VII Data Use Analysis and Processing

CONCEPT OF OPERATIONS

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Abstract

The Michigan Department of Transportation (MDOT) Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing (DUAP) Concept of Operations (ConOps) documents the opportunities and benefits to MDOT of acquiring and using VII data in the management and operations of Michigan's transportation systems. The ConOps provides a link between MDOT's VII Strategic and Business Plan and the development of systems to implement that plan. The ConOps describes the existing systems relevant to transportation operations data; establishes the case for change; describes the capabilities and features of the proposed system; and discusses scenarios illustrating future system operation. The document will be used by MDOT to facilitate communications on VII and transportation operations with its stakeholders and partners and as a basis for generating more detailed user needs and expectations for VII data, use, and processing.

Table of Contents

Table of Figures

Table of Tables

Revision History

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01.00	5/25/2007	Draft		Initial working draft
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1 SCOPE

1.1 Identification

This document describes the Concept of Operations (ConOps) for the Michigan Department of Transportation's (MDOT's) Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing (DUAP) project. The ConOps document describes the current state, establishes the case for change, and describes the proposed system in terms of its features and operations.

1.2 Background

Advances in information and communications technology over recent decades have created the potential for vehicles themselves to become active participants in the management and operations of the transportation infrastructure. Whereas traditional roadway infrastructure and traffic controls are independent of the controls within a vehicle, VII initiatives are aggressively pursuing opportunities for the sensors and controls on vehicles and the roadway to work together.

Federal, state, and local agencies and private commercial stakeholders are working together to evaluate and promote the VII opportunities. To this end, the U.S. Department of Transportation (USDOT), MDOT, other state and local agencies, the Vehicle Infrastructure Integration Consortium (VIIC), and industry associations have established a network of common interests and a process of mutual investment and support intended to develop and realize the potential of VII. The efforts of these participants over the last several years have resulted in a common vision and plan; opportunities for public information and involvement; and the beginnings of a technical (and economic) framework.

MDOT is leading the way among state agencies and has produced a "Vehicle-Infrastructure Integration Strategic and Business Plan" (Ref. 13) that lays out the vision and action plan for VII development in Michigan. The plan describes the institutional relationships, outreach, and technical developments that will be needed to develop and deploy VII. The DUAP project brings together much of the technical development called for in the plan.

The specific purpose of the DUAP project is to support MDOT and its partners in evaluating uses and benefits of VII-related data in transportation agency management and operations. As such, the project complements parallel efforts of MDOT, USDOT, VIIC, and others to design and deploy the VII network[1], vehicle equipment, and initial applications. The DUAP project builds on that foundational work to investigate how the availability of data from VII-equipped vehicles throughout the road network may impact the ways transportation agencies do business. The project will focus specifically on data uses and benefits in responding to safety concerns, managing traffic, and managing MDOT's

[1] Throughout the ConOps, the term "VII network" should be understood to refer to a VII network based on the USDOT's VII National System Requirements.

transportation assets. The work will also support the other VII activities, technology development for MDOT, and economic growth for the state.

The key tasks within the DUAP project are:

- to identify uses for the VII data;
- to develop algorithms to use and process the VII data;
- to develop prototype applications and data management software; and
- to evaluate how well the data and the algorithms function in a department of transportation.

As illustrated in Figure 1, it is envisioned that a DUAP system will draw data from existing MDOT data sources and other relevant data sources to be integrated with VII data. The integrated system output could be returned to the existing MDOT applications as an enriched data stream or could be used in new applications for MDOT. Other MDOT projects may have influence on or facilitate the data integration. Applications outside MDOT could get data through a new MDOT gateway application.

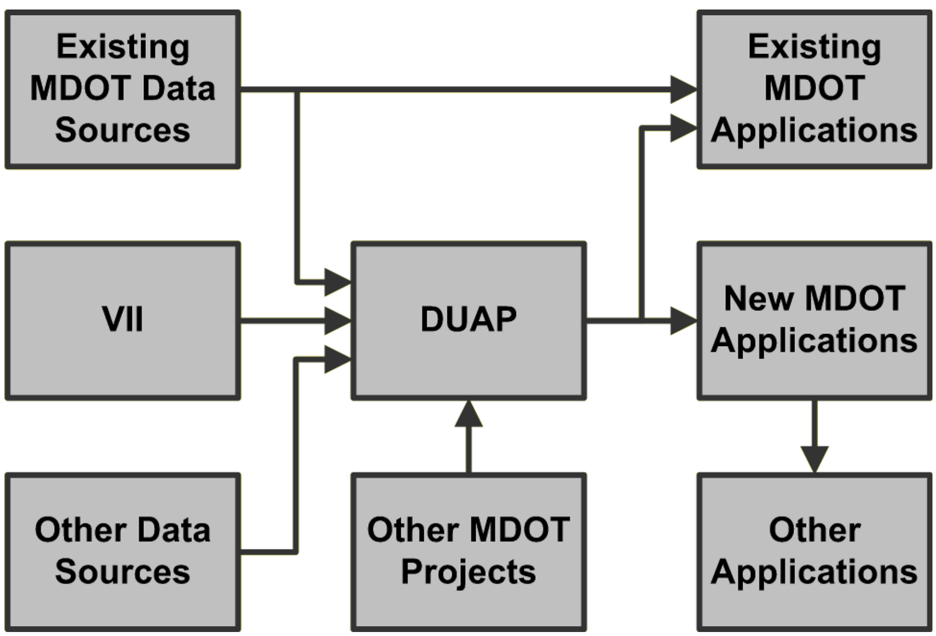


Figure 1 – DUAP Data Flows

1.3 Document Overview

This document consists of the following sections and content:

Section 2 (Current Systems and Situation) of the ConOps describes the current state of the system or situation (either automated or manual). When systems or functionality do not currently exist, the document describes the situation that motivates development of the proposed system.

Section 3 (Case for and Nature of Changes) describes the rationale, justification for, and nature of the proposed changes. This section identifies the shortcomings, if any, of the existing situation and the opportunities and benefits of change.

Section 4 (Concepts for the Proposed System) describes the proposed system that results from the desired changes. This is, necessarily, a high-level description, indicating the operational features of the system when fully deployed. This represents a long-term vision, and the initial deployment may not include all of the features or components described therein.

Section 5 (Operational Scenarios) of the ConOps contains operational scenarios for the system. A scenario is a step-by-step description of how the proposed system might operate and interact with its users and its external interfaces under a given set of circumstances. The scenarios tie together all parts of the proposed system, the users, and other entities by describing how they interact in a particular context.

Section 6 (Summary of Impacts) of the document describes the operational impacts of the proposed system on the users, the developers, and the support and maintenance organizations. This section may also identify temporary impacts of the transition from the old system(s) to the new system.

Section 7 (Analysis of the Proposed System) discusses the benefits, limitations, advantages, disadvantages, alternatives, and trade-offs considered for the proposed system. In the context of this document, alternatives are *operational* alternatives and not *design* alternatives (which would be considered in a Systems Engineering Analysis, if appropriate).

Appendix A (Definitions, Acronyms, and Abbreviations) provides definitions for the terms, acronyms, and abbreviations used throughout the document.

Appendix B provides an extensive list of references for the document.

1.4 Referenced Documents

Full citations for the documents referenced in this ConOps can be found in Appendix B, which also includes documents that have not explicitly been referenced, but contain additional information relevant to the project.

2 THE CURRENT SYSTEMS AND SITUATION

This section describes the current state of data use, analysis, and processing in MDOT transportation management and operations.

2.1 Background, Objectives, and Scope

The mission of MDOT is to provide the highest-quality integrated transportation services for the economic benefit of, and improved quality of life throughout, the State of Michigan (Ref. 15). MDOT strives to be aware of what its customers and stakeholders want and need from Michigan transportation systems. It does that by providing leadership and support for all aspects of a comprehensive integrated transportation system that is:

- Efficient,
- Effective,
- Safe,
- Socially and environmentally responsible,
- Responsive to current and future needs, and
- Supportive of economic growth.

MDOT further recognizes that these ends are best achieved in partnership with other stakeholders who desire the development and operation of an innovative and integrated transportation system. To that end, MDOT has developed an extensive network of working and data-sharing relationships with other Michigan state agencies and departments; regional, county, and local transportation and planning agencies; emergency services; and private providers of transportation services and information.

MDOT and its partners work together in achieving its objectives through a diverse set of processes and systems. The potential applications of VII-originated data are so broad that almost any of these existing processes or systems might be affected. As such, the scope of review of the current state intends to include all major information systems related to transportation management and operations.

2.2 Operational Policies and Constraints for Data

In the current operating environment, policies around the acquisition and use of data from the transportation network are focused on security, ownership, and redistribution. While it is an inherent part of MDOT's mission to provide the public with timely and accurate information on the state of the transportation network, there are limitations on the content and manner of distribution. As described in Section 2.5, the Michigan Department of Information Technology (MDIT) maintains policies and procedures for the management of data and applications that apply to all MDOT systems. MDOT and its partner transportation agencies also have various contracts for transportation information services that include provisions on the use and redistribution of information obtained through those services.

The use, analysis, processing, and redistribution of transportation system information are also constrained by technological and financial resources. While most of MDOT's operations are assisted by some data automation, there are varying degrees of systems integration within and between transportation agencies. This may be due in part to institutional constraints and technology limitations, but is likely aggravated by competing demands for funds.

2.3 Description of the Current Situation

2.3.1 Processes and Activities

Given the breadth of potential applications of VII data, it is important to review the scope of transportation agency activities where greater data availability might be beneficial. Figure 2 illustrates the key high-level processes in MDOT operations as captured in stakeholder meetings and follow-up reviews.

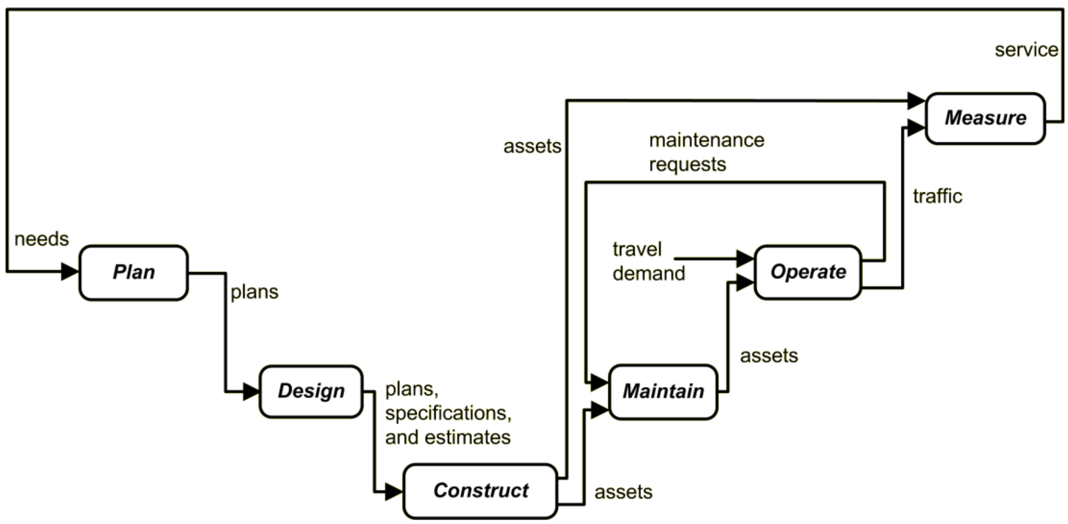


Figure 2 – MDOT Processes

2.3.1.1 Plan

Planning activities within MDOT are generally focused on development of programs and projects for fulfilling customers' travel needs within the constraints of available funding and resources. Within that scope of services, activities may specifically include:

- Establishing system performance objectives and measurements;
- Identifying deficiencies within and potential enhancements to the transportation system based on established performance measurements;
- Establishing strategic and long-range plans;
- Developing state transportation improvement programs and plans to improve deficiencies and implement enhancements to the system;
- Selecting projects and obligating funds; and
- Implementing and overseeing programs.

2.3.1.2 Design

Design activities within MDOT are focused on steps necessary to design transportation projects that have been established by the planning process. Activities may include:

- Acquiring aerial mapping photography and producing topographic maps to be used for design/construction documents of transportation projects;
- Accumulating survey data for the use of Project Development, Road and Bridge Design Units, and the Real Estate Support Area;
- Providing engineering data regarding utilities, drainage, and roadside development to be used for design documents of transportation projects;
- Developing and organizing project study procedures and overseeing multi-discipline project investigations to obtain engineering, planning, and environmental data for analysis;
- Preparing construction plans and related contract documents for the construction/reconstruction of state highways, bridges, and related structures;
- Assuring plans and proposals are prepared in conformance with Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO), and MDOT design procedures, principle standards, and specifications;
- Coordinating and implementing automated engineering systems and standards; and
- Administering the federal and state aid programs for local agencies.

2.3.1.3 Construct

Construction activities at MDOT are primarily those necessary to build projects that have been planned and designed by MDOT or its consultants. Activities include:

- Developing and distributing construction specifications;
- Developing and distributing field consultation standards and performing associated training; and
- Overseeing construction projects.

2.3.1.4 Maintain

Maintenance activities at MDOT ensure that the departmental resources are properly utilized after the projects have been constructed. Activities include:

- Developing and implementing the Capital Preventative Maintenance Program;
- Allocating and dispatching departmental resources to resolve problems identified along the transportation assets;
- Managing materials;
- Preserving infrastructure;

- Performing winter maintenance;
- Inspecting bridges and bridge supports; and
- Maintaining, updating, and reporting from the bridge structure inventory database.

2.3.1.5 Operate

Operations activities make sure that MDOT's assets are being properly utilized. Activities may include the following:

- Controlling access to transportation systems;
- Directing flow within the transportation systems;
- Assuring traffic safety;
- Identifying and removing obstacles on the systems' right-of-way;
- Optimizing the efficiency of traffic flow on signalized arterials; and
- Providing traveler information.

