MANAGEMENT PROCEDURES FOR DATA COLLECTED VIA INTELLIGENT TRANSPORTATION SYSTEMS

July 29, 2015

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Michigan Department of Transportation

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MDOT REQ. NO. 1259, Connected and Automated Industry Coordination
Task A.3. Management Procedures for Data Collected via Intelligent Transportation Systems

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Abstract:
This report is an extension and update of a previous report prepared by CAR, PB, and MDOT in September 2013 entitled *Management Procedures for Data Collected via Intelligent Transportation Systems.* The 2013 report provided an overview and broad discussions of National ITS Architecture and Standards, statewide transportation data management policies, and existing MDOT ITS data systems. This report extends those findings to discuss state-of-industry and best practices and developments of national ITS programs and their implications. It also presents a series of recommendations to improve ITS data management at the state-level.

ACKNOWLEDGMENTS

This document is a product of the Center for Automotive Research and Parsons Brinkerhoff under a State Planning and Research Grant administered by the Michigan Department of Transportation.

EXECUTIVE SUMMARY

The Michigan Department of Transportation (MDOT) has been a leader amongst state transportation agencies in the testing and deployment of intelligent transportation systems (ITS). As part of these efforts, MDOT asked a team led by the Center for Automotive Research (CAR) and assisted by Parsons Brinckerhoff (PB), to evaluate the collection, management, and use of ITS data and to recommend strategies to develop integrated, dynamic, and adaptive data management systems. This report presents the results of the updated findings and a series of recommendations related to ITS data management.

The benefits of being proactive in ITS adoption are numerous. ITS systems can facilitate a safe and efficient transportation system, improve public safety, assist research programs, stimulate economic growth, and improve the environment. Being proactive, however, also carries potential disadvantages in that organizations at the forefront of technology run the risk of deploying before the technologies are fully mature. In the case of Michigan, several ITS programs have been launched successfully but independently of each other. Current standards and best practices in ITS deployment encourage broad interconnectivity and interoperability; especially through use of National ITS data standards and enterprise data warehouse techniques.

To leverage existing and future opportunities effectively, the State of Michigan should develop a statewide master/strategic plan for database aggregation across ITS subsystems and programs. The plan should be developed in conjunction with MDOT, the Michigan Department of Technology, Management & Budget (DTMB), and other key stakeholders. The new Transportation Asset Management System (TAMS)* represents an opportunity to realign existing systems and datasets into a coherent and integrated platform. A comprehensive policy will consider economic, legal, and ethical obligations, and should align with the vision of national standards including the U.S. DOT National ITS Architecture. While various barriers (institutional, political, economic, etc.) might serve to prevent the formation and implementation of such a broad statewide effort, the potential benefits of doing so make such an effort worth pursuing. Strategic database aggregation

* MDOT 2013. Previously known as the Enterprise Asset Management System (EAMS) project.

could multiply the value and utility of current and future ITS programs and datasets. This added value would benefit multiple agencies, organizations, residents, and visitors to the State of Michigan.

By continuing to commit to a leadership role in national efforts to develop and deploy connected vehicle (CV) and ITS technology, Michigan will have a significant role in shaping the future of transportation infrastructure management and ITS information systems development. Through its leadership and implementation expertise, MDOT will be well positioned to reap the benefits of becoming the recognized home of this technology.

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1 INTRODUCTION

Addressing modern transportation planning, operation, and investment challenges require increasingly sophisticated data and information management strategies. Intelligent transportation systems (ITS) provide an opportunity to obtain valuable transportation data in real-time.[1] In many cases, ITS-generated data are similar to other transportation data collected by traditional methods. However, the potential for continuous real-time data in multiple formats implies that ITS data imposes challenges similar to that of other 'big data' applications. Making the best use of current and future ITS investments and associated data requires a data management strategy that addresses all relevant systems, applications, and users.

MDOT is in a unique position to capitalize on statewide investment in application systems, data storage, and other new technologies. The agency has a core focus on understanding the built environment (e.g., transportation system in this context) and the efficient movement of goods, people, and services. Efficient management of digital information, including that from infrastructure and operations based ITS, creates an opportunity for new revenue models, more efficient use of resources, reduction of operational costs and more effective use of the overall transportation system.

This report serves to evaluate and assess business drivers that will influence the collection, management, and use of ITS data, and recommend strategies to develop integrated, dynamic, and adaptive data management systems. To achieve this goal, this report summarizes and discusses state-of-the-industry and best practices, national ITS research programs and their implications, and existing MDOT plans and data systems. Finally, it presents a series of recommendations related to ITS data management.

[1] The concept of "real-time data" in this report refers to data that is available to an agency immediately or soon after the data is initially collected—or subject to a reasonable and controlled delay. This may include data reported in batches at regular intervals (e.g., five-minutes, 24-hours, etc.).

2 LITERATURE REVIEW AND INDUSTRY ASSESSMENT

Transportation agencies have the opportunity to leverage modern information and communications technology to improve the safety, mobility, and efficiency of the transportation system. The challenge for agencies is to determine the right balance of investment in modern technology solutions in an environment of tight budgets and ageing infrastructure. This predicament has inspired an extensive body of literature regarding data-based solutions to transportation management. This chapter summarizes the most relevant elements from this body of literature as related to ITS data management.

2.1 DATA-DRIVEN INTELLIGENT TRANSPORTATION SYSTEMS

The efficient management and operation of future transportation systems will increasingly rely on multiple data sources, including sensors, vehicles, smartphones, parking systems, inventory tracking systems, ticketing systems, energy distribution networks, command/control systems, information management systems, video streams, etc. Substantial benefits accrue from the use and fusion of these data streams to optimize transportation services and improve safety. Some researchers believe that the availability of a large amount of data can lead to a "revolution in ITS development," changing ITS from a conventional technology-driven system into a more powerful multifunctional *data-driven intelligent transportation system* (D^2ITS). A fully mature D^2ITS platform would allow users to utilize interactively multiple data resources pertaining to the management, operation, and services of transportation systems.[2] From this unprecedented volume and speed at which these datasets are generated, managed, stored and processed, risks and challenges of this type platform are induced and have to be addressed.[3] The migration from traditional ITS into D^2ITS environment will require strategic planning for the transition and eventual management of the system and associated data.

[2] Zhang et. al. 2011.
[3] OECD 2014.

2.2 DATA GOVERNANCE

Data governance is the formally authorized organization and implementation of policies, procedures, technologies, structure, roles, and responsibilities that outline and enforce rules of engagement, decision rights, and accountabilities for the effective management of information assets. Data governance could refer to:[4]

- Organizational bodies
- Rules (policies, standards, guidelines, business rules)
- Decision rights (how we "decide how to decide")
- Accountabilities
- Enforcement methods for people and information systems as they perform information-related processes

According to The Data Governance Institute, data governance guiding principles should include integrity, transparency, auditability, accountability, stewardship, checks-and-balances, standardization, and change management. The functional areas of data governance are illustrated in Figure 1. These programs typically come into existence in conjunction with other efforts, such as system acquisition and enforcement of policy, standards, and requirements based on new levels of cross-functional decision-making and accountabilities.[5]

[4] The Data Governance Institute, http://www.datagovernance.com/
[5] The Data Governance Institute, http://www.datagovernance.com/

FIGURE 1: FUNCTIONAL AREAS OF DATA GOVERNANCE[6]

U.S. DOT DATA GOVERNANCE

At the U.S. DOT, data governance is viewed as an enterprise effort involving organizational bodies, policies, principles, and quality that will ensure access to accurate and risk-free data and information. Data governance will establish standards, accountabilities, responsibilities, and ensure that data and information usage achieves maximum value while managing the cost and quality of information handling. Data governance will enforce the consistent, integrated, and disciplined use of information at U.S. DOT.[7]

2.3 DATA MANAGEMENT TECHNOLOGIES

Recent advancements in data science and various technologies are providing new opportunities to public agencies, as well as imposing new challenges. Government officials and agency administrators can be justifiably confused about how to utilize appropriately the latest information and communications technologies. In just the last few years, there has been an increasing sense of a fundamental shift in how government agencies, as well as private organizations, should approach data use and management.

