority of the surface public transit buses and heavy rail (subway) within the five boroughs comprising metropolitan New York City.[2] The NYCT service area covers over 300 mi^2 (777 km^2) and has a resident population of more than 8 million, making NYCT the largest transit operator in the United States.

NCYT runs a fleet of nearly 4,600 buses operating on 320 fixed routes and nearly 6,200 rail vehicles operating on 26 lines. In 2008, it provided over 3.3 billion passenger trips and nearly 505 million revenue passenger miles. Its annual operating budget was nearly $6.2 billion, with approximately 54 percent covered from fare-box revenues. Its 2008 capital budget was $2.5 billion.(10)

1. What roadway features and attributes does your agency collect and maintain yourself?

NYCT maintains a geospatial database of bus stops and subway entrances. The data are maintained and available in Google™’s transit feed specification (GTFS) format. The bus-stop data includes the location, name, and whether the feature is a bus stop or station entrance. This database is also included in Google Transit™.(11)

[2] Other MTA operating divisions include the Metro-North and Long Island commuter railroads, the Staten Island Railway, the Long Island Bus (providing bus service to suburban counties on Long Island), and the MTA Bus Company, which took over bus routes originally provided by private bus companies.

NYCT also maintains geospatial databases of bus and subway routes, which are available in GTFS format. Both the bus route and the subway information is updated regularly. The bus routes are built on a roadway basemap, NYC Map, which is maintained by the New York City Department of Information Technology and Telecommunications.[12] The routes are also stored in NYCT's routing and scheduling software.

NYCT has developed and maintains a detailed geospatial database of fixed guideway transit infrastructure, including track centerlines, station layouts, switches, signals, power stations, etc. This database is primarily used for internal system maintenance and emergency planning and operations.

NYCT does not maintain or utilize data on sidewalk locations, crosswalks, or traffic signal locations. There are currently very few traffic signals with transit priority within the NYCT service area (one BRT route in the Bronx and one on Staten Island). However, future plans for additional BRT routes would most likely involve TSP.

2. Does your agency currently use a geospatial roadway network to display the data items that it maintains?

NYCT uses the NYC Map as its roadway network basemap. The NYC Map includes all roads in the five-borough New York City area and has an absolute horizontal accuracy of 1 ft (0.305 m) or better. It was developed from digital orthoimagery with 6-inch (152.4-mm) pixel resolution.

3. Does your agency currently use any other roadway features or attributes that are developed and maintained by another agency or commercial source?

NYCT does not routinely use any other geospatial roadway features or attributes for its transit operations.

4. What specific IntelliDrive for Transit applications do you foresee being developed and deployed in the next 5 years?

Any IntelliDrive application that could make bus transit more attractive to choice customers, such as BRT service, which utilizes TSP to give buses a competitive advantage over other vehicles using the same roadway, would be the most beneficial applications. This would require a database of traffic signal locations and information about which signals allowed transit priority. These data are currently maintained by the New York City Department of Transportation (NYCDOT). NYCT would have to negotiate with NYCDOT to provide TSP on a route-by-route basis.

Other potential applications, such as utilizing vehicle-to-vehicle communications to inform bus drivers where other buses are located, could help address the problem of bus bunching. If drivers along a route knew that another bus serving the same route was immediately ahead of them, they potentially could skip a stop to get back on schedule.

NYCT is not likely to be an early adopter of IntelliDrive applications unless they were integral to deployment of BRT services.

5. What do you see as the most significant obstacles to the development and deployment of IntelliDrive for Transit applications?

NYCT is a large, complex agency that requires substantial time and effort to introduce new, innovative technologies. Additionally, most of the potential IntelliDrive applications would require changes to roadway infrastructure that is under the control of NYCDOT, not NYCT.