2.3.1.6 Measure

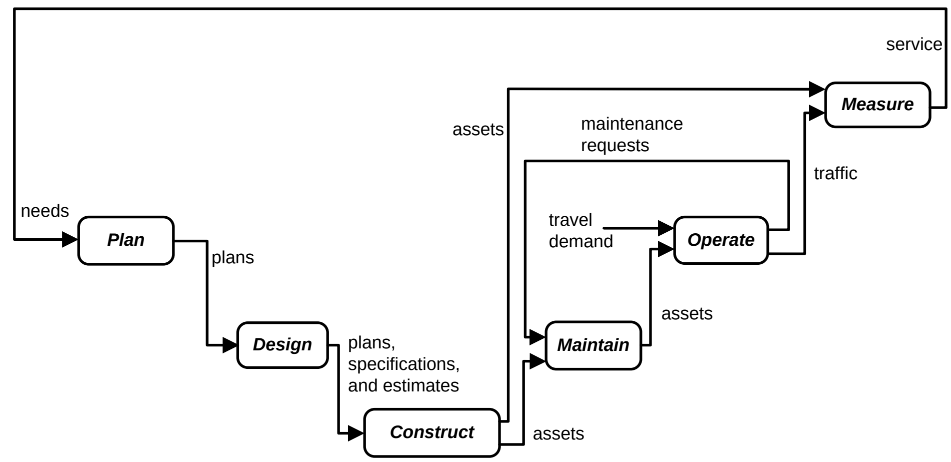
Although MDOT currently has over 100 performance measures, the Department has selected a core set of fourteen measures (Ref. 7) that are used in a crosscutting or matrix fashion, meaning that rather than being tied to one specific goal area like Safety or Mobility, individual measures are viewed as indicators of progress toward all goal areas. Activities related to data that might be enhanced in the DUAP project include:

- Evaluating roadway pavement conditions such as ride quality, crack severity, and rutting;
- Evaluating bridge conditions throughout the state;
- Acquiring traffic and incident data for assessing system-wide safety performance; and
- Measuring highway congestion and assessing capacity for additional traffic growth.

2.3.2 Existing Systems and Interfaces

There are many existing MDOT and partner agency systems and interfaces using data gathered by staff and contractors, roadway sensors, signal systems, and on-board sensors. Many of these data sources will be supplemented or replaced by VII-derived data. Some of these systems are illustrated in relation to MDOT business processes in

Figure 3. This section describes the existing systems and interfaces as a basis for understanding and anticipating the potential for VII enhancements to MDOT data flows.



Planning Systems and Tools

Internal
- TMS
- MTPP
- MDOTBP
- SLRP
- STIP
- 5 Yr Plan
- P/PMS

External
- Paramics
- Vissim
- SimTraffic
- Synchro

Design Systems and Tools
- ProjectWise
- MFOS
- MPINS

Construction Systems and Tools
- ProjectWise
- SWAD
- Field Manager

Maintenance Systems and Tools
- Maintenance System
- TSCs

Operations Systems and Tools
- ATMS
- EMS
- Advanced Transit Management
- CVO
- ATIS
- AVSS
- Courtesy Patrols

Measurement Systems and Tools
- ADMS
- TMS
- TMS/H (HPMS)
- Data Collection System

Figure 3 – MDOT Business Processes with Supporting Systems and Tools

2.3.2.1 Operations Centers

Intelligent Transportation System (ITS) technology for MDOT in Southeastern Michigan is coordinated through the Michigan Intelligent Transportation Systems (MITS) Center. The MITS Center monitors 200 miles of freeway, with 165 closed-circuit television (CCTV) cameras, 64 dynamic message signs (DMSs), one overheight detection system, one speed warning system, and 99 vehicle detection stations. The integrated software system includes incident management functions and Advanced Traveler Information System (ATIS) technology. An expansion of the system will add eighteen CCTV cameras, seven DMS, and up to 53 vehicle detection stations. The center is co-located with a Michigan State Police (MSP) 911 center, which allows for easy facilitation of incident management. The MDOT MITS Center staff includes two operators, a courtesy patrol coordinator, and a construction coordinator. A nearby media room allows for the easy distribution of traffic information to the public via radio, television, and the Web.

An additional traffic management center (TMC), the Western Michigan Traffic Management Center, is located in the greater Grand Rapids area. This traffic system manages 22 miles of freeway in the Grand Rapids area with seventeen CCTV cameras, 10 DMS, and four variable speed limit signs.

In addition to the MDOT centers, some counties have their own traffic operation centers (TOCs). The Road Commission for Oakland County (RCOC) has a TOC connected to the MITS Center through a center-to-center link to facilitate area-wide management of traffic across jurisdictions. A coordinated traffic signal system, called FAST-TRAC (Faster and Safer Travel through Routing and Advanced Controls), has been implemented to control congestion on county arterials. System computers monitor traffic flow and adjust traffic signal timing to balance flow throughout the system. The FAST-TRAC system archives detailed data from the signalized intersections for future analysis.

RCOC also has a road weather information system (RWIS) that provides weather data as recorded at the location of their three environmental sensor stations (ESS). The ESS observe the following information:

- Air temperature;
- Amount and type of precipitation;
- Visibility;
- Dewpoint;
- Pavement surface temperature and condition; and
- Wind speed and direction.

The Road Commission of Macomb County (RCMC) TOC has access to approximately 175 signalized intersections within the county. The staff is able to view traffic signal areas in real time to better anticipate and mitigate traffic congestion and to allow the adjustment of signal timing to aid in redirecting traffic. In addition, the staff is able to detect, analyze, and repair signal malfunctions in a timely manner. There are plans to expand the system to include more vehicle detection stations and to automate signal systems to adjust to changes in traffic patterns.

2.3.2.2 Asset Management Systems

MDOT uses the Transportation Management System (TMS) to manage assets. The system is composed of six components or subsystems:

- Bridge Management System;
- Pavement Management System;
- Congestion Management System;
- Public Transportation Management System;
- Intermodal Management System;
- Safety Management System; and
- Traffic Monitoring System.

These subsystems share a common database, a common set of decision support tools and functionality, and the use of a robust and consistent user interface.

Bridge Management System
The Bridge Management System (BMS) is an important part of MDOT's overall asset management process. The BMS includes an Oracle database that stores

transportation asset inventory for bridges and culverts throughout the state. The database structure is compatible with the AASHTO Pontis bridge management system. The BMS is the decision-support tool responsible for managing the inspection, analysis, and maintenance of the numerous components that make up a bridge.

The Michigan Bridge Reporting System (MBRS) is a Web-based software application built into the Bridge Operations Web site. It is a portal for viewing bridge data and is used to allow non-MDOT entities, including local agencies and consultants, to obtain bridge inspection data in meaningful reports.

The Michigan Bridge Inspection System (MBIS) is a Web-based software application built into the Bridge Operations Web site. MBIS was developed to help MDOT maintain the many bridges and culverts throughout the state, to comply with federal inspection requirements through the National Bridge Inspection Standards (NBIS), and to gather data useful for other divisions within MDOT. MBIS helps to improve communication between local agencies and MDOT and to streamline the process of collecting and distributing data pertaining to bridge safety and project development. MDOT and local agencies are required to perform bridge inspections, the results of which are compiled by MDOT and submitted to the FHWA. Bridge inspectors are the direct customers for the MBIS system. Indirect customers include MDOT staff involved in the design, development, and construction of bridges and culverts.

The Fabrication, Inspection, and Construction System (FICS) is the inspection reporting Web-based system that collects quality assurance inspection reports for bridges and ancillary highway products during the fabrication and erection process. The reports are archived in a database for material acceptance and historical retrievals for project payment and documentation. FICS also ties reports to inspector's time sheets and invoices for Web-based payment purposes.

The Bridge Condition Forecasting System (BCFS) is a bridge-network condition forecasting tool used to develop preservation policies. The BCFS-generated estimate is based on the National Bridge Inventory (NBI) condition ratings, bridge deterioration rate, project cost, expected inflation, and repair strategies.

Pavement Management System

The Pavement Management System (PMS) is used to perform a variety of engineering and planning functions. These include forecasting future network pavement conditions and costs associated with implementing various pavement repair strategies. Two different types of evaluation systems are used. Annually a survey is made of the entire state system by a subjective, visual means. Every two years, a detailed inspection of the pavement condition is made by using specially equipped vehicles to take measurements and record data. The Pavement Preservation Program (PPM) uses the information provided by the PMS to assist staff in determining the appropriate “fix” for a stretch of pavement.

Congestion Management System

The Congestion Management System (CMS) provides access to current system level conditions and identification of current and future congested roadways. It also incorporates travel demand forecasting capabilities for 14 urban and numerous rural areas throughout Michigan to assess transportation system performance and to identify areas with unacceptable performance.

Within the CMS, users can identify specific locations where congestion occurs or is expected to occur. The supporting database incorporates historic traffic data and future traffic forecasts from both the statewide and urban area models. The CMS also provides access to historic and forecasted socioeconomic data from the U.S. Census. Socioeconomic data are stored at both the traffic analysis zone and county levels.

The CMS provides summary statistics and performance measures for user-selected routes by geographical area or by any of several road classification systems. Many performance measures and indicators are available and can be used to measure progress toward meeting the goals and objectives of the State Long-Range Plan (SLRP) and long range plans of regional and metropolitan planning agencies.

Public Transportation Management System

The Public Transportation Management System (PTMS) provides access to data regarding public transportation ridership, finance, vehicles, and performance. PTMS includes a comprehensive list of about 100 Michigan transit agencies, with specific information such as the names of contact people, mail and e-mail addresses, phone numbers, and services provided. PTMS also includes a statewide vehicle inventory used for forecasting needs and a financial database used for both budgeting and obtaining state funds. The Annual Application module contains capital items requested by transit agencies (during their yearly application process) as well as their operating request (budget). The Vehicle Inventory module contains pertinent data about the vehicles owned by an agency. The Equipment and Facility Inventory modules are not currently in use, but they will contain related data about any agency's equipment valued at over $5,000 and any facilities it owns or leases. The Operating Assistance Report module contains budgeted, quarterly, annual (reconciled), and audited financial data as reported by the transit agencies. Reporting of this data is required for agencies to receive state and federal funds.

Intermodal Management System

The Intermodal Management System is a data management and information analysis tool, used to access facts necessary to support decisions involving passenger and freight access to and movement by air, marine, non-motorized, or rail transport. It is designed to support the day-to-day functions of modal specialists, while providing user access to data on intermodal assets.

Within this system, a transportation asset is considered to be any facility, segment, property, or service on which MDOT or its government partners expend funds or to which access is provided. Assets are divided into three groups:

- Facilities: sites specifically intended to provide for the transfer of people and/or goods from one segment of the transportation system to another.
- Segments: the modal connections by which people and/or goods are moved between intermodal facilities and other points.
- Services: scheduled movements of groups of people over the transportation system between facilities.

Safety Management System

The Safety Management System (SMS) is the decision support tool responsible for analyzing vehicular crashes and the roads on which they occur. The SMS pulls data about traffic incidents from the Traffic Crash Reporting System (TCRS). The SMS provides identification, analysis, and implementation of engineering improvements at locations with a high number of crashes.

Traffic Monitoring System for Highways

The Traffic Monitoring System for Highways (TMS/H) is MDOT's program for traffic information. TMS/H meets the FHWA requirements identified in the Traffic Monitoring Guide and the Highway Performance Monitoring System (HPMS) for collecting and reporting traffic information to the FHWA.

MDOT's TMS/H covers traffic data collection, processing, storage, and reporting of traffic information on the state trunkline system. The TMS/H includes data from both short term (typically 48 hour) recorders and permanent traffic recorders.

Short term information includes:

- Traffic volume counts broken into 15 minute and hourly traffic volumes and
- Hourly volumes for each of 13 vehicle type classifications.

Permanent Traffic Recorder (PTR) information includes:

- Continuous traffic volumes of all vehicles;
- Continuous hourly volumes for each of 13 vehicle type classifications;
- Continuous hourly volumes by 15 bins of speed groupings;
- Continuous data collection for truck information such as axle weights and spacing; and
- Station location data identifying the location of the traffic data.

There are approximately 135 PTRs that collect traffic volumes and approximately 40 that collect vehicle classification and truck weight data. Typically, more than 3500 short term volume and classification studies are conducted each year.

The data are stored in an Oracle database. Internal applications allow the database to be updated and maintained, and external applications provide user access to the database. Volume and classification data are retained for ten years, and three years of truck weight data are actively available to the user. Older data are archived "off-system".

2.3.2.3 Other MDOT Tools

MDOT uses a variety of planning tools. These include:

- Michigan Transportation Policy Plan;
- MDOT 2006 Strategic Plan;
- MDOT VII Strategic & Business Plan;
- State Long-Range Plan;
- State Transportation Improvement Program (STIP);
- Five-Year Road & Bridge Program; and
- Program/Project Management System.

Traffic simulation tools used by MDOT to model various traffic scenarios include:

- Paramics;
- Vissim;
- SimTraffic; and
- Synchro.

During design and construction, two different tools are used by MDOT to keep projects on track. The first is TRANSPORT, which consists of four parts:

- Proposal and Estimates System;
- Letting and Award System;
- Construction Administration System; and
- Decision Support System.

The second tool is Field Manager, which is a construction field office system.

MDOT also has access in some locations to the MSP's computer-aided dispatch (CAD) system. Local governmental entities have a 911 system and then transfer calls as necessary to the MSP.

MDOT and its transportation agency partners provide information for the traveler on various Web sites. The traveler is able to find information on incidents such as road construction and lane closures.

2.3.2.4 Michigan Center for Geographic Information Framework

The Michigan Center for Geographic Information (CGI) provides leadership, technical expertise, and policy for the acquisition, development, use, dissemination, promotion, and sharing of geographic information in the state of Michigan.

The Michigan Geographic Framework (MGF) is a digital base map for use by state government. It includes the ability for partner agencies to assist with updates based on data from their business applications. The availability of a common digital state map allows for improved communication and coordination between various transportation agencies.