[6] Source: DAMA International, http://www.dama.org/
[7] Bishop 2014.

Many advancements have been grouped together and given abstract terms, such as ‘big data’ and ‘the cloud.’ The technologies and institutions underlying these concepts are complex. Comprehensive and definitive review of them is outside of the scope of this report. However, it is worth outlining generally what is meant by these terms and how they may affect data management for transportation agencies.

BIG DATA

In general, the word *data* refers to a set of facts or observations that provide information. Twentieth-century digital technologies led to development of computer database applications, allowing manipulation and understanding of data in ways never before possible. *Big data* simply refers to advanced technologies, tools, and methods that allow effective and efficient manipulation and understanding of data over what was possible with twentieth-century databases, at substantially larger storage and managed information scales. Big data has been associated with three attributes that distinguish it from traditional data, known as the ‘three Vs of big data:’ *volume*, *velocity*, and *variety*, (Figure 2).[8]

[8] Edd Dumbill. “Volume, Velocity, and Variety: What You Need to Know About Big Data.” *Forbes*. January 19, 2012. Accessed November 2014 at: http://www.forbes.com/sites/oreillymedia/2012/01/19/volume-velocity-variety-what-you-need-to-know-about-big-data/.

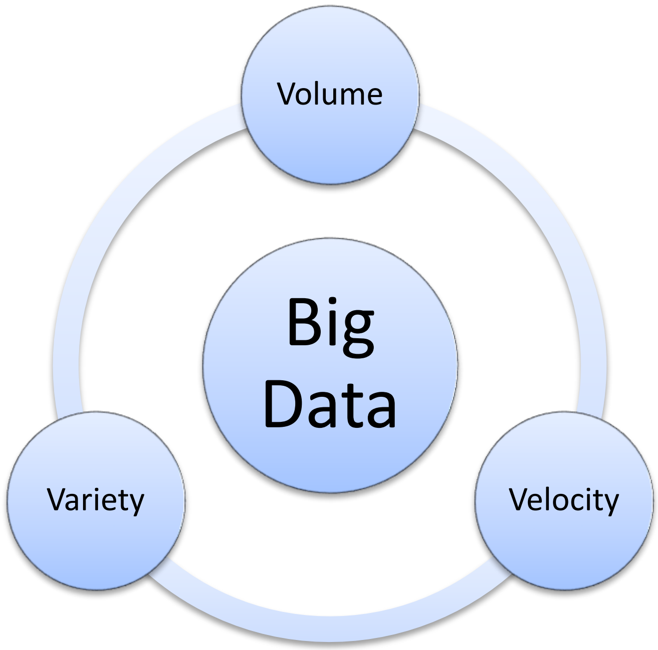

FIGURE 2: THE 'THREE VS' OF BIG DATA

CLOUD SERVICES

Basically cloud services refers to data, systems and servers and ubiquitous access via the *Internet*; the worldwide system of networks and computers linkable though Internet Protocol (IP) addresses.[9] However, the cloud metaphor reflects recent adoption and larger scale datacenters that allow services to be seen by more people at the same time, resulting from easier and larger bandwidth/network capacity to the services. Until recently, moving data between computers and between networks was relatively slow via leased telecommunication links that were constrained or constricted. Limitations on digital communication technology implicitly restricted remote access to large amounts of data. It was practically necessary to have direct physical access. In other words, working with a database required that the database and its software be stored on the users' local network to access, manage and effectively store the information. This is no longer the case with the implementation of Cloud Services for particular systems/information stores.

New advances in information technology (IT) have allowed transmission of digital information at speeds sufficient for remote access and manipulation of

[9] Cloud computing (in the form of email) actually predated the institution of the TCP/IP stack, and thus is older than the World Wide Web—what we now consider 'the internet.'

large amounts of data. The data is not literally floating overhead in a cloud. It still must reside on electronic hardware somewhere in the physical world. However, because data transmission speed has become so fast and widespread, it is no longer particularly important where the data is stored relative and onsite with users of the information.

The use of remote machines for data storage and processing can be a useful IT strategy for large organizations such as government agencies. Cloud services could provide agencies with high quality low cost IT and data services. A potential drawback is that data hosted on remote machines could be vulnerable to unauthorized access, due to ineffective security and data management best practices.[10] Cloud Service providers are currently offering three varieties of access plan types, typically setup as Private Cloud Services, Hosted/Lease Cloud Services, and Hybrid Cloud Services. Private Cloud Services are largely customer owned equipment, network, security, systems and data. This option is the most expensive and also the most flexible. In negotiating these agreements the terms and conditions, and service level agreements are potential legal risk areas. Hosted/Lease Cloud Services are pre-packaged scenarios that affect cost and access speeds. In this option, the customer does not own any equipment. They pay for access and storage in a legally defined environment/configuration and are only responsible for customer data. In this option the security and management practices must be negotiated and reviewed prior to executing any term agreements. In the last option (a Hybrid Cloud Service), the customer selects and invests in a combination of deployment services, equipment and access by data/service type and mixes how the end the users access the information and via which equipment component (some owned by the provider and some owned by the customer).

While Cloud Services are changing our Transportation Industry, DOTs need to understand new and rapidly changing security practices, management practices, legal precedent and very complicated operating/service agreement terms and conditions. Data governance, software/data assurance, and service level agreements for the technology services they own, operate and manage are rapidly becoming the highest risk areas that affect every agency and transportation network user.

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[10] Dennis, Eric Paul; Joshua Cregger, Qiang Hong. *ITS Data Ethics in the Public Sector.* July 2014. http://www.cargroup.org/?module=Publications&event=View&pubID=110

DATA FUSION

The fusion of multiple data sources such as cameras, Global-Positioning System (GPS), cell phone tracking, and probe vehicles are perceived as a well-adapted answer to the operational needs of transportation operation centers (TOCs) and traffic information operators. Data fusion will allow transportation system operators to achieve their goals more efficiently. Wireless technologies, which offer the potential of easier reporting and access to customized information (e.g. cooperative systems with vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-devices) and the new ability of tracking individual vehicles, will certainly accelerate needs for data fusion operational systems.[11]

2.4 SPATIAL DATA WAREHOUSE

Transportation agencies may collect extensive location-based data. Once stored in data warehouses, they form the basis for data analysis and guide the organization's strategic decisions. Due to the need to analyze large volumes of spatial data sets, the spatial data warehouse has been emerging as an important strategy. Examples of spatial data warehouses include the US Census Dataset, Health Resources and Services Administration (HRSA) Data Warehouse, Microsoft Terra server, and Spatial Eye.

Spatial levels, spatial hierarchies, spatial measures and spatial fact relationships are important concepts used in spatial data warehouse and multidimensional model developments. Indexing, aggregation, spatial online analytical processing (SOLAP), and spatial-temporal online analytical processing (STOLAP) are common Geographic Information Systems (GIS) functionalities. Figure 3 represents the taxonomy of spatial and spatiotemporal data warehouse.

[11] El Faouzi, Leung, and Kurian 2011.