INNOVATIVE DATA COLLECTION TECHNOLOGIES

Intermap Technologies

Web site: http://www.intermap.com/

Intermap Technologies produces digital elevation data from IFSAR mounted on aircraft. It claims data accuracy of 3.28 ft (1 m). Coverage is extensive—currently 90 percent of the data for CONUS have been processed, with completion due by the second quarter of 2010. In addition, 17 Western European countries are covered. Intermap products are data sets that can be used in a large variety of common map applications, including transportation.

1. What business are you in and who are your clients?

Intermap does not see itself as a competitor to NAVTEQ™ or Tele Atlas®. Intermap's strength is in radar-based maps such as elevation models and imagery and in keeping an inventory of accurate 3-D road geometry. Its data can be used to add value to commercial mapping products. The mission is to accurately map all roads in each country where Intermap works. The company intends to license to tier-one suppliers in support of OEM safety and energy management applications, as appropriate. The intent is to insert themselves into the supply chain by providing the mapping products that meet the needs of ADAS and energy management applications such as adaptive headlights, eco-drive, etc. Intermap is not yet a supplier to industry but is close to having commercial terms.

Intermap can follow and see the trend in the world of telematics and connectivity in both vehicle-to-vehicle and vehicle-to-infrastructure technology, but the company is unclear how it is going to play out. Currently, the company sees a lot of emphasis on infotainment. Intermap believes that map data needs to be imbedded in the vehicle to support autonomous applications. It is the map in the vehicle that will be used by these various applications, and that is where officials see the market. Intermap is aware of how IntelliDrive is coming together by making better use of infrastructure and believes that road geometry is a principal component of interest.

2. What services do you provide for these clients?

Geometry is captured every 11.48 ft (3.5 m) along the roadway centerline. It is stored as a point. Parameters such as curvature, slope, and line of sight are developed by algorithms using this point data. Measures of confidence in the accuracies also are provided. The product is basic roadway geometry with some additional information on bridge and tunnel locations. The database does not contain a lot of attributes. For example, Intermap cannot provide cross slope of the road.

Data are collected by radar on the plane, which is integrated with inertial navigation systems plus GPS to produce strip maps in 3-D. Then, cross strips are used to tie the data to the ground. Intermap sells a series of derivative products. Applications/markets include the following:

- Flood models and data for insurance companies.
- Visualizations for portable wireless applications, including the iPhone.
- Products for engineering visualizations and design, including line of sight.
- Data in support of consumer products (e.g., Microsoft Flight Simulator™).

Intermap also does a lot of work in the area it describes as the science and art of data conflation. Data conflation is a process where information from different sources is combined. The company overlays other company's attributes onto its road geometry to provide solutions that are customized for each client.

3. What technologies and trends do you see shaping the future of your business?

Intermap hopes to work with other roadway database developers, including Tele Atlas® and NAVTEQ™, on a project-specific basis in support of automotive ADAS and energy management applications. With regard to the future, the principal focus is the commercial automotive market. This is strongly influenced by the Government—for example in the Corporate Average Fuel Economy standards that generate applications to reduce energy consumption.

Intermap sees significant benefits to society if the current technologies can be brought together to help reduce the over 40,000 annual deaths on U.S. highways. Of the five road classes defined by NAVTEQ™ and Tele Atlas®, 75 percent of roads are in class 5, most of which is not digitized at the levels of accuracy needed for IntelliDrive applications. Intermap believes that changes are coming quicker than people think. Sweden is an active example of how these technologies can be brought together. Intermap does not intend to develop their own roadway basemap.

4. What can you share about the data you collect in terms of attributes and accuracy?

The original data are point-by-point, which can be converted to splines or clothoids, or the raw data can be calculated on the fly and then manipulated by the CAN bus applications. Each client wants the data in different formats, so data are processed to meet client-specific functions. An example process may work as follows: the vehicle know where it is from GPS; it then queries the database in the vehicle and uses a concept called the electronic horizon (eHorizon), which looks ahead for a distance, depending on the application. The eHorizon can feed information into different applications, such as engine management or adaptive headlights.