2.3.2.5 Southeast Michigan Snow and Ice Management

The Southeast Michigan Snow and Ice Management (SEMSIM) project joins the RCOC, RCMC, Wayne County Department of Public Services, the City of Detroit, and Suburban Mobility Authority for Regional Transportation (SMART) in a partnership. The SEMSIM project has equipped snow plows/salt trucks from all four jurisdictions with:

- Satellite-based global positioning system (GPS) vehicle tracking devices;
- Air and pavement temperature sensors;
- Plow sensors;
- Salt spreader sensors;
- In-vehicle dashboard computer displays;
- A 900 MHz radio system; and
- Customized computer software.

2.3.2.6 Pending MDOT Projects

There are several MDOT projects either in-progress or pending. These projects will have data that could be integrated with DUAP. These projects include:

- Advanced Traffic Management System (ATMS) Software Design – Depending on the region where the ATMS software is implemented, the ATMS software may include the following features:
  - Signal coordination at rail crossing
  - Network surveillance
  - DMS
  - Satellite TMC
  - Real-time traffic counts
  - RWIS
  - Local parking system management
  - Regional parking management system
  - Drawbridge management system
  - Animal crossing detection
  - Roadway closure management system
- 511® (ATIS)
- TMCs
  - MITS Center upgrade
  - West Michigan upgrade
  - Superior and Traverse City North Regions (in planning stages)
  - Statewide (in planning stage)
- RWIS deployment
  - Superior Region (limited evaluation deployment)
  - Grand/North Region (planning)

- *Clarus* – MDOT is participating in the *Clarus* Initiative which is to provide broader weather information support for surface transportation system operators through the design, demonstration, and deployment of a national surface transportation weather data collection and management system that complements NOAA's Meteorological Assimilation Data Ingest System (MADIS).

2.3.2.7 Public Transit Providers

There are about 100 urbanized and non-urbanized public transit agencies registered within the state of Michigan. These agencies provide services to the specific geographic region which they serve. Each individual agency is responsible for planning, operating, and maintaining the equipment and property owned by the agency.

2.3.2.8 Traffic.com

Traffic.com, a subsidiary of NAVTEQ Corp., acquires, aggregates, processes, and redistributes traffic data in dozens of metropolitan areas around the United States. As a commercial traffic information service provider, Traffic.com subscribes to publicly available data provided by transportation agencies, monitors law enforcement and emergency service activity, and deploys its own detectors in priority corridors not otherwise instrumented by a transportation agency. Basic traffic information, including selected travel times, is available to the public from Traffic.com. More detailed data are available via a Traffic.com subscription service.

2.4 Stakeholders

Stakeholders for the existing situation include all those who provide, create, or use the data and systems described in Section 2.3.2. Stakeholders in this case are predominantly MDOT staff but also include those who work with MDOT or who exchange data with MDOT.

MDOT operators have the objective of minimizing the impact of planned and unplanned events on the normal flow of traffic. In order to meet this objective, operators perform the following tasks:

- Review major incidents and events that impact travel;
- Assess potential impact on travelers;
- Determine response actions needed; and
- Monitor incident or event for status changes.

MDOT maintenance personnel maintain the roadways and bridges within their particular jurisdiction. They provide snow removal and pavement treatment in the winter, perform routine reactive maintenance, and clean up and repair roadway as needed in response to incidents.

MDOT asset managers and planners analyze the data and information collected about the assets in their area to determine the annual programs and projects. Their goal is a cost-effective use of resources within the agency. Planning and pavement and bridge management personnel are included in this group of stakeholders.

MDOT executives, such as the MDOT Director, MDOT Executive Bureau, and State Transportation Commission provide oversight and make final decisions on investments in Michigan's transportation infrastructure. Information from existing systems is used to guide and support the decisions made by the executives.

MDOT system administrators are part of the MDIT. Their goal is to have all collected data available for use by the other stakeholders. MDIT Enterprise IT policies, standards, and procedures are documented to assure consistency, efficiency, and effectiveness in the delivery of information technology services that support the business functions of the state.

Local and regional transportation agencies (including transit agencies) interact with existing MDOT systems where their areas of operation interface with MDOT. Stakeholders within these agencies may include executives, managers, operators, maintainers, and system administrators. Other DOTs are stakeholders in the existing data where there is cooperation across state or provincial boundaries.

MDOT's Asset Management Council brings together state and local transportation agencies from across Michigan to invest more efficiently in Michigan's roads and bridges. The Council provides coordination and collaboration in asset management policies, programs, and practices among the member agencies.

The USDOT is focused on the safety, mobility, and economic impact of the nation's transportation systems. USDOT works with each state to gather quality data that are used for national statistical reporting. Often these data have an impact upon the prioritization of state projects.

International highway and transportation agencies and authorities share MDOT's interests in the development and deployment of VII technologies. As such, they are actively monitoring VII developments in Michigan, the US, and the rest of the world, and will continue to be stakeholders throughout the development of the DUAP program.

Travelers are all the people who use the roadways, whether driving or riding in private or commercial vehicles. They obtain their trip information from various sources and use it to prepare for their daily commute or for an extended trip. The trip information may be used by the traveler for determining possible delays along desired route(s) or choosing an alternative route or mode of transportation.

Commercial fleets are those transportation vehicles which are used by business for economic purposes. These fleets obtain route information from the existing data in order to select the most economical route.

Commercial information service providers (ISPs) and other media outlets use data from the existing traveler information systems to redistribute information to their audiences. This information may be provided as part of a newscast (free) or as a subscription service.

Universities and the research community assist MDOT and other transportation agencies in both acquiring and analyzing traffic, environmental, and asset data.

Emergency Services are staffed with trained personnel who respond to emergency incidents or major disasters both on and off the roadway system. Their primary goal is to provide appropriate services—for example, medical, law enforcement, or hazardous materials—while protecting the public and services personnel from further injury or loss during the response. The data from the roadway system will assist them initially in getting to the incident location. After Emergency Services personnel are on-site, the data can be used to help evaluate the impact of the incident on the current traffic and help determine if additional resources are needed.

Other Michigan state and local agencies may use existing transportation systems data for planning and operational needs specific to their agency. The Michigan Economic Development Corporation (MEDC), for example, provides assistance to small and large companies in Michigan seeking to grow in a very competitive and challenging global economy. Efficient transportation systems and data are essential to those companies' operations and can catalyze further opportunities for growth.

2.5 Support Environment

Support for MDOT systems and data is provided by MDIT, whose goal is to achieve a unified and more cost-effective approach for managing information technology among all the Executive Branch agencies while delivering innovative business solutions with their partners.

MDIT Enterprise IT policies, standards, and procedures (Ref. 18) are established and implemented to assure consistency, efficiency, and effectiveness in the delivery of IT services that support the business functions of the State. Generally, MDIT prefers adherence to widely available technology standards, software tools, and frameworks that have open-software interfaces and broad industry support, and hardware that historically is of outstanding build quality and high reliability.

Specific products having been identified as Enterprise IT standards for the State are reviewed, at a minimum, every two years. Currently, standard products have been defined for the desktop environment, Web tools, database software and tools, servers, network devices, and network monitoring tools.

3 THE CASE FOR AND NATURE OF CHANGES

This section describes the shortcomings of the existing situation and opportunities for improvement of the current situation that motivate development of a new system.

3.1 Case for Changes

MDOT's VII Strategic and Business Plan (Ref. 13) provides a broad view of the opportunities and agency's intentions for development of VII leadership, partnerships, and technologies. Starting from MDOT's mission and vision statements, the plan lays out a vision and identifies needs, goals, measures, and activities for VII in Michigan. The resulting strategy includes three high-level VII use cases: safety, traffic management, and asset management. These use cases provide the context for DUAP and for building the more detailed case for change.

3.1.1 Improving Safety

The opportunity to make travel safer is a key motivator in the development and implementation of VII systems. Reductions in injuries, deaths, and property damage associated with crashes are tangible objectives shared by all stakeholders in VII and DUAP. Safety improvements also provide benefits in traffic management by reducing the number and severity of incidents that may cause travel delays and in transportation system asset management by reducing maintenance and repair costs on damaged assets.

Safety improvement needs are found on both the vehicle and infrastructure sides of the VII opportunity. In-vehicle systems have never had access to information about the location of other vehicles or downstream roadway conditions. Transportation agency systems have generally not had access to detailed real-time information on vehicle locations or roadway conditions. While substantial effort is being made in other VII initiatives to build in-vehicle systems to enhance safety, the need for MDOT in DUAP is to gather more information about travel conditions from the vehicles so that it can be used to provide more specific information to travelers.

Safety-related traveler information is currently provided through traffic control devices outside the vehicle and supplemented with broadcast traveler information. In the case of traffic control devices, the information is generally static—for example, fixed warning signs for Slippery When Wet or Bridge Ices Before Road. Although the warning is generally relevant to that location, it may not indicate the actual road conditions at the time a traveler sees it. Broadcast traveler information—whether on highway advisory radio, commercial media, or the Internet—is generally descriptive of conditions over a wider geographical area, but may be more specific to the time at which it is broadcast. Even the most specific traveler information, such as traffic broadcasts in urban areas, provides only guidance on routes or highway segments, and generally only as it relates to particular incidents.

VII-related needs for improving safety on Michigan roadways are therefore focused on:

- Collecting road condition information more frequently;
- Collecting road condition information at finer resolutions;
- Having access to vehicle locations; and
- Providing targeted in-vehicle messaging of local road conditions.

Data coming from VII-equipped vehicles could be used to generate warnings of hazardous traffic and road weather conditions. The data could be combined in real time with location-specific information to provide warnings that supplement existing traffic control devices such as curve and work zone speed warnings, school zones, low overheads, and wrong way signs.

3.1.2 Improving Traffic Management

The most direct benefits to MDOT from VII may be in improving the agency's ability to manage traffic. Congestion and traffic delays cost money and time and create frustration for Michigan travelers. Improvements in traffic efficiency also improve traffic safety by reducing the likelihood of secondary collisions and make more productive use of the existing transportation assets.

Currently, traffic management data are gathered primarily from video cameras and vehicle detections stations. The 222 miles of freeway currently monitored represent a small percentage of the more than 9700 miles of major highways within the state. Although system deployment has been prioritized to monitor the areas with the worst congestion, many unmonitored areas experience recurring and incident related congestion. There is therefore a need for additional data within the existing infrastructure in order to fill gaps in the existing roadway surveillance. The use of VII data would allow additional information to be gathered from roadways currently being monitored and would also allow more roadways to be monitored without requiring the installation of additional fixed monitoring equipment. Data from VII sources can be combined with data from the existing surveillance devices to provide a seamless view of traffic conditions.

Both the traveling public and commercial traveler information service providers have expressed a desire for more comprehensive information about incidents, congestion, and delays on state roadways. MDOT's ability to meet this desire has been limited not only by the scarcity of data, but also by options for redistributing the data. Existing capabilities provide traveler information on current conditions through broadcast media and Web sites, and, to a lesser extent, on changeable or dynamic message signs (CMS/DMS).

The need for better traffic management information is therefore focused on:

- Collecting traffic data throughout the entire roadway network;
- Collecting traffic data at finer resolutions;
- Collecting traffic data in near real time;
- Creating more accurate traveler information based on this wealth of data; and

- Redistributing the data with as little time delay as possible.

These data can be used in conjunction with existing monitoring capabilities to provide a broad real-time view of conditions across the state. VII greatly extends MDOT's ability to gather traffic data, which creates opportunity for enhancing traffic management through advanced arterial traffic signal and ramp metering controls. VII capabilities for routing messages directly to vehicles would enable traveler information to be presented within the vehicles, informing and allowing drivers to select alternative routes.

3.1.3 Improving Asset Management

Asset management processes involve the full range of MDOT activities from planning to traffic management, throughout the full life cycle of MDOT's transportation assets. As such, asset management data needs are closely coupled to improving the cost-effectiveness of MDOT's infrastructure investment. The SLRP, STIP, and Call for Projects all depend on having the best possible information on pavement and bridge conditions and on reliable forecasts of traffic volumes across the statewide system. Unfortunately, current asset data collection methods are relatively expensive, time consuming, and may provide only intermittent (annual or biennial) snapshots of the state of most of the assets.

Historic traffic data are used in traffic simulations and forecasts for planning. Granularity of the data varies widely across the state, correlating largely with traffic volumes. In urban areas with permanent vehicle detection stations (for example, in those areas of the Detroit metro monitored by the MITS Center), archived traffic data may be available at 30 second intervals on two-mile segments. Selected locations around the state have permanent counting stations for monitoring volumes. Some segments may only be counted once every two years. There is also significant interest in gathering information on traffic volumes by vehicle class and weight. It is generally believed that heavy vehicles are responsible for the majority of pavement and bridge "wear and tear," but the state currently has no means of obtaining data specifically for those heavy vehicles.

Collection of pavement and bridge condition information is more consistent across the state, but is performed only on an annual cycle. Programmed inspections are performed during summer months by specially-equipped maintenance vehicles driving over every lane-mile of state roadway. While this inspection frequency is generally adequate for annual planning and the Call for Projects, it provides too few data points to reliably detect variation from expected trends in surface deterioration. Potholes or cracks requiring immediate repair may be identified by Transportation Service Center (TSC) staff during the course of routine operations or might even be called in by observant and helpful drivers.

The need for better asset management data from VII is therefore focused on:

- Collecting traffic data consistently throughout the entire roadway network;
- Collecting traffic data at finer resolutions;
- Collecting traffic data throughout the year;
- Collecting data on vehicle class within the traffic data;

- Collecting asset condition throughout the year; and
- Reducing the cost of collecting asset condition data.

Obtaining these data through VII could significantly reduce the cost and extend the reach of data collection for planning and asset management processes within MDOT. For example, more complete and consistent historical traffic information would improve transportation simulation and forecasting in support of planning. More continuous monitoring of pavement and bridge condition data might be able to automate identification of potholes and cracks, and could enable faster spotting of trends in pavement deterioration. Correlations of pavement conditions with traffic data and vehicle classes could facilitate studies of prevention and mitigation of surface damage from heavy vehicles.