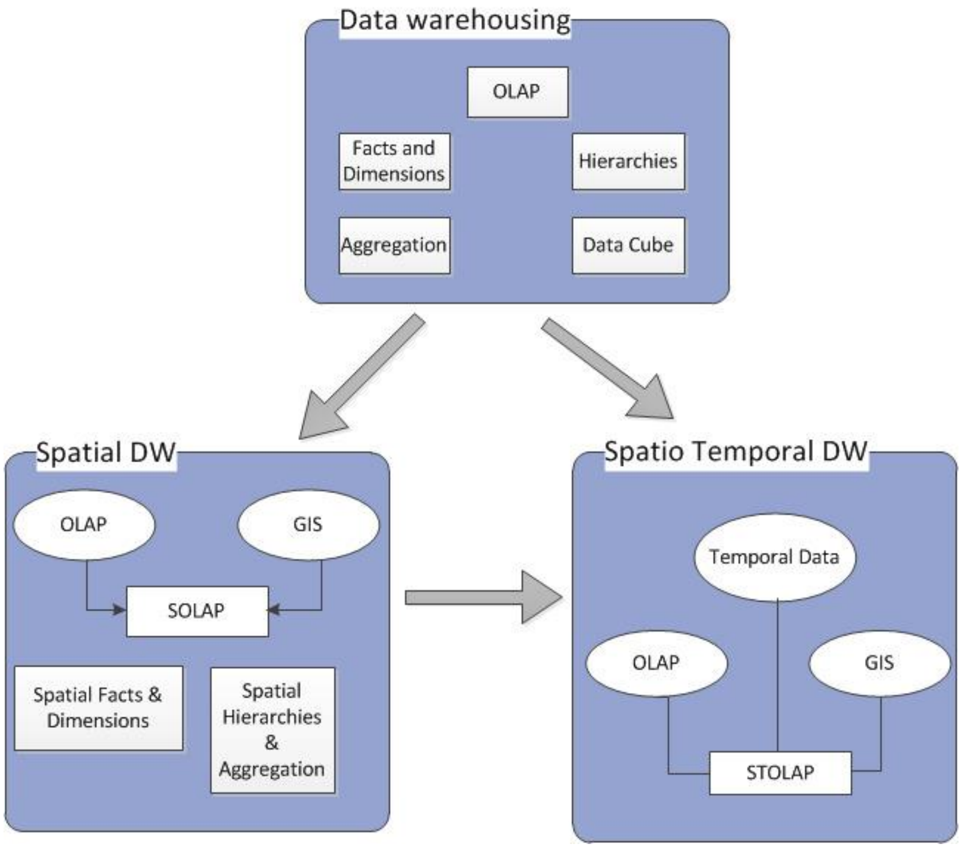

FIGURE 3: TAXONOMY OF SPATIAL AND SPATIOTEMPORAL DATA WAREHOUSE[12]

Evaluating the business requirements of the end user is a crucial step during design of a spatial data warehouse. Tao and Hung (2013) proposed Web-based GIS-Transportation (GIS-T) data warehouse systems that leverage geographically referenced data and online spatial analytical tools specifically to support transportation decision making processes. The GIS-T platform utilizes ArcGIS software, which can provide functions of data query, data service, Web map service, and hyperlink with other agencies for general users.[13] Additionally, the industry marketplace for geospatial services is rapidly developing, including delivering open-source (non-proprietary) GIS solutions (for the desktop) and for web-based service delivery. These new tools and solutions, will help improve the sustainability and operational cost budgets for DOTs over the next decade.

[12] Source: Garg, Nipun; Surabhi Mithal. "Spatial Data Warehouses: A Survey."University of Minnesota. http://www-users.cs.umn.edu/~smithal/8715_Midterm_group4.ppt, accessed December 2014.

[13] Tao and Hung 2013.

CITRA is another example of a software product for analysis, modeling and exchange of complex spatial information between GIS and databases.[14] A CITRA spatial data warehouse features following capabilities:

- Constant growth of spatial datasets
- Increasing demand for use of spatial data
- Data exchange between different GIS-Applications and GIS-Technologies
- Internal exchange & with external partners
- Concepts for keeping data from the various systems and applications up-to-date
- Contemporary IT structures (focusing on IT not on GIS)
- Separation of production and usage of data

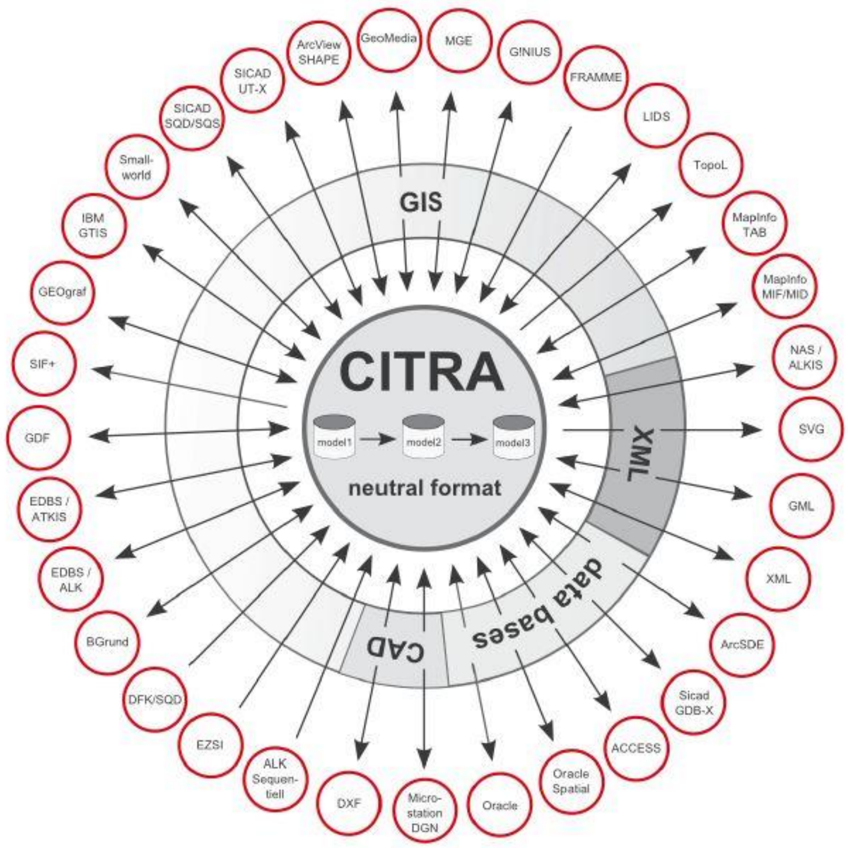

FIGURE 4: CITRA SPATIAL DATA FRAMEWORK[15]

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[14] Figura 2012.
[15] Source: Figura 2012.

3 U.S. DOT CONNECTED VEHICLE PROGRAMS AND PHYSICAL ARCHITECTURE FOR DATA MANAGEMENT

The U.S. DOT has put considerable effort into developing nationwide interoperable ITS standards. The baseline document outlining U.S. DOT ITS research efforts is the *ITS Strategic Research Plan 2015-2019*, [16] maintained by the ITS Joint Program Office (ITS JPO) within the Office of the Assistant Secretary for Research and Technology (OST-R) of U.S. DOT.[17]

Elements of the U.S. DOT ITS Connected Vehicle Program most relevant to data management described in this Chapter include:

- Data Capture and Management (DCM)
- Dynamic Mobility Applications (DMA)
- Research Data Exchange (RDE)
- Connected Vehicle Safety Pilot Model Deployment

3.1 DATA CAPTURE AND MANAGEMENT (DCM)

Data Capture and Management (DCM) is designed to create and expand access to high quality, real-time, multimodal transportation data, captured from connected vehicles, mobile devices, and infrastructure. DCM technologies collect real-time data from a variety of sources and modes and integrate the data across modes and sources or make it available for users to incorporate according to their needs.[18]

The vision of the DCM program is to enhance current operational practices and transform future transportation systems management and traveler information through active acquisition of integrated multi-source data from vehicles, travelers, mobile devices, and fixed sensors. The objectives of the DCM program are to:[19]

[16] U.S. DOT 2014.
[17] The ITS JPO was formally within the Research and Innovative Technology Administration (RITA). RITA was dissolved in 2014, concurrent with the creation of OST-R.
[18] http://www.its.dot.gov/data_capture/index.htm
[19] http://www.its.dot.gov/data_capture/index.htm

- Enable systematic data capture from connected vehicles (automobiles, transit, and trucks), mobile devices, and infrastructure.
- Develop data environments that enable integration of high-quality data from multiple sources for transportation management and performance measurement.
- Reduce costs of data management.
- Eliminate technical and institutional barriers to the capture, management, and sharing of data.
- Determine required infrastructure for transformative applications implementation, along with associated costs and benefits.