Intermap's AccuRoad™ Geometric Accuracy Standards for Driver Assistance Systems states, "The goal of this document is to define the geometric accuracy of the primary map database by providing standard specifications, definitions, and validation of the geometry." The document defines specifications for Intermap's centerline model with definitions of the various geometric attributes accuracy requirements and validation procedures.

Mandli Communications, Inc.

Web site: http://www.mandli.com/

Mandli provides both equipment and mapping services. Mobile LIDAR equipment installed on roadway inventory vehicles is the principle product. This equipment uses multiple spinning lasers that scan the road and its surrounding geometry and use the reflections to provide a profile of the street and nearby objects. Mandli also provides road imaging systems from various camera-based devices that can be used to collect highway inventory data and a laser-based rut measurement system. In addition, the company provides software products that can be used to view and analyze the data collected with its devices.

1. What business are you in and who are your clients?

Mandli provides mobile data collection services primarily for State DOTs. It also does some work with the commercial roadway map developers. About 90 percent of its business is for State DOTs and 10 percent for private mapping companies. Mandli principally provides map data to the States. The data types are referred to as identifiable assets and are listed later in this section.

Mandli has worked in over 30 States but recently conducted major projects in Texas, Tennessee, Nevada, Hawaii, and Indiana. In addition, it does work associated with various accident investigations.

Mandli also sells mobile data collection equipment, but most of the current work involves data collection services using mobile LIDAR.

2. What services do you provide for these clients?

Mandli principally provides the measurement of geometric data. The vehicle travels in the outermost right lane, and the LIDAR unit scans the road geometry. With regard to the possible use for IntelliDrive applications (if needed in the future) LIDAR can be used to measure the paint striping and, hence, deduce the number of lanes. LIDAR produces about one million points per second on one pass and provides 0.394-inch (10-mm) accuracy relative to the vehicle. Most mobile projects are for State DOTs that typically specify 3.28-ft (1-m) positioning accuracy.

The services Mandli provides are divided into asset mapping and survey mapping. Asset mapping is less accurate and often involves a contract for the whole State. When survey mapping is used, base stations are added to get very accurate measurements. Mandli’s work is driven by the project and customer requirements.

For example, in Tennessee, Mandli measured 27,000 lane miles with an accuracy of 3.28 ft (1 m). The data were used for HPMS reporting. In some circumstances, data are used in combination with other data sets. For example, a pavement management application may create a shapefile that is then snapped to the Mandli centerline. Another example is when a State DOT using Intergraph wants to use an existing basemap. The data Mandli collects are snapped to the map that is specified by the client.

3. What technologies and trends do you see shaping the future of your business?

Historically, pavement data was king. However, with technology changes, it is not just width that is being collected but a variety of data types. Mandli believes that mobile LIDAR is the future preferred technology. Clients are moving toward wanting 3-D representations, and this will result in more demand for LIDAR and airborne radar.

Mandli also uses videologs for collecting some roadway inventory data but has to manually code the sign type into the database. Mandli does not use character recognition to read sign types.

4.What can you share about the data you collect in terms of attributes and accuracy?

The data provide a combination of forward images at 500 pictures per mile together with LIDAR and is time- and distance-based. The set of identifiable assets include the following:

- Shoulder width and lane width.
- Sign location and size.
- Passing areas and acceleration and deceleration lanes.
- Acres of landscape, wildflowers, and mowing limits areas.
- Miles and type of access control fence.
- Height, width, and length of attenuators.
- Number of delineators.
- Width of each tunnel.
- Width and length of ramp lanes and shoulders, with pavement type of each identified.
- Line miles, type, and color of pavement markings. Widths of pavement-marking lines are measured.
- Specialty marking square footage; the specific type of specialty marking and any legend is identified.
- Length of curb and gutter segments.
- Length and height of guardrail and guardrail terminus and type of guardrail terminus.
- Height of concrete barrier walls.
- Distance of trees, nonbreakaway poles, and walls.
- Curve, grade, and superelevation.