3.2 Description of Opportunities and Desired Changes

As stated in the Introduction, the purpose of the DUAP project is to support MDOT and its partners in evaluating uses and benefits of VII-related data in transportation agency management and operations. Within this purpose, opportunities are available not only within VII data available from formalized government-funded programs, but also from similar public and commercial vehicle probe data networks. Applications of the data will include not only the existing MDOT systems that may benefit from having access to more data, but also better integration between systems, even between agencies.

3.2.1 Obtaining VII Probe Data

The USDOT/VIIC's VII Proof-of-Concept (POC) Development Test Environment (DTE) will make use of a set of initial applications that obtain and use data from VII-equipped vehicles to evaluate VII operational concepts. The DTE will become operational in the Detroit metro area during the fourth quarter of 2007, with operations to be extended into 2008 to support ongoing evaluations and MDOT's DUAP project. POC results will become part of the basis for deciding whether it is technically feasible, economically viable, and socially acceptable to recommend the deployment of a nationwide communication system on the road infrastructure and in all vehicles sold in the U.S.

Tables 1 and 2 below list and describe the probe data elements to be made available from the VII POC, as detailed in the following documents:

- *SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary – Dec. 2006, (VIIC Doc. No. APP190-01),* Reference 16, contains the initial specification for data generated during the VII POC.
- *POC Additions and Exceptions to APP190-01 (VIIC Doc. Number: APP190-02),* Reference 29, contains modifications to data specifications noted in Reference 16.
- *Software Requirements Document (SRS) for the POC Vehicle Probe Data Generation Application (VIIC Doc. Number APP220-01),* Reference 30, indicates the data elements that will be supported by the Probe Data Generation Vehicle Application for POC. The sizes and units for the

elements are specified in APP190-02. It is expected that every supported POC element will be provided by at least one vehicle.

The POC testing will utilize the data elements noted in Table 1 that will be provided from all VII-equipped vehicles. Probe data snapshots containing these data elements will be available for use by DUAP.

Table 1 – VII POC Required Probe Data Elements

Element	Description
Time	Local time
Date	Local date
Latitude	Latitude of the center of the vehicle
Longitude	Longitude of the center of the vehicle
Elevation	Elevation of the center of the vehicle
Heading	Current heading of the vehicle
Speed	Current vehicle speed

In addition to the elements provided by all VII-equipped vehicles in the POC, the optional data elements listed in Table 2 may also be provided by some vehicles for input into DUAP.

DUAP will subscribe to VII probe data elements described in these tables as one set of inputs to DUAP applications. As described later in Sections 4 and 5 of the ConOps, these applications will convert the vehicle data to traffic and road condition information to be used in addressing the needs described earlier in Section 3.

Table 2 – VII POC Optional Probe Data Elements

Element	Description
Air Temperature	Ambient air temperature
Wiper Status	Indication of wiper status. Settings could be: not equipped, off, intermittent, low, high or automatic.
Vehicle Exterior Lights	Status of exterior lights. Settings could be: parking lights, headlights (low and high beam, automatic light control), fog lights, daytime running lights, turn signals (right / left), and hazard signals.
Rain Sensor	Rain/snow intensity. The value of the Rain Sensor data element ranges from 0-7, with 0 indicating "No Rain/Snow", 1 indicating "Light Mist", and 7 indicating "Heavy Downpour".
Sun Sensor	Level of sunlight. The value of the Sun Sensor data element ranges from 0-7, with 0 indicating "Complete Darkness", 1 indicating "Minimal Sun Light", and 7 indicating "Maximum Sun Light".
Traction Control	Indication of whether one or more of the vehicle's drive wheels was slipping during an acceleration. Values could indicate no traction control system, or whether the system is off, on or engaged.
Stability Control	Indication of whether the vehicle’s stability control system is activated because of the vehicle being too far off-axis during a turn. Values could indicate no stability control, or whether the system is off or active.
Anti-Lock Brakes	Indication of whether the vehicles anti-lock brake system is activated due to an extreme braking condition or a slippery roadway condition. Values could be not equipped, off, on or engaged.
Vertical Acceleration	Vehicle’s vertical G acceleration per second.
Brake Applied	Wheel braking status. Values could indicate whether all brakes are off, which wheel brakes are applied, or whether all brakes are applied.
Steering Wheel Angle	Angle relative to straight that the steering wheel is turned.
Steering Wheel Angle Rate of Change	Rate of change of the steering wheel angle.

Element	Description
Longitudinal Acceleration	Acceleration along the X axis or the vehicle's direction of travel in parallel with a front to rear centerline. Negative values indicate braking action.
Lateral Acceleration	Acceleration along the Y axis or perpendicular to the vehicle's direction of travel in parallel with a left-to-right centerline. Negative values indicate left turning action and positive values indicate right turning action.
Yaw Rate	Amount of rotation about vehicle's longitudinal axis within a certain time period.
100% Brake Boost Applied	Indication of emergency braking. This data element is an on/off value which indicates engagement of the vehicle's brake boost assist function.
Barometric (Ambient) Pressure	Barometric pressure ranging from 580 hPa to 1,090 hPa with a resolution of 2 hPa.
Tire Pressure	Provides Tire Pressure for up to four tires each with a range of 1 to 255 psi.
Tire Pressure Monitoring System	Indication of whether the vehicle's tire pressure monitoring system is activated. Values could indicate no monitoring system or whether the system is off or active.

3.2.2 Obtaining Probe Data from Non-VII Sources

Vehicle probe data networks other than the VII POC could provide significant quantities of information to DUAP.

Even though vehicle manufacturers as a group are well represented by the VIIC, many of the manufacturers have other telematics networks that could provide probe data for DUAP. Data elements from these networks would likely be similar to those described earlier.

Truck fleets may have monitoring systems using GPS or radio frequency identification (RFID) capabilities. GPS tracking system providers can provide information such as vehicle location, speed, origin/destination (O/D), and stops/starts that could be assimilated into DUAP. RFID tracking systems are also used for vehicle location and O/D gathering within trucking fleets.

Car rental fleets may also have vehicle tracking systems which can provide information such as vehicle location, speed, O/D, and stops/starts that could be assimilated into DUAP.

Commercial traffic information service providers (such as Traffic.com in the Detroit metro) receive information from their own traffic sensors and operations centers, as well as from commercial and government partners. That traffic information could be subscribed to, processed, and assimilated into DUAP to supplement other data streams.

3.2.3 Integrating Operational Data into MDOT Systems

While much information is available within MDOT and its partners' systems, the data are not always shared between organizations. DUAP will be designed to allow data to be shared between the different MDOT groups and partners. As more data becomes available and the data reliability increases, additional applications can be developed that will allow additional data sharing and two-way data flows between systems with DUAP acting as a data broker.

For example, DUAP will gather traffic information on road segment speed, volume, and occupancy from a variety of systems. These data will be integrated with traffic information derived from VII vehicle probe data to create a single integrated view of traffic conditions. The integrated data could be published directly to the ATMS in a TOC and also be available to real-time traffic forecasting applications. Similarly, data could be published from public transit agencies as input to DUAP, where the transit fleet information could be passed on to the MDOT ATMS.

Road and lane closure data from MDOT and other transportation agency construction and maintenance databases could be acquired by DUAP and integrated with other event data. The integrated event data set could be shared with the MDOT ATMS, ISPs, and the traveling public and be used in traffic data validation or demand forecasts.

3.3 Priorities among Changes

Determining priorities among potential system changes should begin by considering the impacts that DUAP might have on the needs discussed in section 3.1. Decisions on implementation of changes would then be based on those priorities and on the programmatic, institutional, and financial needs and constraints discussed in the MDOT VII Strategic and Business Plan. Implementation viability and risks may also be factors in setting priorities.

The highest priorities among the changes would be those related to safety and mobility. Preventing accidents and allowing free flow of traffic on the highways is of utmost importance. For example, secondary incidents can be prevented if incident management response time is decreased through use of VII and DUAP.

Safety due to weather issues is also a high priority. Having additional weather data available to the organizations responsible for salting, sanding, and plowing can allow those groups to respond more quickly to problem areas and prevent additional accidents. Likewise, the traveling public will be able to make safer choices while driving in inclement weather if VII and DUAP can provide more specific and accurate information on road conditions.

Asset monitoring, particularly monitoring of pavement conditions, is a significant priority for MDOT operations but may be a less immediate priority for the public. By having additional data on pavement conditions, problem areas can be quickly assessed and addressed to prevent future degradation of facilities, but this will generally not be a safety issue. Similarly, having information on traffic flow along the highways, especially the number of heavy vehicles, would enable traffic utilization studies to determine if modifications might need to be made, such as having specific truck lanes or high occupancy vehicle lanes.

3.4 Changes Considered But Not Included

Proprietary telematics systems were considered but not explicitly included as sources of data in this document. While integration with independent telematics systems may occur in the future, the necessary institutional agreements and intellectual property agreements are generally beyond the scope of this project.

CAD systems operated by emergency management services or agencies could be significant sources of traffic and operations data. The CAD systems within Michigan represent a potential external integration point, but the number of systems, proprietary interfaces, and institutional agreements required to include CAD systems in this project made it impractical to include CAD integration in this deployment.

3.5 Assumptions and Constraints

Data latency is the time delay experienced when data are sent from one point to another. Latency enters into the data collection process in several ways:

- The time required for vehicle systems to collect and store vehicle data;
- The delay between the data collection and the data transmission from the vehicle to DUAP;
- The time required for DUAP pre-processing of data;
- The time required for the DUAP system to process the data and publish it to other systems; and
- The time between the DUAP processing and the transmission to the end systems.

While the VII data may be more timely and complete than data currently being processed, participants must recognize that VII data is *near* real-time data. Each system using DUAP data must be capable of evaluating the data based on the source and date/time stamps to determine the suitability of each data element for the intended purpose.

Data quality may also be an issue. Vehicle sensors may be in various states of calibration and may even function in degraded modes. Each application using the VII and DUAP data will need to have the capability of assessing the quality of data and making appropriate use of any available data quality flags.

Finally, the amount of data coming into DUAP from VII is highly dependent on the amount of data collected by each vehicle, the number of VII-equipped vehicles, and the means of data collection from the vehicles. While these factors can be controlled during the evaluation phase of this project, only the means of data collection will be within the control of agencies during the full production roll-out of the system. As such, reliance on VII data to address transportation agency management and operations challenges should be tempered by the uncertainties of how quickly data may become available from the vehicles.

4 CONCEPTS FOR THE PROPOSED SYSTEM

This section describes concepts for the proposed system that respond to needs identified in Section 3. Concepts are described as operational features and are not intended to specify or imply particular designs or implementations.

4.1 Background, Objectives, and Scope

The current state of processes and systems available to MDOT as described in Section 2 contains significant opportunities to improve safety, mobility, and efficient use of the state's transportation system. Expectations for delivery of transportation services continue to grow[2], while resources for service delivery are externally constrained. Transportation agencies are expected to satisfy greater demand for services for less cost, all the while making a net positive contribution to the state's broader economic development.

These demands are illustrated in the case for change described in Section 3. The traveling public wants more real-time information about traffic and road conditions. MDOT wants more information about its assets and how they are used by the traveling public. Everyone wants to travel in complete safety. While travel demand is increasing, funding levels have not kept sufficient pace to allow meeting that demand with new pavement or bridges alone. New technologies will have to fill that capacity gap, and the integration of those new capabilities with existing applications will bridge the remainder.

To that end, a strategy is put forth in MDOT's Vehicle Infrastructure Integration Strategic and Business Plan (Ref. 13) that focuses on partnering, developing, and deploying a VII infrastructure and testbeds; increasing safety and mobility; improving asset management; developing outreach programs to better expose others to VII in Michigan; justifying the need for VII; and determining creative investment funding venues for VII activities.

Within this context, the DUAP project will investigate and evaluate the utility of VII data and its integration with other transportation agency sources in enhancing safety, increasing mobility, and improving asset management. Tasks within DUAP will identify uses for the VII data, develop algorithms to use and process the VII data, develop prototype applications and data management software, and evaluate the utility of the processed data for MDOT and its partners. Data processing will require acquisition from a variety of sources, standardization and integration, storage, synthesis for particular applications, and dissemination.

4.2 Stakeholders

Stakeholders in DUAP-enhanced transportation system operations are almost entirely the same as those involved in the current state of operations. The intent of adding new data sources is to provide a more complete dataset upon which the

[2] AASHTO reports, for example, that "Interstate highway travel demand measured through vehicle miles traveled (VMT) will increase from 690 billion in 2002 to 1.3 trillion by 2026." (Ref. 1, page 20)

transportation agencies can base operational decisions, but there are not necessarily any new *users* of VII data within the agencies. The *providers* of VII data are, however, new stakeholders in transportation operations.

The automobile manufacturers (or original equipment manufacturers, OEMs) and their suppliers become stakeholders in DUAP because VII data become available to transportation agencies only if those OEMs provide equipment and communication systems in their vehicles for transmitting the data to the VII network. Many of the OEMs are members of the VIIC, which is developing the on-board equipment (OBE) and assisting the USDOT in development of applications for VII infrastructure and data. OEMs are in many cases also developing independent telematics networks from which transportation agencies might be able to obtain data similar to that provided through the USDOT/VIIC efforts.

Automotive industry research groups and associations become stakeholders in DUAP through their support of the MEDC and the automotive manufacturers. The Center for Automotive Research (CAR) and Connected Vehicle Trade Association (CVTA), for example, provide perspective and research on industry trends, policies, and methodologies. In particular, the Connected Vehicle Proving Center (CVPC) under development by CAR and CVTA will test and evaluate connected vehicle systems by integrating connected vehicles, smart roadway infrastructure, and communication technologies to showcase the potential of VII and related vehicle-communications initiatives.