3.2 DYNAMIC MOBILITY APPLICATIONS

The objective of the U.S. DOT Dynamic Mobility Application (DMA) research program is to foster release of high-value, open-source applications that use synthesized, multisource ITS data to transform surface transportation management and information. The research conducted in this program focuses on developing the tools,[20] metrics, and concepts that support application development.[21]

The DMA program is composed of six bundles of applications reflecting the vision of the DMA program to enable greater multimodal system management and modal integration. Each bundle contains a set of related applications that are focused on similar outcomes (i.e., more efficient signal prioritization and timing for mobility), but perform in different capacities (i.e., transit signal priority versus emergency preemption). Importantly, each application could not work as effectively without understanding the influence of the other applications. The timeframe that they have to operate (sometimes within seconds), and the nature of the impacts and the need to sequence the impacts are highly related. Thus, by developing the applications together, synergistic relationships are embedded into the algorithms resulting in:[22]

- Greater efficiencies – the same data and observations can be used across all applications as opposed to deriving such inputs separately or in varying formats

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[20] For instance, an open source portal.
[21] http://www.its.dot.gov/dma/index.htm, accessed December 2014.
[22] http://www.its.dot.gov/dma/index.htm, accessed December 2014.

- Less stove-piping as the applications must effectively interact
- Greater safety and operational awareness of a broad range of impacts

3.3 RESEARCH DATA EXCHANGE

The Research Data Exchange (RDE) is being developed as a U.S. DOT data sharing system that promotes sharing of both archived and real-time data from multiple sources (including vehicle probes) and multiple modes. This new data sharing capability will better support the needs of ITS researchers and developers while reducing costs and encouraging innovation.[23]

3.4 SAFETY PILOT MODEL DEPLOYMENT

In support of the potential National Highway Traffic Safety Administration (NHTSA) connected vehicle regulation described in the previous subsection, MDOT has partnered with U.S. DOT and others on a public test-bed project for a prototype dedicated short-range communication (DSRC) connected vehicle ITS system in Ann Arbor, MI. The *U.S. DOT Safety Pilot Model Deployment* was designed to collect connected vehicle data on a publicly deployed test fleet. Various vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications are being tested under this program. Data sets collected under this program include:

- Basic Safety Messages (BSM)
- Traveler Information Messages (TIM)
- Signal Phase and Timing (SPaT) Messages
- Geographic Intersection Description (GID) Messages

All DSRC messages are relayed from roadside units (RSU) to a back office data management system managed by the University of Michigan Transportation Research Institute (UMTRI). The foundational message in the V2V system is the BSM. This message is broadcast from each vehicle and provides the vehicle's location, speed, and direction.[24]

A significant portion of the data collected through the Safety Pilot Model Deployment will be stored in the Research Data Exchange (RDE). Figure 5 previews datasets encapsulated within this environment.

[23] https://www.its-rde.net/home, accessed December 2014.
[24] http://www.its.dot.gov/safety_pilot/, accessed December 2014.

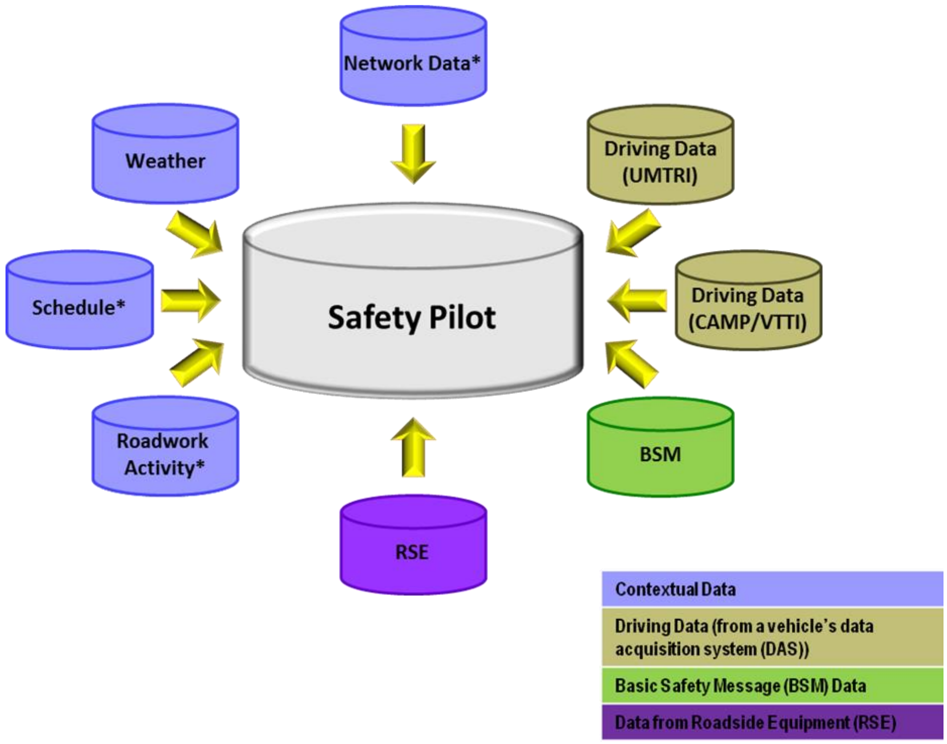

FIGURE 5: POTENTIAL CONTENTS OF THE RESEARCH DATA EXCHANGE SAFETY PILOT DATA ENVIRONMENT[25]

[25] Source: U.S. DOT 2014b. Datasets to be populated as soon as (additional) data becomes available.

4 UPDATE OF EXISTING MICHIGAN PLANS, POLICIES, AND STUDIES

The State of Michigan and MDOT impact the management of any data collected via ITS in various ways. Describing the full extent and impact of these interactions is beyond the scope of this study. However, this chapter provides a summary overview of plans, policies, and studies that are most likely to impact ITS data management.

4.1 MICHIGAN DEPARTMENT OF TRANSPORTATION STRATEGIC PLANNING

DEPARTMENT-WIDE STRATEGIC PLAN

MDOT's mission is to "provide the highest quality integrated transportation services for economic benefit and improved quality of life." To further this mission, MDOT has established seven strategic areas of focus:[26]

- Leadership
- Safety
- Customer-centered
- Partners
- System Focus
- Innovative and Efficient
- Workforce

SUPPLEMENTARY PLANNING PROCESSES AND DOCUMENTS

MDOT has several planning documents and ongoing processes in support of overall departmental strategies and goals. Additional strategic planning documents include:

- State Long-Range Transportation Plan (MI Transportation Plan)[27]

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[26] MDOT's strategic plan is available online at: http://www.michigan.gov/documents/mdot/MDOT_mission_vision_and_goals_2_375168_7.pdf, accessed November 2014.

[27] The SLRP is a federally mandated 25-year master plan for the transportation system updated every five years. MDOT has recently adopted a freight master plan as an addendum to the SLRP. All relevant documents can be accessed at:

(continued on next page...)

- Five Year Transportation Program and State Transportation Improvement Program (STIP)[28]
- Michigan Freight Plan[29]
- Michigan State Rail Plan[30]
- Michigan Transit Strategic Plan[31]
- Connected Vehicle Infostructure Plan[32]
- Connected and Automated Vehicle Technology Strategic Plan[33]
- ITS Investment Plan[34]

4.2 DTMB INFORMATION TECHNOLOGY POLICIES

The Michigan Department of Technology, Management & Budget (DTMB) has a broad spectrum of responsibility, ranging from procurement and facilities management to technology solutions. DTMB has the authority to establish statewide technical policies, standards, and procedures in the specified areas. They represent a portion of the Administrative Guide to State Government (Ad Guide), used by state of Michigan employees in the course of conducting business. Statewide technical policies, standards, and procedures include:[35]

- Enterprise Information Technology Policy
- Security Awareness Policy
- Access Control Policy

(...continued from previous page)

http://www.michigan.gov/mdot/0,1607,7-151-9621_14807_14809---,00.html, last accessed November 2014.

[28] Michigan's five-year transportation program is a precursor to the federally-mandated STIP, which lists projects that state and local transportation agencies have committed to for the next four years. Both plans are updated on a rolling annual basis.