With regard to road geometry, the available output fields for curve calculation are as follows:

- Starting distance.
- Ending distance.
- Total distance.
- Curve degree.
- Curve class.
- Curve radius.
- Latitude start.
- Latitude stop.
- Longitude start.
- Longitude stop.

Curves can be calculated using a chord or an arc length as set by the user. The curve class is fully customizable, so the user can set value ranges and names for each range and set to output in HPMS format. Using the curve class customization, it is possible to exclude certain values (such as straightaways of degree less than 1.0) from the report.

The available output fields for grade are as follows:

- Starting distance.
- Ending distance.
- Total distance.
- Grade.
- Grade class.
- Latitude start.
- Latitude stop.
- Longitude start.
- Longitude stop.

Grade values are output as percentages. (Vertical curve calculations are not currently available.) The grade class is fully customizable so the user can set value ranges and names for each range and set to output HPMS format. Using the grade class customization, it is possible to exclude certain values (for instance, flat segments less than 1.0 percent) from the report.

Fugro Roadware

Web site: http://www.roadware.com/

Roadware provides both data collection equipment and services. It develops and markets a range of vehicle equipment that can take a wide variety of road surface measures, including friction, pavement distress, photogrammetric data, rutting, roughness, and road profile. It also has software that gathers and reports on the data from its devices, including such features as automated crack detection.

1. What business are you in and who are your clients?

Roadware provides mapping equipment and services to State DOTs, departments of public works, and MPOs throughout North America. The vast majority of the work is for State DOTs.

2. What services do you provide for these clients?

The company uses its equipment to collect data for the States. Data are often fed into the HPMS system, providing intelligence in terms of signing and curvature. Roadware collects data based on customer specifications. The company does not make maps of any sort. Typically, a client will ask for data, video, or images to suit requirements and will provide or specify an existing map. Roadware will then set up vehicles accordingly and gather the data needed at the resolution requested by the customer's specifications.

Roadware also sells Automatic Road Analyzer products, which include a range of devices that equip vehicles to provide the following services:

- Pavement assessment.
- HPMS data collection.
- Road geometry.
- Video logging.
- Asset inventory.
- Mobile mapping.

Users also include Federal agencies such as FHWA and the U.S. Park Service. In addition, Roadware sells equipment globally with a substantial market in China. The vehicle itself is a minor part of the company's sales. Mostly, Roadware configures a series of subsystems for the client on some vehicle platform.

The level of data provided depends on the application. Generally, Roadware works at the network level (i.e., a statewide contract has lower resolution but a lot more miles). Videologs that could be used to obtain some of the IntelliDrive data are taken. The entire State roadway network is driven in the primary travel lane, which is typically the one with the worst roadway condition and where there are the most problems. Most data collection is motivated either by pavement or asset management needs.

Data collection is often more than roadway geometry. There is typically a variety of data attributes collected, based on end-user needs. Geometry is measured, but the client looks for the data they want, for example, inadequate road profile, poor curves, or ponding.

Roadware does not create roadway maps, but customers can turn the data into maps. What Roadware provides is a database. The customers take the data and apply it to their own structures. This structure could be a map, an LRS, or some State-specific format.

3*. What technologies and trends do you see shaping the future of your business?*

The company does not think the market is changing rapidly. However, one definite trend is that resolution is increasing. There is possibly a trend toward 3-D profiles of the road. Currently, Roadware makes a longitudinal path and takes two-dimensional measurements. Needing a 3-D mesh for the data seems to be coming. With regard to IntelliDrive data needs by lane, Roadware does not measure data in all lanes; it gathers data for the lane the equipment is in unless the data are for paint striping measurements. Then, Roadware equipment views the state of the paint in all lanes from the lane it is in. Although measurements are taken in the travel lane, some clients can get shoulder width from the videolog.

Retroreflectivity off the paint strip is another attribute. Roadware usually collects multiple data types when passing by. Customers define the data types. These customers can be different departments within one DOT (e.g., planning and maintenance).