The VII network (and any similar independent telematics networks) will also introduce a network operating entity as a stakeholder to DUAP and transportation system operations. Once the VII field infrastructure is in place, a network operating entity will be needed to operate, monitor, and maintain the flow of VII data and the infrastructure enabling it. The operating entity's responsibilities in this capacity are similar to those of a transportation agency relative to the transportation network. The operating entity's telecommunications service providers would be indirect stakeholders in DUAP.

4.3 Description of the Proposed System

When describing a system, there are many ways to represent what the system will do and how it will be implemented. Each representation has its own strengths and limitations, but all are intended to create understanding of the system's boundaries, components, and interactions. Each representation has its own set of basic units and interactions. One or more of these representations taken together describe the system architecture.

Systems similar to the DUAP system are frequently and effectively represented as sets of interacting services. Each service has one or more interfaces by which the services interact. This representation is a very natural way of approaching a potentially complex system with a basic repeatable model.

A representation based on services and interfaces inherently leads to a flexible, scalable, and maintainable design. With well-defined interfaces, it is possible to improve the functions of the system by adding services that conform to the interfaces, but provide new operations. Services do not unnecessarily constrain the physical and computational hardware to which they might be deployed. It is possible to scale the system by adding hardware to support the processing needs of new services as they are developed and deployed. Maintainability can be preserved by being able to update both hardware and software components while the system is running.

A DUAP system based on a service-oriented architecture will then be flexible, scalable, and maintainable. It will be capable of handling large amounts of continuously streaming data. It will support current and future MDOT missions and goals.

Figure 4 is a simple (but abstract) representation of the DUAP system as a set of services. As shown in the figure, the basic services provided by DUAP are input, dynamic data, computational, persistent data, output, presentation, and administrative. These basic services are common to all information systems, but will have specific implementations for DUAP to assure that it meets the needs described earlier in the ConOps.

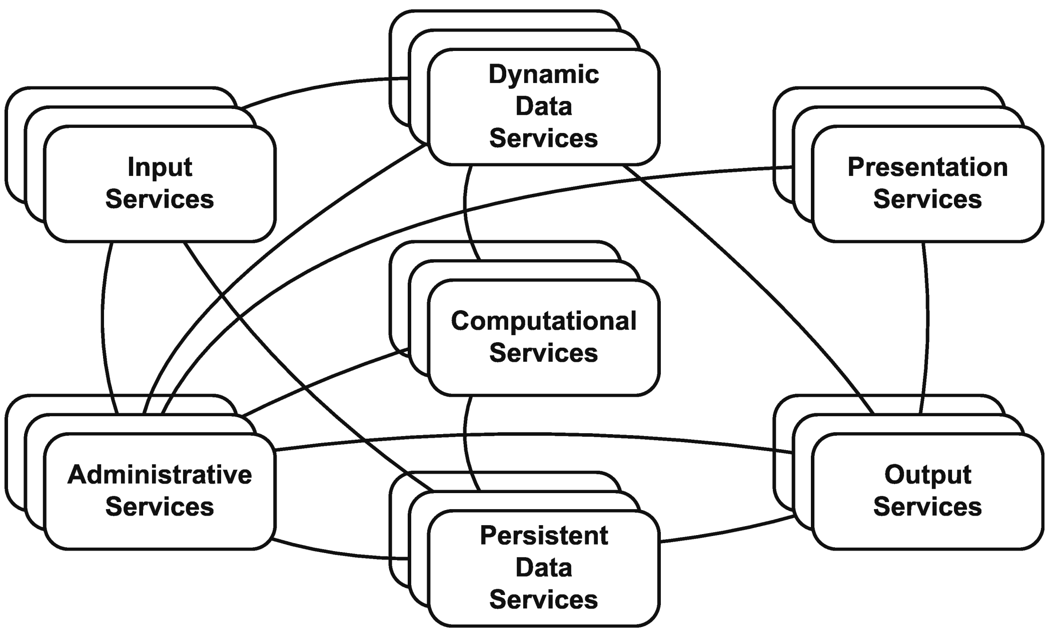


Figure 4 – DUAP System Services

4.3.1 Input Services

Input services provide the ability for DUAP to interact with any other system that might have data needed by DUAP. As described in Section 3, these other systems could include the VII POC, other probe data services, other transportation agency traffic management systems, commercial traffic information service providers, and weather service providers. A specific DUAP input service would be needed for each source of data.

The VII POC input services, for example, will use the X-031 Probe Data Service interface as described by the VII Network User to Service Delivery Node Subsystem document. DUAP data input services will send a subscription request to the Probe Data Service, to be fulfilled within the VII network. As infrastructure data are collected from the vehicles by the network, the network feeds the data continuously to the subscribed DUAP services.

Input services will also receive speed, volume, and occupancy data from ATIS throughout the state. The MITS Center ATMS, for example, will have its own input service for collecting speed, volume, and occupancy, and may also obtain event descriptions and messages posted on CMS/DMS.

4.3.2 Dynamic Data Services

The Dynamic Data Services are the active memory of DUAP. Data obtained by the Input Services are stored here for use by other DUAP components. Following a pattern similar to the input services, the Dynamic Data Services (and other services within the DUAP system) register with the Input Services to receive copies (subscriptions) of the data for their use. The Dynamic Data Services then provide a buffering service within the DUAP system to increase the data longevity so that other more complex services will have an opportunity to process the data completely. As input data are buffered, they are immediately made available to other services.

4.3.3 Persistent Data Services

The Persistent Data Services are the long-term memory of DUAP. While buffering services like the Dynamic Data Services are intended to store data that are readily accessible and saved for a relatively short duration, longer-term storage will be fulfilled by Persistent Data Services. Archive services, for example, will receive vehicle data from buffering services just like other services in the DUAP system. Buffering services provide fast access to the most recent vehicle data, while archive services will organize and provide long-term storage for vehicle information to support future data analysis and management needs.

4.3.4 Computational Services

The purpose of the DUAP system's Computational Services is to apply logical algorithms to incoming vehicle and traffic observations in order to transform those observations into data that are directly applicable to transportation management and operations processes. Computational services will operate on the dynamic and persistent data to perform analysis functions that derive new and useful information about what is occurring within the public infrastructure. Derived information can then be operated upon by still other computational services for further analysis.

Many computational services are possible. A list of immediately useful algorithms follows:

- Incident Detection and Location

- Queue Length
- Travel Time
- Segment Aggregation
- Weather Condition
- Road/Bridge Condition
- Pothole Locator
- Data Quality Checking

4.3.5 Output Services

Output Services subscribe to data within DUAP Dynamic and Persistent Data Services and structure and format it for use by other services within and external to the DUAP system. For example, SAE J2354 XML-formatted data can be produced as data output to other systems that provide traveler information and enhance public safety.

Data output services also format analyzed data for use by presentation services. An example of this relationship between data output and presentation services is sending information messages to a VII participating vehicle. This interaction could be achieved by preparing data according to the X-032 interface—described by VII National System Specification—to an Advisory Message Distribution Service.

4.3.6 Presentation Services

Presentation Services support human interpretation of DUAP data. Due to the inherent flexibility in modular service implementation, presentation services—and the data output services that support those presentation services—can be added to the system as needed.

For example, a traveler information presentation service might be expected to provide information on incidents and travel times through a Web page. Other computational services—incident detection travel time calculation, and incident status monitoring, for example—would generate the data, and an output service would package the data. A presentation service, however, would create the user interface. Similarly, presentation services for maintenance support systems could be deployed to generate pavement segment maintenance priority lists, immediate maintenance alerts, and estimated segment roadway life expectancy from data created by other computational services.

4.3.7 Administrative Services

Administrative Services exist within the DUAP system to configure other services. Essentially, administrative services fulfill the role of "meta-services." These services will be used to organize the sequence of execution for any of the other services, to view logging information, and to change the operating modes of the system.

4.4 Operational Policies and Constraints

Operational policies will need to be established to protect the privacy and data ownership of the data originators. While the USDOT VII program is addressing policy issues for the VII network itself, MDOT will be faced with many of the same issues as it seeks to integrate VII data into its operations.

For example, while VII probe data are "anonymized" to the extent that information is not associated directly with a particular vehicle or driver, there are inherent limitations to that anonymity. In the simplest such case, the VII-originated record of a vehicle's behavior could be uniquely correlated to a particular vehicle if it were the only such vehicle on a roadway at a particular time and corroborated by other observations. While this may not be a significant policy issue during system development and testing or after every vehicle on the road is VII-enabled, it could become an issue in the transition—when some but not all vehicles are so equipped and are therefore more easily identifiable.

The question of ownership of comingled data may become an issue for DUAP-based information. MDOT and its partner transportation agencies currently subscribe to selected traffic, vehicle location, and weather information services that would be blended into the DUAP data streams. While the bulk of data will be from the VII network, other sources present opportunities for data expansion and validation that might be necessary for DUAP to succeed. Limitations on the use or redistribution of data from these third-party sources could hamper the usefulness of DUAP and will need to be considered in agreements for those services.

4.5 Modes of Operation

Modes of operation are a way of defining and expressing sets of conditions under which a system is expected to operate. From a system user's perspective, the modes define what can (or can't) happen while the system is in that mode. From a system developer's perspective, modes prescribe what the system should (or should not) do while the system is in that mode. In an automobile, for example, the mode is driver-selected by the ignition switch, which then constrains what vehicle subsystems are enabled or disabled. The modes of operation for the DUAP software system are:

- Start – Start is the mode that tells the administrative services to start the dependent processes sequentially as defined. A system in this mode will either transition to Normal mode or to Shutdown mode.
- Normal – Normal is the desired mode for the system. In this mode, the system is ready to receive and process data as designed. From this mode, the system can either go into Abnormal mode, Diagnostic/Repair mode, or Shutdown mode.
- Abnormal – In this mode, the system is still functioning but is also experiencing a problem. From this mode, the system can either go into Diagnostic/Repair mode or Shutdown mode.

- Diagnostic/Repair – In this mode, the system runs diagnostic services in order to attempt a repair. From this mode the system can either go back into Normal Mode or go into Shutdown mode.
- Shutdown – In this mode, the system is shutting down dependent processes in a predefined sequence. When shutdown is complete, the system will be in Off mode.
- Off – In this mode, the system is completely shutdown. From this mode, the system can go only to Start mode.

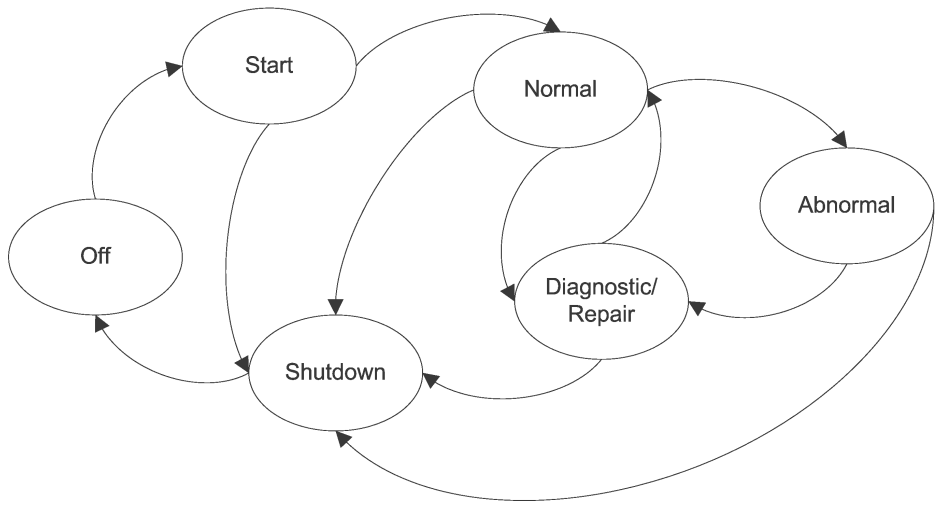


Figure 5 – Modes of Operation

4.6 Support Environment

During the DUAP demonstration phase, the initial hardware and software will be housed and operated by the contractor. The hardware will be and remain the property of the State of Michigan. After the demonstration phase has concluded, the desired hardware and software will be delivered to MDIT for acceptance into their infrastructure.

The support environment for the DUAP project has four areas for consideration: communications, power and environmental control, hardware, and software.

4.6.1 Communications

The purpose of the DUAP project is to acquire more detailed information about the state of Michigan trunklines and bridges and to use that information to improve the quality and safety of the State highways. To that end, robust communications are needed to allow for the transmission of data.

The communications bandwidth calculated for the DUAP demonstration is estimated to be 1.175 Mb/s. A T1 communication line has a bandwidth of 1.536 Mb/s. A single T1 line will suffice for the proof-of-concept data needs.

The DUAP demonstration communications bandwidth estimate does not account for future growth as more vehicles and more data about vehicle operations becomes available. Should it become necessary during the DUAP demonstration, the proposed solution is to purchase additional T1 lines up to a maximum of eight. At that point, it is more economical to purchase a single DS3 line (equivalent to 28 T1 lines). It is unlikely that the data volume will reach that high level during the demonstration. MDIT will be able to make its own assessment of communication needs based on its existing infrastructure and the additional demands placed on it through the deployment of the DUAP system.

The communications needs just discussed are from the perspective of the wide area network (WAN) segment of the DUAP system connected to the VII network. Local area networks (LANs) are connected to the WAN using switches and routers. The LAN for the DUAP project will be connected using Gigabit Ethernet switches and routers. Gigabit Ethernet equipment is widely available and cost effective. Through the use of modular networking equipment, it is possible to upgrade to higher communication bandwidth by replacing computer network interface cards and switches as it becomes necessary and economical to do so.

4.6.2 Power and Environmental Control

The computer hardware will be housed in a restricted access, environmentally controlled room. The servers will be mounted in standard (42U, 19-inch) racks. Uninterruptible power supplies (UPS) will provide conditioned and continuous power for the system and will be mounted near the servers.