[29] http://www.michigan.gov/mdot/0,4616,7-151-9621_68051-306924--,00.html, accessed January 2015.

[30] http://www.michigan.gov/mdot/0,4616,7-151-9621_14807-242455--,00.html, last accessed November 2014.

[31] http://www.michigan.gov/documents/mtsp_22988_7.pdf, accessed November 2014.

[32] http://www.michigan.gov/documents/mdot/10-09-2012_Connected_Vehicle_Infostructure_Plan_401340_7.pdf, accessed November 2014.

[33] http://www.michigan.gov/documents/mdot/07-24-2013_Strategic_Business_Plan_430242_7.pdf, accessed November 2014.

[34] http://www.michigan.gov/documents/mdot/10-14-2013_MDOT_ITS_Investment_Plan_437498_7.pdf, accessed November 2014.

[35] Michigan Department of Management and Budget website, accessed November 2014 at: http://michigan.gov/dtmb/0,4568,7-150-56355_56579_56755---,00.html

- Information Security and Acceptable Use Policy
- Network & Infrastructure Policy
- Network and Communications Managed LAN Cabling Standard
- Project Management Methodology Policy
- Project Management Methodology
- Systems Engineering Methodology
- IT Standards Adoption, Acquisition, Development, and Implementation Policy
- Information Technology Configuration Management
- Information Technology Continuity of Business Planning

4.3 PERFORMANCE-BASED OPERATING SYSTEM FOR MAINTENANCE

As Michigan's transportation infrastructure is largely mature, an increasing percentage of transportation investments are shifting from construction to maintenance activities. MDOT is seeking to improve the efficiency of maintenance operations by transitioning to a performance-based operating system (PBOS). An essential component of implementing PBOS is having a complete and easily updatable inventory of system assets, and a systematic process to manage that inventory.[36] The platform for the maintenance PBOS will be provided by the future transportation asset management system (TAMS), currently under development by DTMB and MDOT.

4.4 MDOT VIDEO SHARING POLICY

MDOT utilizes closed circuit television (CCTV) cameras as part of the ITS program, as part of the ITS program. MDOT has implemented ITS data sharing policy which includes CCTV access, distribution, and use for stakeholder and constituent Agencies. CCTV cameras assist in monitoring traffic conditions and the effectiveness of countermeasures. The video sharing policy recently developed by MDOT provides guidance to the collection, distribution, and retention of CCTV video and images. For example, MDOT may share CCTV views with other entities to achieve common transportation objectives in improving planning, traffic management, and traveler

[36] MDOT 2013.

information. Cooperative understandings in the form of a signed agreement are required in order to share CCTV video/images. Personally identifiable information (PII) shall not be knowingly shared with private entities or the public.

5 UPDATE OF EXISTING MDOT TRANSPORTATION DATA SYSTEMS

Most of MDOT's ITS subsystems function as single-purpose platforms maintained by third-party contractors. This chapter describes the primary MDOT ITS subsystems and the potential to achieve increased efficiency through improved integration of systems.

5.1 REGIONAL INTEGRATED TRANSPORTATION INFORMATION SYSTEM

MDOT has an agreement in place with the University of Maryland to provide data fusion and regionalized access/distribution of some specific ITS information. This utilizes Regional Integrated Transportation Information System (RITIS), an automated data sharing, dissemination, and archiving system. RITIS includes many performance measure, dashboard, and visual analytics tools that help agencies gain situational awareness, measure performance, and communicate information between agencies and to the public. The former is via a data fusion service between the source agency and other regional data providers. The fusion engine then combines the source data and rebroadcasts it to the Agency consumers/stakeholders for an annual license and service fee.

5.2 OEM FLEET AND TELETRAC DATA SERVERS

MDOT uses two subsystems for fleet management and reporting: the OEM Fleet Data Server and the Teletrac Data Server. Together, these systems support analysis of routes, miles travelled, maintenance performed/maintenance cycles, regulatory compliance, and GPS tracking/routing for MDOT fleet vehicles.

5.3 TRANSPORTATION MANAGEMENT SYSTEM

MDOT's Transportation Management System (TMS) is a series of individual data schemas used to analyze, manage, monitor, and report conditions on a wide variety of transportation assets. The TMS has provided MDOT a platform to establish, track and report key metrics to legislators, local and federal administrators, engineers, planners, analysts and the public. The information generated supports decision making over a range of functions.

The TMS platform began development in the 1990s and (while successful) has become somewhat dated. This series of data schemas may be superseded by the upcoming Transportation Asset Management System (TAMS) project, currently under development by DTMB and MDOT.[37]

5.4 HIGHWAY PERFORMANCE MONITORING SYSTEM

HPMS is a national-level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways. MDOT annually utilizes and participates in the U.S. DOT HPMS program. Data from the program helps both agencies with transportation funding allocations. In general, HPMS contains administrative and system information on all public roads, while information on other characteristics is represented in HPMS as a mix of universe and sample data for arterial and collector functional systems. Limited information on travel and paved miles is included in summary form for the lowest functional systems.

The HPMS was originally developed in 1978 as a continuing database to replace special biennial condition studies that had been conducted by the States since 1965. The HPMS has been modified several times since its inception, most recently in 1998; changes in coverage and detail have been made since 1978 to reflect changes in highway systems, legislation, and national priorities, to reflect new technology, and to consolidate or streamline reporting requirements. The major purpose of the HPMS is to support a data driven decision process within FHWA, the DOT, and the Congress. The HPMS datasets are used extensively in the analysis of highway system condition, performance, and investment needs that make up the biennial Condition and Performance Reports to Congress. These Reports are used by the Congress in establishing both authorization and appropriation legislation, activities that ultimately determine the scope and size of the Federal-aid Highway Program, and determine the level of Federal highway taxation.

These data are also used for assessing changes in highway system performance brought about by implementing funded highway system improvement programs under the GPRA, and for apportioning Federal-aid Highway Funds to individual States under TEA-21. HPMS is a nationally unique source of highway system information that is made available to those

[37] MDOT 2013.

in the transportation community for highway and transportation planning and other purposes through the annual Highway Statistics and other data dissemination media. Additionally, many jurisdictions utilize this data in conjunction with real-time vehicle detectors to supplement volume/capacity data in support of congestion and travel time analysis and analyze locations to target enforcement of oversize/overweight vehicles.[38]

5.5 ROAD WEATHER INFORMATION SYSTEM

Road Weather Information System (RWIS) is an ITS subsystem expressly used to collect, analyze and report current roadway environmental conditions (e.g. pavement surface; moisture salinity, temperature, rate of cooling, etc.) and specific atmospheric conditions (e.g. ambient air temperature, precipitation, humidity, wind speed/direction, fog, etc.). MDOT maintenance garages use RWIS in combination with the data provided and analyzed by MDOT through the Maintenance Decision Support System (MDSS) primarily to deploy maintenance fleets for salting operations. This effective deployment operationally allows for reductions in staff time, idling emissions, fuel consumption and potential reductions in fleet maintenance. MDSS route monitoring also optimizes Winter maintenance operations including equipment/material usage.

5.6 ADVANCED TRAFFIC MANAGEMENT SYSTEM

MDOT's Advanced Traffic Management System (ATMS) software platform[39] integrates data from roadside sensors and third-party-provided traffic data,[40] and enables TOCs to adjust travel time estimates and dynamic message signs. Each Traffic Operations Center (TOC) location has a unique installation of the software and database management solution. It also controls/views CCTV cameras, collects truck parking availability data, border wait time data, supports integrated corridor management, as well as performance metrics on travel times and incident management.

This platform allows each TOC to more effectively manage and respond to highway incidents and to monitor the current health (e.g. performance measures)of the highway infrastructure. The system also supports

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[38] http://www.fhwa.dot.gov/policyinformation/hpms.cfm
[39] MDOT's ATMS is provided by Delcan.
[40] MDOT currently contracts with HERE (by Nokia) to obtain real-time traffic data.

management and monitoring of performance measures (e.g., travel time, incident management/number of incidence, capacity/flow rate, etc…).