Roadware is not familiar with IntelliDrive, but the company is aware of a lot of safety research with cameras in the vehicles. It would be possible to take all the State data and put it together in a Federal database, but Roadware does not own the data it collects. Data are the property of the customer who paid for them, so the legal issues would need to be addressed. From Roadware's perspective, the customers would need to change their priorities in order for Roadware to change the data it collects.

4. What can you share about the data you collect in terms of attributes and accuracy?

Roadware uses GPS equipment plus inertial navigation, a combination of subsystems that also measures pitch and roll. The information is collected in a database, and customers turn it into a map. Frequency of collection and required attributes are defined by the customer. Frequency varies from 1 ft (0.305 m) up to about 15 ft (4.57 m). Data are rolled up into summary files every 0.1 mi (0.16 km) or 0.01 mi (0.016 km), but raw data are provided as well. The data collected most, in order, is as follows:

1. Roughness—IRI.

2. Rutting.

3. Imagery.

4. Pavement distress (cracking).

FHWA DHMS

1. What is the primary objective of FHWA's DHMS project?

The principal objectives of DHMS and all the research conducted at FHWA's Digital Highway Measurement Laboratory (DHML), are as follows:

- To support FHWA's strategic commitment to data-driven decisions by developing and demonstrating technologies for the high-speed, high-accuracy collection and processing of roadway data.

- To work with States to demonstrate and refine particular data collection methods through field deployment of prototype technologies.

The DHMS is one output of DHML at the Turner-Fairbank Highway Research Center in McLean, VA. Research at DHML directly supports FHWA strategic objectives to improve the quantity and quality of data available to safety and asset management programs. However, for such increasing demands for data to be economically met, new high-speed, high-accuracy data collection technologies are needed.

Since the late 1990s, researchers at DHML have developed and applied advanced technologies for the automated collection of information about the roadway and its environment. Measurement systems developed in DHML include DHMS, the Ultra-Light Inertial Profiler (ULIP), and the Advanced Pavement Evaluation (APE) system.

DHMS is a prototype instrumented vehicle which combines LIDAR, high-accuracy NDGPS and an aviation-quality inertial navigation unit. As it drives along, DHMS accurately measures roadway geometry and builds 3-D maps of features of interest on, over, or beside the road. DHMS was put into use in 2003. ULIP is a Segway-mounted system to collect and map profile and texture information on sidewalks and other narrow paths. APE is a separate vehicle designed to create 3-D subsurface maps using step-frequency ground penetrating radar (SFGPR) in order to measure pavement thickness, locate subsurface objects such as rebar or utilities, and detect and classify pavement distress such as delamination, voids, and fractures.

The FHWA commitment to data-driven decisions goes beyond sensor systems. Other related efforts include the following:

- **Model Inventory of Roadway Elements (MIRE)**: Standard definitions and coding for over 200 roadway data elements. Data that are consistent across jurisdictional lines will enable investigation of safety questions that could not be answered based on narrower data sets. MIRE is a voluntary standard, but FHWA hopes that it will be widely adopted as a de facto roadway data dictionary. For more information, see http://www.mireinfo.org/.

- **SafetyAnalyst**: A software package for safety analysis on a network level; an implementation of Part B of the *Highway Safety Manual*.

- **Interactive Highway Design Model**: A software package for safety analysis on a project level; an implementation of Part C of the *Highway Safety Manual*.

One vision for mobile digital roadway data measurement systems in general is that they will eventually be capable of collecting most of the data elements needed by these tools and will deliver that data to the analytical tools in a common format. MIRE is the prototype of a common set of roadway element definitions. Mobile roadway data collection systems such as DHMS also offer the possibility of reducing the cost of collecting and delivering HPMS data each year.

Another role for FHWA and DHML is to advocate for and support development of roadway data collection standards. At present, States are on their own when planning for data collection. Each vendor specifies its equipment and services differently. Well-crafted standards, particularly technology-neutral performance standards, would simplify contracting for data collection services by the States and would make it easier for new technologies to be accepted.