UPS will be able to sustain the DUAP system for 20 minutes in the event of total power failure. This level of UPS is sufficient for the DUAP proof-of-concept as 95% of all power interruptions in a metropolitan area last less than two minutes. Power interruptions lasting more than 20 minutes will result in temporary loss of access to the DUAP demonstration system. Access to the DUAP system will be automatically restored when main power is restored.

4.6.3 Hardware

The equipment and software for this project will meet the MDIT guidelines provided at the start of the project. Any exceptions will be documented and approved by MDIT before implementation.

Computing hardware will consist of Sun Microsystems X4200 servers or equivalent models. Each server will contain a minimum of two dual-core processors, equating to at least four processors per machine. Memory will be maximized according to server purpose and software needs. Up to 16 gigabytes (GB) of random access memory can be installed for each server. Storage will consist of high-speed, 73 GB serial-attached SCSI disk drives. Up to four disk drives per server can be installed.

Sun servers have a feature called Integrated Lights-Out Management (ILOM). Essentially there is a small computer built into the server that monitors the server health. With ILOM, it is possible to securely and remotely monitor, shut down, and restart the DUAP system when necessary.

4.6.4 Software

The software for this project will meet MDIT standards provided at the start of this project. Any exceptions will be documented and approved by MDIT before implementation. MDIT will be consulted throughout this project to ensure compliance with these standards.

MDIT is skilled in the use of Java technologies. Building on a Java software foundation has the advantage of being operating system agnostic. It is possible to install Microsoft, Sun, or other open source operating systems on the suggested server hardware. MDIT is currently running the Solaris operating system and the DUAP software will follow that lead.

Java and its related software frameworks and technologies will be used to develop the applications. Java Database Connectivity (JDBC) enables generic access to differing vendor databases. The selected relational database will be Oracle 10G, and database information requests will be handled through standard Structured Query Language (SQL) commands.

MDOT and MDIT may have existing algorithms and software modules that can be leveraged for the DUAP project. Software modules will be interfaced to the system using the Java Native Interface (JNI) where possible. Algorithms and non-interfaced software modules can be implemented using JAVA and will then be directly usable by the DUAP project.

Configuring the DUAP system as a set of services has an advantage in flexibility. It will be possible to re-organize service deployments across the available computing hardware. Fewer very demanding computational services can be installed on one set of servers while less demanding services can be installed on another set of servers. Processing load will be distributed more evenly across the available computing resources, minimizing information bottlenecks.

5 OPERATIONAL SCENARIOS

A scenario is a step-by-step description of how the proposed system should operate and interact with its users and its external interfaces under a given set of circumstances. The following scenarios will allow readers to walk through activities and gain an understanding of how the various parts of the proposed system function and interact. The scenarios will tie together the system, the users, and other entities by describing how they interact.

Scenarios are not limited to addressing specific needs (Section 3.1), but discuss the future system in the larger context of potential future operations. In addition, the specific parameters to be provided by VII in any particular scenario are representative of the DOT's interests, but may not be in the immediate scope of VII implementation plans. Similarly, the scenarios are not specific about the networks through which data from VII-equipped vehicles are obtained by DUAP applications. Future VII networks could use a variety of technologies, implemented in phases beyond the existing VII POC program.

5.1 Traffic Incident

A crash occurs during typical rush hour congestion with clear weather conditions on the southbound segment of I-275/I-96 just north of 10 Mile where it reduces down to four lanes. For the purposes of the scenario, it is assumed that the segment is not being monitored by video surveillance but does have traffic sensors that are monitored at the MITS Center. Detector stations are located about 0.5 mile upstream and 1.5 miles downstream of the event location. Vehicle 1 is hit in the left rear end by Vehicle 2, and the impact activates the airbags in Vehicle 2. The accident blocks the left two lanes of the roadway.

Numerous vehicles behind the accident apply brakes, and the Antilock Brake Systems (ABS) are activated in some vehicles. The vehicles reduce speed to avoid disabled Vehicles 1 and 2. Vehicles attempt to merge from the left lanes into the right two lanes, resulting in turn signal activations, changes in steering wheel angle, wheel angle, heading, and further reduction in speed. On-board equipment acquires a mix of periodic snapshots (views of all data available at any particular time) and vehicle event data (snapshots taken based on a vehicle systems event such as ABS actuation). Data received from the vehicles includes:

- Location
- Speed
- Heading
- Longitudinal Acceleration
- ABS
- Wheel Angle

Meanwhile, numerous vehicle drivers call 911, whereby a general description of the event and its location are picked up by local emergency services. An incident notification is received in the MITS Center CAD system approximately 60 seconds after the incident is first called in. The traffic queue behind the crash reaches the upstream detector station in about 60 seconds, and the MITS Center ATMS picks up the traffic speed change as the queue passes the loops. VII-enabled vehicle data are transmitted through the VII network and acquired by the DUAP system.

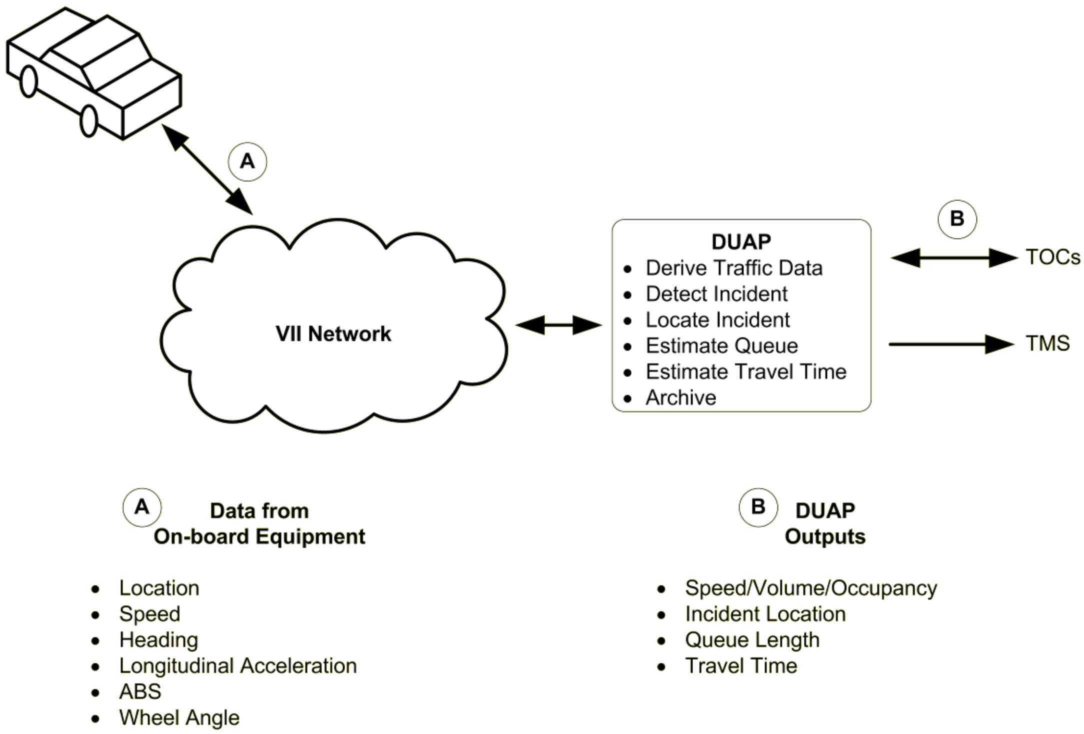


Figure 6 – Incident Scenario[3]

The DUAP system receives and sorts the VII data into particular vehicle condition observations. The DUAP system also collects loop detector data from the MITS Center ATMS and parses data into traffic condition observations. Once these data are available within the system, a variety of algorithms are applied to synthesize new information for operators. For example:

- The incident detection algorithm determines an incident has occurred based on speed changes as seen in composites of vehicle and loop data; ABS activations; indications of brakes having been applied; and longitudinal accelerations.
- The incident locator algorithm locates the incident based on speed change profiles, wheel angles, and headings.
- The queue length algorithm determines the stop location and length of any mainline queues.
- The travel time algorithm calculates travel times and travel time reliability for links throughout the road network.

[3] The time and location of the observed data are part of every observation record and are not explicitly shown in this and other similar figures in the ConOps.

The DUAP system creates outputs to notify and provide incident data to interacting applications through the publication of SAE J2354 center-to-center (C2C) traveler information messages.

Information is picked up from the DUAP system by the MITS ATMS (and any other subscribing transportation agency center systems), which then presents data to operators.

Information is also picked up from the DUAP system by VII traveler information services, which then structure and forward messages in appropriate formats to the VII network for broadcast to affected vehicles. Messages from the DUAP system may include link speeds, travel times, and event descriptions. Some VII messages may contain value-added elements such as recommended routing to minimize travel time of affected travelers.

Finally, data and outgoing messages are logged by the DUAP system archiving services. This preserves both the data for replaying events or for future analysis and the record of system activities for system monitoring and operations.

The DUAP system data supplements, but does not replace, existing MITS Center operator interfaces (e.g., maps, alerts, event reports). Operators relate and confirm the incident with information received from the native ATMS interfaces and emergency services dispatch. Operators then create messages for display on signs along the affected corridor, and the ATMS publishes a new update of those messages. Operators may dispatch Courtesy Patrol and maintenance vehicles as needed to support clearance and restoration of traffic flow.

The DUAP system then collects the MITS ATMS CMS/DMS messages for republication in the SAE J2354 format back to other users such as VII.

The event is resolved as emergency services clear the incident from active traffic lanes. The incident is “closed” from a traffic perspective when performance conditions are restored to pre-incident levels, which could be determined or verified by a DUAP algorithm. The incident is documented in MSP Form UD-10, which is incorporated into MDOT TMS and can be correlated with the DUAP system data archive.

5.2 Weather Response

An unexpected early spring storm has brought a mix of rain, sleet, and snow over southeast Michigan. The ground is still largely frozen from winter, and air temperatures are hovering just above freezing. Conditions worsen through the day, and forecasts are now predicting the most intense precipitation to occur during the evening rush hour. Pretreatment options are limited because of the rain; any chemicals applied would be wasted. Forecasts are not clear on what form the precipitation will take—rain, sleet, or snow—in any particular location. Conditions are particularly problematic on road segments near any of the larger lakes. Lake effect snows could intensify quickly. Operationally, MDOT and the county maintenance crews will have to depend on near real-time data routed through the maintenance dispatcher to prioritize treatment beyond their planned routes.

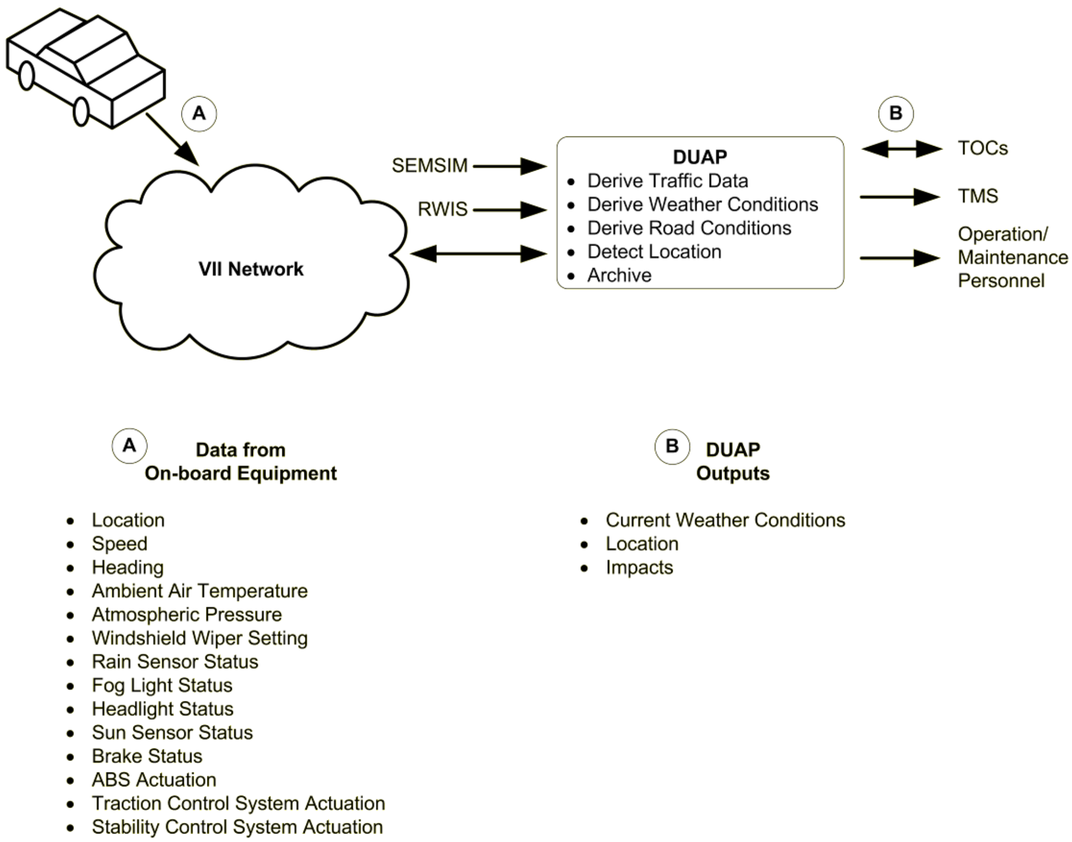


Figure 7 – Weather Response Scenario

VII-equipped vehicles provide a wealth of direct and indirect indications of weather conditions on the road network. Sensors throughout the vehicle monitor weather-related parameters for both the atmosphere and the road surface. While most of these measurements are needed for effective operation of specific vehicle subsystems, some are made available on the vehicle's control network. Parameters that are potentially available and of interest to weather responders include:

- Location
- Speed
- Heading
- Ambient air temperature
- Atmospheric pressure
- Windshield wiper setting
- Rain sensor status
- Fog light status
- Headlight status
- Sun sensor status
- Brake status

- ABS actuation
- Traction control system actuation
- Stability control system actuation

These observations are collected on the vehicle for publishing through the VII network to subscribing weather analysis services. For example:

- The DUAP system subscribes specifically to weather data with immediate operational impact. This subscription reduces the latency of data transmission and analysis, and allows DUAP to anticipate significant changes in weather conditions and in forecasts.
- FHWA's Weather Data Translator (WDT) subscribes to the VII data so that it can be correlated with supplemental data sets to synthesize pseudo-observations along road segments. The output is consistent with the *Clarus* system. *Clarus* then checks the quality of the data with *in situ* observations to present a unified view of the observation field for mapping and analysis.
- Enhanced local weather response systems can subscribe to VII data to supplement their existing detection. A bridge-deicing system, for example, could use not just measurements of road surface temperature and conductivity from its own instruments, but could monitor vehicle response to determine appropriate deicing strategies.