5.7 DATA USE ANALYSIS AND PROCESSING

The Data Use Analysis and Processing (DUAP) program was initiated in 2006 to support federal ITS research by designing and deploying connected vehicle infrastructure and initial applications. The intent of the program is to support performance management by enhancing agency-wide usage of connected vehicle and mobile data and increasing data sharing, availability, and awareness across the agency. Now in a second phase, the DUAP2 system is intended to draw data from a variety of existing and potential data sources. The integrated system output would be returned to existing MDOT applications as an enriched data stream or could be used in new applications for MDOT.

The operational scenarios within the proposed DUAP2 system primarily consist of the ways that the systems will interact with each other and the external environment. For the data input environment, the data collectors read and process data from each source in its native format using existing communications infrastructure. An archival process also stores the collected data in its native format in a file tagged with the source and collection time for future retrieval and verification needs. Once the data is processed and stored in the back office system, it becomes available for access by the data output environment. The data applications previously discussed will allow users to interface with the system. They are configured to make requests to the system to access the data.[41]

5.8 VEHICLE-BASED INFORMATION AND DATA ACQUISITION SYSTEM

Vehicle-based Information and Data Acquisition System (VIDAS) will support DUAP2 applications by equipping MDOT fleet vehicles with an array of sensors. Some mobility data from instrumented vehicles will be sent to the DUAP-2 database in near-time via cellular links. Due to its large size and no need for real-time use, pavement asset data (accelerometer or distance measurement) will be transmitted utilizing Wi-Fi.

[41] Mixon Hill 2013.

This will allow MDOT to evaluate the performance and accuracy of roadway data for use in pavement condition and management, as well as roadway surface conditions (cracking, heaving, etc.). A visual assessment of pavement defects, can be collected via profilometry vans while collecting and analyzing pavement management critical elements. During pavement management analysis, International Roughness Index (IRI) values are determined from the datasets. As a final step in the project, MDOT will also compare visual observations to determine the accuracy of RWIS data. This data provides a longer-term opportunity to evaluate current conditions of travelled roadways and to manage effectively the roadway infrastructure from a pavement performance and system preservation perspective.

6 IMPLICATIONS OF EXISTING POLICIES, PLANS, AND ITS DATA SYSTEMS

Data and information management technology has advanced dramatically in recent years. As the number of tools and systems continue to increase, there are new opportunities to achieve operational efficiencies through data fusion and systems integration. Meanwhile, Michigan has established itself as a national leader in ITS, transportation asset management, GIS, and connected vehicle technologies. In continuing to develop its regional, statewide and national role as an innovative leader in technology, there are several opportunities for MDOT to leverage from the integration and aggregation of ITS subsystems. These opportunities include:

- Improved Safety of the Transportation Network
- Improved Mobility
- Improved Sustainability of the Transportation Network
- Reduced Fatalities
- Reduced Crash/Incident Related Injuries
- Congestion Management and Traffic Shaping/Smoothing
- Integrated Corridor Management (including alternate routing)
- Congestion Mitigation/Avoidance
- Signal Timing and Corridor Progression
- Improved Air Quality and Environmental Affects
- Work Zone Protection/Management
- Bridge Performance Validation and Load Rating Analysis
- Operations and Incident Management
- System Preservation
- Fleet Maintenance Management
- Dynamic Best Route and Work Scheduling for Fleet Trip Reductions
- Financial Programming/Investment Prioritization
- Business Intelligence/Data Mining
- Travel Patterns and Alternate Routing
- Legislative Metrics/Performance Metrics Analysis Dashboards
- Value Pricing
- Construction Management
- Lifecycle Infrastructure Management

6.1 POTENTIAL FOR ITS SUBSYSTEM INTEGRATION

Currently, MDOT's ITS deployments are generally single-purposed and non-integrated. Several systems are vended solutions requiring ongoing maintenance contracts for both licensing and continual operations. Additionally, several have some overlapping features/functions. This presents an opportunity for consolidation and reduction in long-term costs.

Most of MDOT's existing ITS subsystem datasets do not require substantial storage (approximately 30 Gigabytes (GB) or less annually). The DUAP2 subsystem, potential TAMS program, and any integration efforts undertaken to aggregate datasets within a larger data warehouse will change the storage requirements rather substantially (1-3 Terabytes (TB) approximately on an annual basis). Integrating the connected vehicle datasets into an effective enterprise data repository would significantly increase the size (15-25 TB annually based on the fleet and infrastructure device deployments). The primary drivers in this storage increase are the statewide/regional stakeholder orthophotography, integrated data between subsystems, and real-time data analytics/datasets from multiple vehicles (ongoing connected vehicle programs, infrastructure device deployments, and planned fleet integration/deployment). While the real-time connected vehicle datasets offer huge opportunities and rich information datasets, the ongoing trade-off will be costs associated with long-term storage, archival and data management practices.

Managing large quantities of information is both a system architecture (design premise) consideration and a technical challenge for storage, processing, and analytics. In combination, whether housed in a single repository or multiple, it requires constant monitoring and tracking of key performance indicators to ensure operational, cost and safety benefits for specific data systems. Data growth rate, cost in storage, backup/retention, data archiving/retention processes, and recovery management all require a comprehensive data management plan based upon input from key stakeholders on policy and system design/deployment.

6.2 ENTERPRISE DATABASE SYSTEM ARCHITECTURE

Data integration and repository data management create the best value and return on investment and must be based on the effective and efficient data management. Initially, database or repository design fundamentals need to be assessed and developed by determining and implementing tables and data stores with common similarity and function. As a secondary implementation, the repository design needs to be merged with common keys or data fields between datasets. Currently, the vast majority of transportation data has a direct spatial correlation; that is, the data is based on real-world positioning and GIS. While a number of these datasets have a geospatial correlation, very few of the larger cross-system datasets are merged/overlaid with the fundamental position or operations data and real-time traffic/connected vehicle datasets. Data fusion and integration methods could allow users to understand and interact dynamically with data in both time and position. They could then better support their decision support system/framework (best route, best time of day, alternate location, alternate mode, peak/off-peak pricing, etc.).

Efficient GIS-ITS data integration is complicated because GIS datasets are traditionally considered from a fixed-asset perspective (roadway, railway, signage, addresses, hydrographic features, bridges, etc.). Traditionally, the world of GIS data and management does not interact directly or consume production data directly from real-time ITS subsystems. Far too often, each agency takes responsibility for its own datasets and does not create or leverage operational agreements to share data or create a master data repository with appropriate failover/resumption designs.

As a key initiative outlined in the 2011 U.S. DOT's *Transportation for the Nation Strategic Plan*, data sharing and seamless information models should be a main directive for each state DOTs in order to achieve maximum cost-benefit.[42] Updates to the Highway Performance Management requirements from U.S. DOT/FHWA also include key positional, common link/node descriptions of infrastructure, and integration with vehicle classifications. Additionally, best practices guidance updates from FHWA and FTA for asset management data tracking and lifecycle maintenance include implementation with GIS, fixed assets and condition assessments to support funding and business intelligence analytics.

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[42] U.S. DOT 2011.

6.3 INTEGRATION WITH U.S. DOT CONNECTED VEHICLE PROGRAM AND TAMS

The U.S. DOT Connected Vehicle program is a distinct opportunity for MDOT to analyze asset datasets from vehicles and evaluate operational decisions. To be used effectively for data-mining, business intelligence, and secondary post-processing, connected vehicle data requires integration in an enterprise data warehouse. The potential of real-time datasets from connected vehicles to improve safety, mobility, and sustainability of the transportation infrastructure/network is significant.

A concerted effort amongst enterprise stakeholders is required to establish an official Enterprise Architecture and Data Model/Information Exchange between existing and planned systems. Such an effort should be a fundamental and key objective for developing the Transportation Asset Management System (TAMS).