2. Does this program work directly with State DOTs? If so what is the nature of their involvement?

Researchers work directly with State DOTs during field trials and demonstrations of data collection technologies. In some instances, the State DOT is interested in collecting data for its own purposes, for which one of the DHML vehicles may be uniquely equipped. At other times, the State is willing to make available a section of their road system so that FHWA researchers can collect data in support of DHML objectives.

3.Does this program work directly with commercial roadway data collection services such as Mandli or Roadware? If so, what is the nature of their involvement?

The only formal interaction between DHML and manufacturers was an FHWA-hosted meeting in 2007, which approximately 35 industry representatives attended. The purpose of the meeting was to update the industry on DHMS progress. FHWA also participates in conferences focused on roadway data collection and related topics.

The Federal Lands Highway Division of FHWA has directly hired mobile roadway data collection vendors and owns at least one data collection van.

4. What new roadway data collection technologies are you testing/evaluating/demonstrating at this time?

At present, the primary focus of the DHML is the application of SFGPR to highway safety and infrastructure applications.

The following are broader long-term objectives subject to funding:

- **The fusion or integration of data from multiple sources:** The goal is for all data collection processes to be accessible through one user interface. This effort includes research on improved visualization of the output. In industry today, different data types are typically gathered as distinct applications, with integration taking place during postprocessing.

- **Real-time data processing:** Currently, for most roadway applications, it takes much more time to process data than to collect it. Real-time output would necessarily reduce processing costs, probably significantly. Near-real-time data processing also makes the output potentially more relevant to ITS/IntelliDrive applications, though that is not a focus of any DHML project at this point.

- **Automated identification of residual capacity in roadside hardware:** For example, damage to guardrail installations can already be seen in LIDAR data and optical images. A major improvement would be for the data collection system to automatically determine whether the dent in the guardrail is severe enough to need repairs.

5. For each new data collection technology identified, what specific roadway data items or attributes are the technology designed to collect and what benefit does the new technology have over previous data collection methods (e.g., increased accuracy, lower processing cost, data could not be collected before)?

Data fusion and improved visualization of information make it more likely that a practitioner will clearly understand that information and will therefore be able to make better decisions in the field. Near-real-time output of data collection offers lower costs by reducing the amount and complexity of postprocessing activities.

6. Are any of the State DOTs currently using any of the innovative technologies for collecting their roadway inventory or geometry data?

Most State uses of cutting edge technology for roadway data collection is indirect, through contracts with private sector service providers and equipment manufacturers, though there are a few States, including Virginia, Minnesota, Washington, Texas, and California, that conduct at least some research on their own initiative.

Some of these active State DOTs and their respective areas of focus relative to pavement nondestructive evaluation are as follows:

- Texas has developed a certification procedure for pavement roughness equipment.

- Minnesota is working on several pavement condition measurements through its MnROAD program, including the use of infrared, lasers, and nondestructive evaluation methods.

- Penn State University's Pennsylvania Transportation Institute is doing work on measuring pavement friction.

- The Virginia Tech Transportation Institute is working on a variety of data collection methods for pavement evaluation.

- Caltrans has a location near San Diego that the agency uses to check the calibration of data collection equipment.

Other State DOTs not included in the list participate in pooled fund studies related to the development of innovative technologies for collecting roadway inventory data.

7. Is it difficult to get State DOTs to adopt new data collection technologies or to collect new roadway data items?

The process is slow due in part to a combination of budgetary concerns and the current lack of any standard yardstick for performance. Particularly when a State does not already use a given data element in its own operations, allocating time and funds to collecting that additional data element is a tough sell.

8. What are the most effective incentives for getting State DOTs to utilize new data collection technologies? (e.g., will States adopt new data collection technologies without either a Federal mandate or some funding incentive?)

There should be a mandate or financial incentive. Most States collect the HPMS-mandated data elements only because it is required. Only a handful of States have research programs that consider data collection and analysis independent of legislative or regulatory mandates.

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