SEMSIM-equipped maintenance vehicles throughout the area are out on the roads monitoring conditions specifically in order to improve safety and mobility of the traveling public. Data on road conditions and atmospheric observations are collected in real-time and sent immediately to the SEMSIM servers. The trucks also send information on any treatment and plowing operations they may be executing. These data are sent with the vehicle location and observation time to the automatic vehicle location (AVL) system servers, from which they are taken for presentation in the SEMSIM user interfaces and for incorporation in DUAP applications.

Fixed ESS are deployed at specific locations throughout the region to address local weather-dependent concerns such as bridge icing, low visibility due to fog or intense precipitation, and flooding. Other ESS are deployed regionally to provide characteristic surface conditions and to supplement atmospheric observations from the National Oceanic & Atmospheric Administration (NOAA), the Michigan Department of Natural Resources (DNR), and other agencies concerned with more generalized observations and forecasting. Observations are collected by the RWIS servers from the ESS, and are subsequently collected from those servers by the DUAP system, the *Clarus* system, and other NOAA and commercial meteorological interests.

The DUAP system aggregates all the weather observations from these disparate sources to create a consistent set of observation fields. The system can then integrate the weather observations with corresponding traffic observations to correlate weather impacts and identify weather-response priorities. For example[4]:

- Air temperature change and relative humidity (from ESS), headlights, and vehicle speed changes (braking) might be used to indicate fog development; and
- Headlight state, windshield wiper settings, and vehicle speed changes could be used to indicate the presence of precipitation.

Once these direct and correlated observations are available, watch points and thresholds on key weather condition measures can be set to notify traffic operations and maintenance personnel. Weather information messages may be created for posting on CMS/DMS and publication to traveler information outlets. Further correlation of weather and traffic conditions could generate real-time risk maps to support dispatch of traffic control, Emergency Management Services (EMS), and/or courtesy patrols to the highest priority locations.

Based on these correlations, the DUAP system will send notices to subscribers via email, pager, or instant messaging (IM) whenever particular watch parameters exceed their notification thresholds.

Among automated system interfaces, the MITS ATMS and other traffic management systems could be provided with weather and road condition reports to overlay on network maps. SEMSIM could get additional data for faster and more granular updates on specific road segment conditions and combine those with a maintenance decision support system (MDSS) to dynamically update and optimize treatment plans. RCOC's FAST-TRAC system could get notice of the need for extended signal phases to facilitate mobility on snow routes.

In response to these notifications, the MITS Center would be enabled to provide information on specific weather hazards (e.g., icing, flooding) just as it provides information on other traffic events. SEMSIM could improve deployment of vehicles to prioritized maintenance needs; change treatment and plowing routes dynamically; monitor segments that are temporarily inaccessible or not otherwise able to be monitored; and allow for more accurate treatment analysis and deployment, thereby reducing costs. RCOC could use FAST-TRAC to create true emergency snow routes, rerouting traffic either to predetermined high-priority roadways, or dynamically adjusting timing to store and buffer or redistribute flows based on real-time roadway conditions.

5.3 Special Event Planning and Execution

The National Baby Food Festival (http://www.babyfoodfest.com) in Fremont, Michigan (population 4500) has in past years presented only a minor challenge for traffic planning and management. The town is reached primarily by highway

[4] The National Center for Atmospheric Research (NCAR) has performed a preliminary analysis of possible correlations that go beyond the direct vehicle/VII-provided observations and would provide significant meteorological value.

M-82, which also serves as the town's main thoroughfare. Four blocks of M-82 are closed in Fremont for one week each July to become the festival site. Even though up to 125,000 people attend each year (about 30,000 on Saturday alone), patrons self-park on city streets. Event planners this year would like to prolong activities by adding a Diaper Day that would extend the closure by one day and, hopefully, significantly increase attendance. The city is seeking permits for the event from MDOT, but approval is being held pending analysis of traffic impacts.

As chance would have it, significant numbers of VII-enabled vehicles attended the event in immediate prior years, providing detailed records of movement in and around the event site. Some O/D data were collected from vehicles whose owners had opted into MDOT's Congestion Relief Program[5]. As is the general case, traffic-related data originating on the vehicle consist of:

- Location
- Speed
- Heading
- Longitudinal acceleration
- Vertical acceleration
- ABS
- Wheel angle

The data were captured in periodic snapshots at a given location and time and then collected by the VII network.

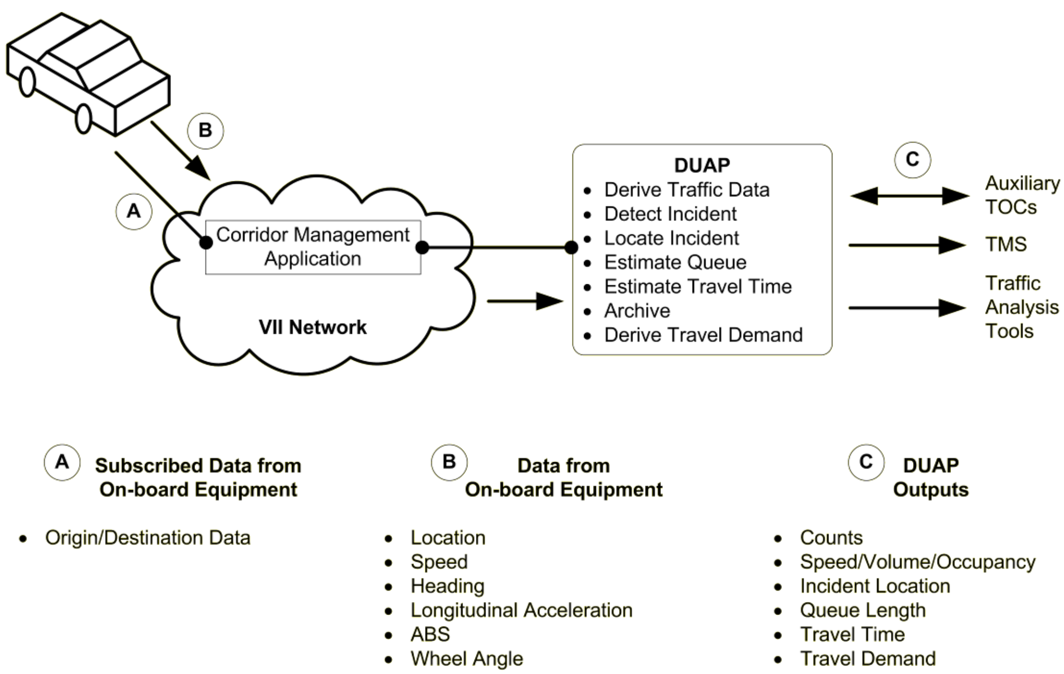


Figure 8 – Special Event Scenario

[5] A program conceived specifically for purposes of these scenarios and described in concept in the "Asset Management and Planning" scenario.

Data from last year's event were collected by DUAP and processed into traffic management parameters. As in other scenarios utilizing traffic data for operations monitoring and congestion planning, the DUAP system converted vehicle movement data into more traditional measures of speed, volume, and occupancy on given segments and synthesizes turning movements and any trip data not provided directly by the VII network. Data were archived within DUAP and converted to TMS/H-compliant forms for export.

Availability of data from the VII network in the prior year facilitated the use of MDOT's mobile Auxiliary TOC, which received event data through DUAP. This combination of resources enabled MDOT and event managers to provide real-time traffic information and travel times on CMS on approaches into and in town during the event. The CMS could also be used during the event to advise attendees of parking locations and availability.

In this year's event planning study, O/D, demand, turning movement, and parking data from last year's event are fed into simulation models with the proposed event changes to determine the impact of increased demand. Output from the simulation can be used to make modifications to last year's event traffic management plan to accommodate the increased demand. Deployment of the Auxiliary TOC in conjunction with increasing proportions of VII-enabled vehicles can then be used to verify the simulation forecasts and collect data for subsequent years.

5.4 Maintenance Planning

A section of highway consisting of an interchange, ramps, and overpass is seeing exceptionally high degradation rates. The pavement has visible rutting and cracking, and potholes have developed on joints. The bridge/pavement interface is developing significant gaps and potholes/ledges on the approach side. The interchange and arterial were expanded three years ago, and there is significant new industrial development in the area.

The increased traffic in the area is providing more VII data as well as increased pavement wear. VII-equipped vehicles are experiencing significant vertical and longitudinal accelerations from potholes, cracks, and gaps, and a noticeable increase in rapid wheel angle changes due to swerves and lane changes to avoid the surface defects and obstacles. Data collected in these vehicles include:

- Location
- Speed
- Heading
- Longitudinal acceleration
- Vertical acceleration
- ABS
- Wheel angle

DUAP receives this information from the VII network as it does any other set of vehicle observations, and the observations are available for use with other VII data for correlation with traffic, incident, and weather data. There are, however, data processing algorithms to be applied before the information can be interpreted in terms of surface conditions.

- DUAP converts vehicle directional accelerations, steering data, and location data to infer probable pothole locations and severities.
- DUAP tracks and correlates directional acceleration trends over time to infer rates of degradation in road and bridge surface conditions.
- DUAP derives pavement and bridge conditions from VII-originated accelerometry consistent with TMS/Pavement and TMS/Bridge data definitions.

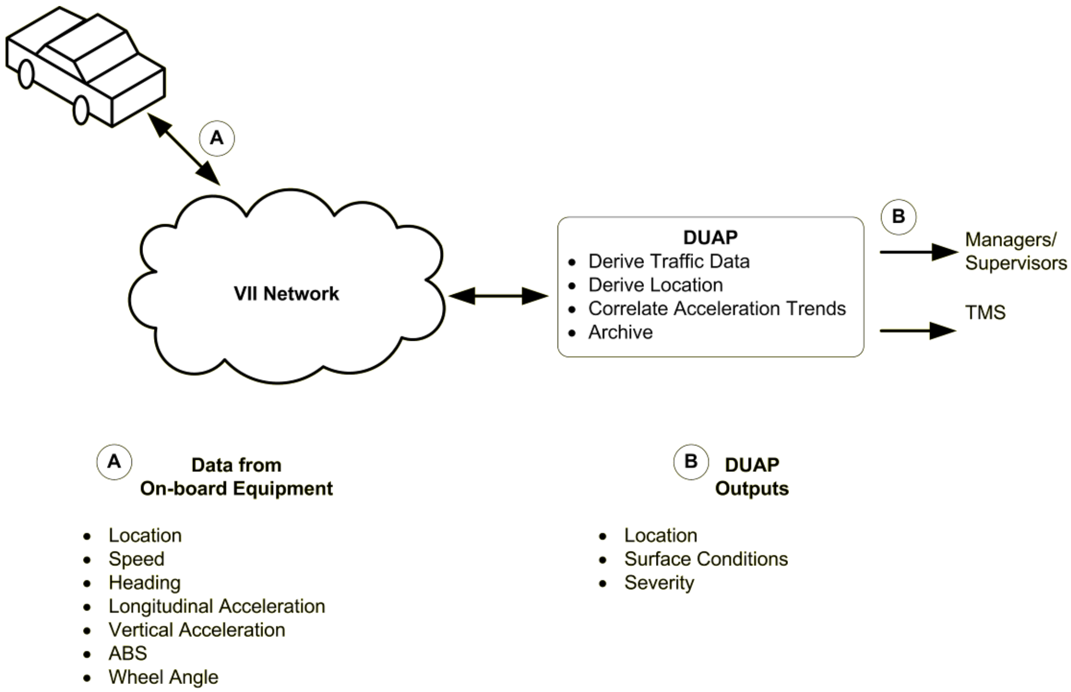


Figure 9 – Maintenance Scenario

Alerts of potential pavement degradation are then sent from the DUAP system to pavement managers and maintenance supervisors. Similarly, alerts on potential bridge condition degradation are sent to bridge managers.

Having received alerts of likely pothole locations, maintenance supervisors can dispatch crews to inspect and repair pavement as required. Likewise, bridge and pavement managers, alerted by the DUAP system, can:

- Perform augmented inspections;
- Perform analyses to determine progression of damage and remaining life at the current rate of degradation; and
- Reprioritize maintenance and restoration projects as required.

The derived roadway surface observations are sent to TMS/Pavement and TMS/Bridge data stores. Both the road surface condition data received from the VII network and the calculated performance information are sent to the DUAP archive.

If thresholds for alerts were not exceeded, degradation would be confirmed in regular (biennial) bridge and pavement surveys.

In this case, the accelerated loss of roadway surface integrity is determined to be due to the increased number of heavy vehicles used in adjacent development. The availability of more pavement condition information in a more timely manner provides an increasingly objective basis for project prioritization and allows the Call for Projects, Five-Year Road and Bridge Program, SLRP, and STIP to be updated. Restoration and interchange improvements are accelerated beyond the original SLRP, thus bringing the highway back into compliance with its performance benchmarks for mobility and safety.

5.5 Asset Management and Planning

Increasing traffic demands within Michigan generally cause increasing congestion and decreasing mobility. This results in safety issues and negative economic impacts due to the amount of time spent in traffic queues. As part of a Congestion Relief Program, MDOT studies various locations to assess and implement a solution. The congested corridor consists of a section of highway, including interchange and ramps, together with the major arterial feeding the interchange and its nearby intersections.