6.4 STAKEHOLDER PERSPECTIVE

As part of this project, we reached out to a number of agency stakeholders, several of whom provided feedback in data use and ITS data interviews. We successfully discussed data initiatives and systems implementation with a number of people regarding ITS subsystem maintenance, management and data practices for this report. Key stakeholders within the region that would benefit from the combined dataset would be MDOT, U.S. DOT, DTMB, Southeast Michigan Council of Governments (SEMCOG), Road Commissions, *Michigan Geographic Framework* (MGF), first responders, as well as other regional and state agencies.

The theme arising from the discussions is that the data collected today/currently has value and use, but trending and analytics is not performed often nor easily. Many datasets are very single-ended with distinct purpose (e.g., evaluation of weather data or signal timings). There is not a universal view of data across ITS subsystems or datasets. Most agencies are not handling data in support of, or integrating with, asset management or business intelligence. The smaller agencies have a better intra-agency relationship with access to quality IT assistance, and an ability to strategically implement programs and/or new initiatives. Larger agencies are hamstrung by bureaucratic process and limited technology support. Nevertheless, most agencies are generally looking for approval of new initiatives through a budget, or executive approval, prior to attempting any integration or asset management approach.

6.5 LONG-TERM STRATEGY

Inter-agency relationships are often subject to funding issues and effective talent pools for new or expanded technology initiatives. The stove piping of implementation teams and divisions is a key breakdown area within many DOTs. A top-down overhaul and renegotiation of services, support, and performance measures with IT and DOT business units during project deployments and system integration should be a priority for MDOT. Over time, it may become more effective for DOTs to implement a strategic data user group,[43] to guide and conceptualize best practice opportunities to fuse data between disparate systems and discuss prioritization and return-on-investment opportunities.

In the long-term, it will be advantageous for MDOT to consolidate the array of disparate ITS subsystems and data sources into a single platform and data repository. MDOT and DTMB are currently focusing on this approach in the development of a future Transportation Asset Management System (TAMS).[44]

[43] For example, such a group may include two key stakeholders from each Division within a DOT, or two key staff members from Operations, IT, Division Units, and Executive Leadership.
[44] MDOT 2013.

7 CONCLUSIONS AND RECOMMENDATIONS

To effectively capitalize and leverage new opportunities, MDOT should utilize the developing Transportation Asset Management System (TAMS) project to develop a statewide master/strategic plan for database aggregation across ITS subsystems and programs. This strategic plan would facilitate and establish the framework for an enterprise data warehouse integrating GIS, Asset Management and ITS datasets. Each information model (GIS, TAMS, ITS, etc.) should contain best practices for database schema design and integration, leveraging a core geospatially enabled and accurate base map (centerline and cadastral data layers), which are effectively maintained through the MGF. Statewide Light Detection and Ranging (LIDAR) and Orthophoto datasets should be collected on an annual or semi-annual basis. Once the data are collected, they should be integrated with the baseline GIS data model within the data warehouse. This can be purchased commercially. However, the decision should be based on an evaluation of use and technical requirements in combination with operational budget resources. Direct integration with the enterprise data warehouse is recommended, not replication through secondary systems, as shown in Figure 6.

Once a migration plan is established, the enterprise data warehouse hardware and software should be procured and setup. Viable enterprise database management software that supports native high-availability clustering should be a priority. At this scale, ideally it would be an open-source solution (like MySQL or MongoDB) in place of any licensed commercial products. As an initial proof-of-concept, these open-source solutions are an opportunity for MDOT to evaluate a limited group of key stakeholders within the department. Ideally, this would be implemented under the auspices of a data management committee who would evaluate open-source industry tools on an annual basis.

Data aggregation should be undertaken in a series of phases by ITS subsystems and performed based on prioritization of the datasets. Based on the initial projections, the hardware and database type required to perform under this load condition would most likely be Oracle or DB2 running on dedicated application hardware with a separate storage platform/architecture. Data aggregation would be best served by integrating real-time data (one per minute or one per five-minute intervals) from key ITS subsystems, with a retention period of 45 days being represented as current data.

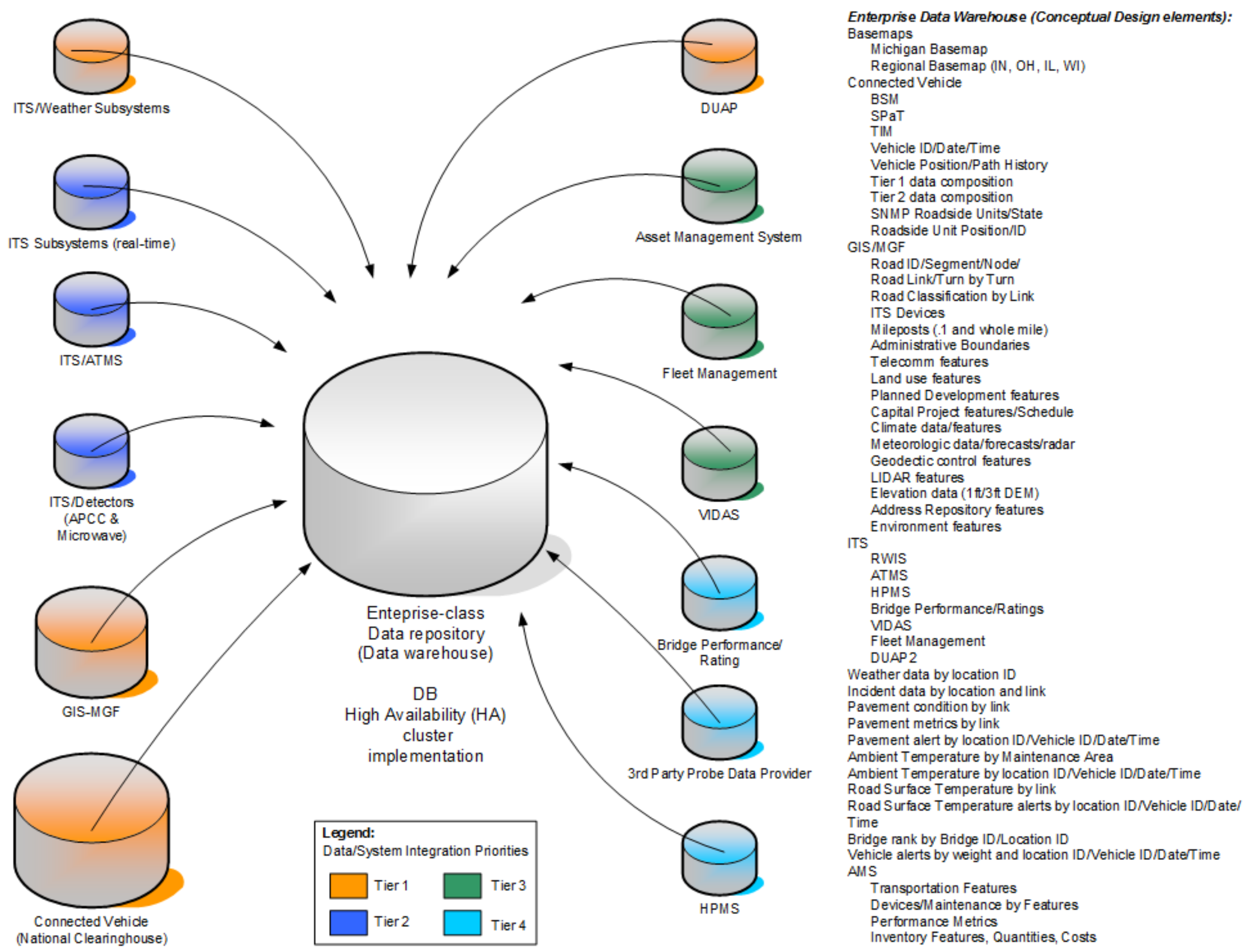
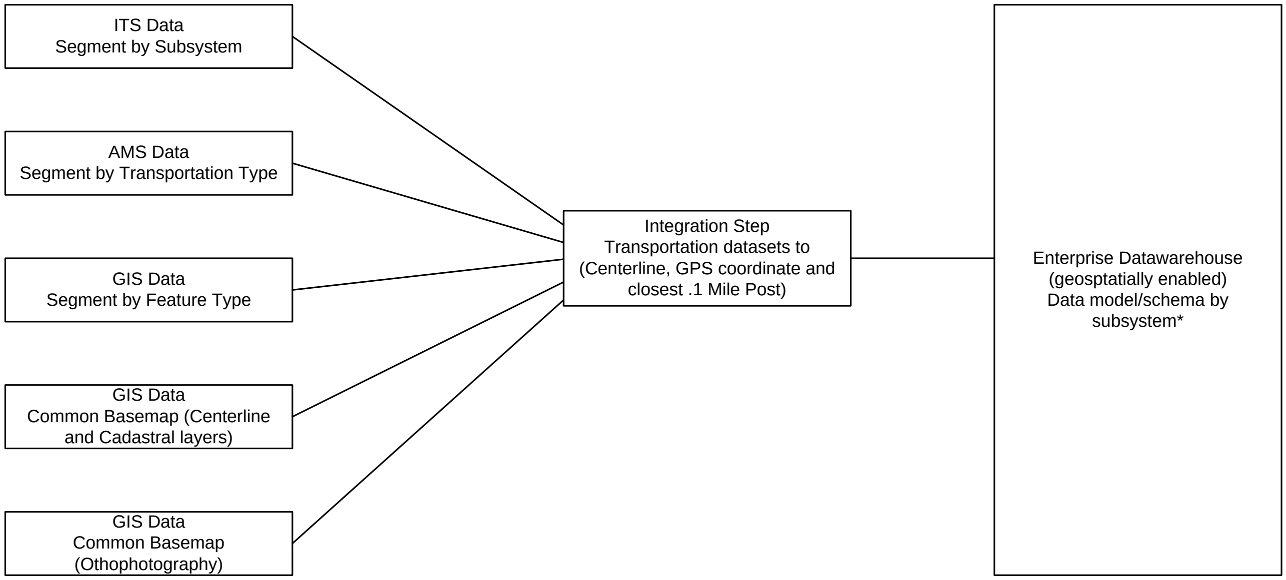