VII-equipped vehicles moving through the corridor provide data which includes:

- Location
- Speed
- Heading
- Longitudinal acceleration
- ABS
- Wheel angle

By VII design, data are provided as sequences of periodic location/speed/heading snapshots without reference to the particular vehicle generating the data. This scheme is intended to protect the anonymity of the drivers and vehicles by limiting the ability to identify individuals by their travel patterns. Drivers and vehicles opting into the MDOT Congestion Relief Program, however, can remove the restrictions toward anonymity and provide continuous trip data, from origin to destination, throughout the range of the VII network.

Data acquired on VII-equipped vehicles are sent through normal VII network operations and received by the DUAP system. These data are then combined with other data from fixed monitoring devices and correlated with asset, incident, and weather data.

- DUAP correlates location, speed, heading, and brake activity for multiple vehicles to infer and synthesize volume and occupancy along segments being observed. The individual vehicle speed data can be compressed into characteristic pseudo-observations for each lane and segment.
- DUAP converts the time-dependent location data into trip/segment profiles detailing lane changes and turning movements.

While the DUAP system performs data transformations to provide a base of traffic information, there are a variety of tools already in existence for analyzing and forecasting traffic conditions. To that end, traffic data (speed, volume, and occupancy) synthesized from VII data are provided by DUAP to TMS/H to take advantage of existing analytical processes. Similarly, the segment trip profiles and O/D pairs provided through VII are stored for use in travel demand models. Traffic data received from the VII network and the derived observations are also sent to the DUAP archive for later reuse.

Having synthesized a consistently detailed view of traffic throughout the corridor, the enriched traffic data are brought into existing analysis tools to evaluate sources and potential remediation of increased congestion. For example, the availability of trip/segment data provides details on turning movements to fine-tune models and signal plans along arterials. Similarly, greater availability of O/D pairs enables more complete analysis of corridor demand, intermodal solutions, and potential new developments in the region.

The traffic analyses in this case might determine that the congestion in question is a consequence of increased demand from new development, temporary detours associated with construction, and no provision for alternative vehicular or intermodal capacity. Ongoing monitoring of the corridor using the capabilities provided by VII and DUAP would validate or refine that analysis. Some potential countermeasures—modifying signal timing plans on arterials or adding high-occupancy vehicle (HOV) lanes, for example—could be facilitated and measured using the same VII and DUAP capabilities.

6 SUMMARY OF IMPACTS

This section describes the operational impacts of the proposed system on the users, the developers, and the support and maintenance organizations. It also describes the temporary impacts on users, buyers, developers, and the support and maintenance organizations while the new system is being developed, installed, or used for training.

6.1 Operational Impacts

DUAP impacts on the management and operations of MDOT systems are best understood in terms of its data flows. VII and DUAP affect the collection of data about the transportation system, how those data are processed within MDOT, and the dissemination of data to MDOT's customers. The DUAP data flows contain more data types of a greater variety and are received more frequently than any current MDOT data streams.

Data collection is both more efficient and more effective with VII and DUAP. MDOT is able with DUAP to extend its data gathering capabilities beyond its own resources and those of its partnered transportations agencies. Data used for other purposes on vehicles that are using the transportation system are repurposed with VII to support management and operation of that system. Much of the data collection needed by MDOT is automated, allowing reduction of MDOT resources to gather those data. Data are gathered in near real time wherever and whenever vehicles are using the infrastructure—not just where and when specially instrumented devices are installed or dispatched. The resource cost savings with VII data availability are large in both infrastructure and personnel.

The availability of VII data for MDOT management and operations extends the capabilities of existing systems and enables new applications. More data gathered in near real time enables systems to respond dynamically to changing conditions throughout the transportation network. While traffic management systems like the MITS Center have paved the way for system monitoring, reactive response, and dynamic traveler information, DUAP provides the capability to be proactive in system management and operations. Many lower level functions can be automated, and decision support rests on a larger foundation of more diverse information.

The potential for enhancing existing systems does not necessarily mean, however, that existing operating procedures will be forced to change. Enhancements could work through the existing user interfaces to extend the geographical and operational reach of the management and operations centers. Automation of the information exchange would minimize any incremental workload to operators, and it would also allow for quicker responses to events.

The price for the increased DUAP data flow is paid largely in data management and control. VII provides order-of-magnitude increases in the amount of data to be received, stored, managed, and retrieved. Data management challenges—identifying and maintaining the data relationships, maintaining the security and integrity of the data stores, for example—increase exponentially because of the complexity and quantity of the data. New skills and many of the human resources released from data collection will be needed in data management.

Similarly, implementing VII and DUAP systems will require administrative effort to build and maintain the interfaces between these and other systems already in existence. Changes affecting the data published from any system—new or existing—on the network would need to be evaluated for their impact on other systems and operations.

DUAP will also impact the means and content of MDOT's information distribution to stakeholders including the traveling public, other transportation agencies, contractors, and commercial ISPs. New messaging capabilities could be used for both public traveler information and for enhancing MDOT business processes.

For example, VII and DUAP are capable of sending data back to the vehicles in order to provide additional information to the drivers. The information to be sent to the driver might originate with MDOT, but could pass first to a third-party provider to supplement the content or provide formatting for the in-vehicle context. These capabilities create significant new operational opportunities and challenges in tailoring communications to local real-time conditions while remaining consistent with existing means of communication and control—like fixed signage, dynamic message signs, and commercial radio traffic broadcasts—and emerging telematics services.

Similarly, DUAP-enhanced information distribution could be used to facilitate communication between MDOT and its own contractors and service providers. Work zones, for example, become much "smarter" when real-time traffic and road weather conditions are made available to the maintenance and construction crews. Reactive maintenance dispatch can be expedited or automated with alerts based on VII-originated pavement condition data.

6.2 Impacts during Development

As noted in the discussion of operational impacts, development and deployment of the VII and DUAP systems will require some agency technical, administrative, and financial resources beyond those provided by the development team.

- Establishing effective standards and procedures for information exchange will need a team of technical representatives from affected agencies and supporting system vendors.
- Making existing system modifications to publish and ingest the DUAP data streams may require agency technical and financial support beyond that needed for DUAP development.
- Integration of DUAP development with other MDOT projects (for example, the MITS Center ATMS upgrade) may require additional analysis and testing on both the project and DUAP sides of the interface.

Because DUAP-generated data are intended to supplement existing data wherever possible, impact on existing systems is expected to be minimal during the development process. Testing will need to be performed in order to confirm that DUAP data are in the correct format for integration into the existing databases. Plans need to be developed and implemented, however, to allow for increases in the database storage, retrieval, and archival capabilities in those systems.

7 ANALYSIS OF THE PROPOSED SYSTEM

This section provides an analysis of the benefits, limitations, advantages, disadvantages, and alternatives and trade-offs considered for the proposed system.

7.1 Summary of Improvements

DUAP allows participating agencies to extend the reach of their existing management and operations systems.

The following are some of the examples of benefits from DUAP applications.

- DUAP system data supplement existing TMC/TOC data.
- Accident occurrence and location can be detected through the incident detection and incident locator algorithms.
- Mainline queues can be determined from the queue length algorithm.
- Road network link travel times can be determined from the travel time algorithm.
- Other applications can be notified of incidents through the C2C traveler information messages.
- VII traveler information, such as trip routing, can be obtained from DUAP and sent back to vehicles.
- The DUAP system combines meteorological data from many disparate sources to create a consistent set of observation fields and identify weather-response priorities.
- DUAP can send notices to subscribers whenever particular meteorological watch parameters exceed their notification thresholds.
- The weather benefits include:
    - Roads get cleared faster;
    - More accurate traveler information is provided;
    - Weather-related accident risks are reduced;
    - Weather-related mobility impacts are lessened; and
    - Treatment material costs are reduced.
- Surface conditions can be inferred from data generated from DUAP:
    - Pothole locations and severities;
    - Road and Bridge surface degradation; and
    - Additional pseudo-observations for bridge and pavement conditions can be generated.
- Surface condition information inferred from DUAP data can be used to request augmented inspections, and to reprioritize maintenance and restoration projects.
- DUAP can generate trip/segment profiles detailing lane changes and turning movements.
- Traffic data such as speed, volume, and occupancy can be provided by DUAP to TMS/H to supplement existing data processes.
- Segment trip profiles and O/D pairs can be used in more-detailed travel demand models.
- Data and outgoing messages are logged by DUAP archiving services.

7.2 Limitations

Although the DUAP concept provides significant flexibility in terms of the data to be exchanged by participating agencies, those advantages are the source of some limitations in its deployment and operations.

The data feeds to DUAP will initially be limited by the relative scarcity of VII-equipped vehicles and infrastructure. Over time, however, the trickle of data will become a flood. Both extremes create unique sets of problems, and it is dangerous to try to scale results from one extreme to the other. For example, obtaining reliable traffic information from a small number of vehicles may require algorithms that become incorrect or unnecessary as volumes of VII data increase. It may also be possible to have too much data—to the extent that it may become necessary to sample, aggregate, or average data from VII. While the system concepts described in Section 4 accommodate an evolution of services, DUAP system measures will have to be monitored for those slow changes in performance.

Because of the volume of data, plans need to be implemented to allow for increases in the data storage, retrieval, and archival capabilities of systems that may be receiving data from DUAP—TMS, for example. If no increase in capacity or capability is implemented, the DUAP concept may not work because the additional data generated by DUAP could conceivably overwhelm the downstream databases.

The ability to add new input and output interfaces to DUAP makes it somewhat sensitive to changes in data and messaging standards. The ease with which new interfaces are added ensures that DUAP will accumulate many such interfaces. Each interface, however, may be subject to changes coming from the interfacing system. It may be necessary to modify DUAP as those systems change over time, creating configuration control and maintenance costs outside the direct control of MDOT.

The collection of more data of such diverse types creates user demand for more (and more) reports and analysis of the data. While this should generally be seen as a tremendous opportunity, the ongoing cost of supporting specialized reports and analysis tools tends to be much larger than the initial cost of development. Procedures for requesting, implementing, maintaining, and decommissioning specialized analyses and reports will need to be created.

APPENDIX A - DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly interpret this Concept of Operations.

Term	Definition
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Brake System
ADMS	Archived Data Management System
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
AVL	Automatic Vehicle Location
AVSS	Advanced Vehicle Safety System
BCFS	Bridge Condition Forecasting System
BMS	Bridge Management System
C2C	Center to Center
CAD	Computer Aided Dispatch
CAR	Center for Automotive Research
CCTV	Closed-Circuit Television
CGI	Center for Geographic Information
Clarus	The *Clarus* (which is Latin for "clear") System is an integrated surface transportation weather observing, forecasting and data management system.
CMS	Changeable Message Sign; or Congestion Management System
ConOps	Concept of Operations
CVO	Commercial Vehicle Operations
CVPC	Connected Vehicular Proving Center
CVTA	Connected Vehicle Trade Association
DMS	Dynamic Message Signs
DNR	Department of Natural Resources
DSRC	Dedicated Short Range Communications
DTE	Development Test Environment

DUAP	Data Use Analysis and Processing
EMS	Emergency Management Services
ESS	Environmental Sensor Station
FAST-TRAC	Faster And Safer Travel Through Routing and Advanced Controls
FHWA	Federal Highway Administration
FICS	Fabrication Inspection and Construction System
G	A unit of force that is equal to the force exerted by gravity on a body at rest
GB	Gigabyte(s)
GPS	Global Positioning System
HOV	High Occupancy Vehicle
hPa	Hectopascal – one hundred Pascals (equal to one millibar)
HPMS	Highway Performance Monitoring System
ILOM	Integrated Lights-Out Management
IM	Instant Messaging
ISP	Information Service Provider
IT	Information Technology
ITS	Intelligent Transportation Systems
JNI	Java Native Interface
LAN	Local Area Network
MADIS	Meteorological Assimilation Data Ingest System
Mb/s	Megabit per second
MBIS	Michigan Bridge Inspection System
MBRS	Michigan Bridge Reporting System
MDIT	Michigan Department of Information Technology
MDOT	Michigan Department of Transportation
MDOTBP	Michigan Department of Transportation Business Plan
MDSS	Maintenance Decision Support System
MEDC	Michigan Economic Development Corporation
MFOS	MDOT Financial Obligation System
MGF	Michigan Geographic Format

MITS	Michigan Intelligent Transportation Systems
MPINS	Map Project Information System
MSP	Michigan State Police
MTPP	Michigan Transportation Policy Plan
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic & Atmospheric Administration
O/D	Origin / Destination
OBE	On Board Equipment
OEM	Original Equipment Manufacturer
PMS	Pavement Management System
POC	Proof of Concept
PPM	Pavement Preservation Program
P/PMS	Program/Project Management System
psi	Pound per square inch
PTMS	Public Transportation Management System
PTR	Permanent Traffic Recorder
RCMC	Road Commission of Macomb County
RCOC	Road Commission for Oakland County
RFID	Radio Frequency Identification
RWIS	Road Weather Information System
SAE	An organization formerly known as Society of Automotive Engineers, now known as SAE International
SDN	Service Delivery Node
SEMSIM	Southeast Michigan Snow and Ice Management
SLRP	State Long-Range Plan
SMART	Suburban Mobility Authority for Regional Transportation
SMS	Safety Management System
SQL	Structured Query Language
SRS	Software Requirements
STIP	State Transportation Improvement Plan

SWAD	Statewide Warranty Administration Database
TCRS	Traffic Crash Reporting System
TMC	Traffic Management Center
TMS	Transportation Management System
TMS/H	Traffic Monitoring System for Highways
TOC	Traffic Operations Center
TSC	Transportation Service Center
UPS	Uninterruptible Power Supply
USDOT	United States Department of Transportation
VII	Vehicle Infrastructure Integration
VIIC	Vehicle Infrastructure Integration Consortium
WAN	Wide Area Network
WDT	Weather Data Translator
XML	eXtensible Markup Language

APPENDIX B - REFERENCED DOCUMENTS

The following documents contain additional information pertaining to this project or have been referenced within this document:

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