FIGURE 6: CONCEPTUAL FRAMEWORK OF ENTERPRISE DATA WAREHOUSE

After 45 days, data should be stored for trending and current analysis due to recent occurrence. After 12 months, data should be moved on an annual basis to secondary storage disks to allow for rapid access but represented as archival. This would allow for longer-term business analytics and metrics analysis/trending. Once data is past five years old, it can be permanently archived to a hierarchical storage platform for periodic use and access. Use of this methodology of storage and database record management would allow MDOT to cost effectively integrate ITS subsystems into an enterprise data warehouse with an effective data storage solution.

The information model is a conceptual model based on the integration of ITS subsystems and integrated into an enterprise data warehouse. The information model is outlined in Figure 7.



*Note: To properly scale and design the enterprise data warehouse, data schema and documentation are required for each of the current and planned ITS subsystems. Data dictionaries supplied by vendors would be very helpful in determining the final schema.

FIGURE 7: INTEGRATION OF ITS SUBSYSTEMS

The enterprise data warehouse would best be geographically dispersed within the State as regional nodes within a Database Management System (DBMS) High Availability (HA) Cluster. The DBMS HA cluster nodes support single database instance with availability between facilities in the event of a node or server failure. This design architecture creates a fault-tolerant enterprise solution for the data warehouse instance. This clustered design premise would support real-time database updates from SQL triggers or dynamic data replication per each ITS subsystem into the enterprise data warehouse information model. The hierarchical storage would become an integrated component and directly attached to each DBMS cluster node using a NetApp Scalar storage appliance or similarly performing device. This allows for the database to utilize the storage tiers directly while maintaining performance, data hierarchies, and archival processes.

Data security and privacy are large and distinct concerns of both the public at-large, key stakeholders, and funding providers. Long-term, the best practices outline encryption methods such as Secure Sockets Layer (SSL) with active wildcards certificates across the application-tier on the front-end applications. For any implementation of an enterprise data warehouse, MDOT should implement security practices with their network domain (Lightweight Directory Access Protocol (LDAP), Virtual Private Network (VPN), Public

Key Infrastructure (PKI) systems), with regimented database and web application patch management practice, and maintain both hardware/software security devices (e.g., load balancers, web application firewalls, firewalls, DeMilitarized Zone (DMZ), etc.). These practices will support a substantial architecture and leverage the most value from connected vehicle datasets.

Each ITS subsystem should have a full legal review to determine the current rights and restrictions for use, data, database schema, and data publication. If any of the license agreements are too restrictive to support data integration and the eventual enterprise data warehouse, ongoing maintenance contracts should be re-negotiated to include more favorable terms for data use/publication. An MDOT data use and integration policy should be developed in conjunction with IT, legal, and other key stakeholders and then published as part of any future systems that uses or reports data from these integrated components.

Additionally, as a key lesson learned from vendor deployed systems, several issues need to be agreed upon in contract prior to system/solution procurement. First, data use agreements must include data warehousing/integration and publication/re-distribution both internally and externally to MDOT without excess fees or license cost. Second, each vended solution must be turned over to MDOT at Acceptance Testing with a full data dictionary and database entity relationship diagram of the database deployed for each ITS subsystem. These conditions will enable MDOT to utilize the disparate ITS subsystem data effectively, without requiring database schema reverse engineering or substantial database analysis to determine the schema implemented by the vended solution.

In summary, Michigan has a distinct leadership role and opportunity to realize the safety, mobility, environmental, social, and personal/business benefits through advanced ITS data management practices. By continuing to commit to this leadership role in national efforts to develop and deploy connected vehicle and ITS technology, Michigan will have a significant role in shaping the future of transportation and infrastructure management. Through its leadership and implementation expertise, MDOT will be well positioned to reap the benefits of becoming the recognized home of this technology. These benefits could include early deployment and associated lives saved, as well as thousands of jobs within the automotive and transportation industries, and reduced capital costs for operations and ongoing maintenance of the transportation network.

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APPENDIX A: LIST OF ABBREVIATIONS

AMS	Asset Management System
ATMS	Advanced Transportation Management System
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partnership
CAR	Center for Automotive Research
CAV	Connected and Automated Vehicle
CCTV	Closed Circuit Television
D^2ITS	Data-driven ITS
DAS	Data Acquisition System
DB	Database
DBMS	Database Management System
DCM	Data Capture and Management
DMA	Dynamic Mobility Applications
DMZ	Demilitarized Zone
DOT	Department of Transportation
DSRC	Dedicated Short-range Communication
DTMB	Department of Technology, Management, and Budget
DUAP	Data Use Analysis and Processing
EAMS	Enterprise Asset Management System
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GB	Gigabyte
GIS	Geographic Information System
GIS-T	GIS-Transportation
HA	High Availability
HPMS	Highway Performance Monitoring System
HRSA	Health Resources and Services Administration
IP	Internet Protocol

IRI	International Roughness Index
IT	Information Technology
ITS	Intelligent Transportation Systems
LAN	Local Area Network
LDAP	Lightweight Directory Access Protocol
MDOT	Michigan Department of Transportation
MGF	Michigan Geographical Framework
OEM	Original Equipment Manufacturer
OLAP	Online Analytical Processing
OST-R	Office of the Assistant Secretary for Research and Technology
PB	Parsons Brinkerhoff
PBOS	Performance-based Operational System
RITA	Research and Innovative Technology Administration
PKI	Public Key Infrastructure
RSE	Roadside Equipment
RWIS	Road Weather Information System
SDW	Spatial Data Warehouse
SEMCOG	Southeast Michigan Council of Governments
SLRP	State Long-range Plan
SOLAP	Spatial Online Analytical Processing
SPaT	Signal Phase and Timing
SQL	Structured Query Language
SSL	Secure Sockets Layer
STIP	State Transportation Improvement Program
STOLAP	Spatial-Temporal Online Analytical Processing
T	Terabyte
TAMS	Transportation Asset Management System
TMS	Transportation Management System
TOC	Traffic Operations Center

U.S. DOT	United States Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VPN	Virtual Private Network
VIDAS	Vehicle-based Information and Data Acquisition System