Analysis, Modeling, and Simulation (AMS) Testbed Requirements for Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs

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16. Abstract

The document presents a combined set of requirements for an AMS Testbed based on the foundational research already conducted under the ATDM Program, and the analytical needs of the DMA bundles. A total of 103 requirements are identified to represent the following:

- System Entities ("nodes") (System Users, Connected Vehicles/Devices, Communications Systems, Operational Data Environments, and System Managers)
- Data and Information Flows ("arcs") connecting system entities, including attributes of latency, aggregation, message content, range, reliability, and accuracy (error)
- ATDM Strategies and DMA Applications enhancing current decision-making by System User or System Managers or enabling new forms of decision-making by Users and Managers
- Operational Conditions (ambient demand, incident, and weather conditions)
- System Performance Measurement (mobility, safety, environmental, cost)

Each requirement is assigned a technical risk, an importance rating, and priority. Technical risk represents a subjective assessment of the difficulty in meeting this requirement within a near-term test bed compared to current modeling capabilities. This subjective assessment is calculated using inputs from expert stakeholder feedback (collected as a part of workshop held at the 2013 TRB Annual Meeting), members of the USDOT key content review team, and the authors of this document. Importance ratings were assembled in a similar manner to technical risk assessment, and represents a subjective measure of how critical this requirement will be in differentiating among expected alternatives. Priority ratings are non-subjective measures calculated combining the expert panel assessments of technical risk and importance by modeling scale (tactical and strategic). For this effort, USDOT seeks testbed development that maximizes the number of important requirements, while minimizing technical risk. The collection of functional requirements presented in this report represent a high-level set of capabilities required by an ATDM-DMA Testbed. However, these functional requirements are not detailed enough to allow an analyst to directly create one or more testbeds. Each of these high-level functional requirements will have to be broken down into more detailed requirements in any follow-on testbed design and test effort.

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Executive Summary

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1 Introduction

1.1 Background

Effective congestion management involves a systematic process that enhances mobility and safety of people and goods, and reduces emissions and fuel consumption through innovative, practical, and cost-effective strategies and technologies. In response, the Federal Highway Administration (FHWA) Office of Operations initiated the Active Transportation and Demand Management (ATDM) Program to seek active, integrated and performance based solutions to improve safety, maximize system productivity, and enhance individual mobility in multi-modal surface transportation systems [1]. ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real-time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency. Under an ATDM approach, the transportation system is continuously monitored. Using historical and real-time data, predictions of traffic conditions are generated and actions are performed in real-time to achieve or maintain system performance. The ATDM Program is intended to support agencies and regions considering moving towards an active management approach. Through ATDM, regions attain the capability to monitor, control, and influence travel, traffic, and facility demand of the entire transportation system and over a traveler's entire trip chain. This notion of dynamically managing across the trip chain is the ultimate vision of ATDM. ATDM builds upon existing capabilities, assets, and programs and enables agencies to leverage existing investments - creating a more efficient and effective system and extending the service life of existing capital investments. All agencies and entities operating transportation systems can advance towards a more active management philosophy.

While active management can be applied to any part of our transportation system (such as implementing dynamic pricing on a facility to manage congestion, or informing travelers of specific or compatible transit operations for their trip), it is most beneficial when the relationships and synergies to other parts of the system are considered. For example, an agency could apply adaptive ramp metering to improve freeway traffic flow. However, if the effect of ramp metering on connecting arterials is not considered or if dynamic actions to manage overall demand are not implemented, some of the system-wide performance gains from the ramp metering system may be compromised. The ATDM Program has identified 23 strategies that fall under three major categories (Active Demand Management, Active Traffic Management, Active Parking Management) are documented in the ATDM Analysis, Modeling, and Simulation (AMS) Concept of Operations [2]. These strategies (Table 1-1) are not intended to be inclusive, but are intended to demonstrate how the ATDM concept of dynamically managing the entire trip chain can be manifested in individual strategies. Figure 1-1illustrates the five stages in a trip chain that represent a series of decisions that affect demand and utilization of the network.

Table 1-1: List of ATDM Strategies

Active Demand Management	Active Traffic Management Strategies	Active Parking Management Strategies
Dynamic Fare Reduction	Adaptive Ramp Metering	Dynamic Overflow Transit Parking
Dynamic HOV/Managed Lanes	Adaptive Traffic Signal Control	Dynamic Parking Reservation
Dynamic Pricing	Dynamic Junction Control	Dynamic Wayfinding
Dynamic Ridesharing	Dynamic Lane Reversal or Contraflow Lane Reversal	Dynamically Priced Parking
Dynamic Routing	Dynamic Lane Use Control	
Dynamic Transit Capacity Assignment	Dynamic Merge Control	
On-Demand Transit	Dynamic Shoulder Lanes	
Predictive Traveler Information	Dynamic Speed Limits	
Transfer Connection Protection	Queue Warning	
	Transit Signal Priority	

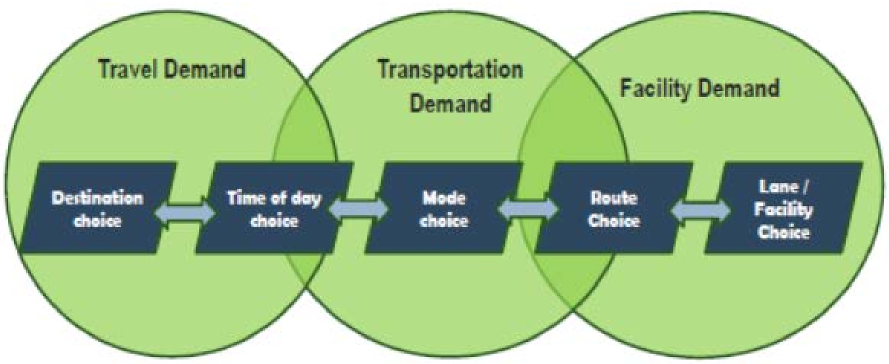

Figure 1-1: Trip Chain and Relation to Demand Activities [2]

Simultaneously, the USDOT initiated connected vehicle research to evaluate the merit of applications that leverage connected vehicles, travelers, and Intelligent Transportation Systems (ITS) infrastructure to enhance current operational practices and transform future surface transportation systems management. According to the USDOT, "*Connected vehicles refer to the ability of vehicles of all types to communicate wirelessly with other vehicles and roadway equipment, such as traffic signals, to support a range of safety, mobility and environmental applications of interest to the public and private sectors. Vehicles include light, heavy and transit vehicles. The concept also extends to compatible aftermarket devices brought into vehicles and to pedestrians, motorcycles, cyclists and transit users carrying compatible devices, which could make these vulnerable users more visible to surrounding traffic.*" This research program is a collaborative initiative spanning the Intelligent Transportation Systems Joint Program Office (ITS JPO), Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA). One foundational element of the connected vehicle research is the Dynamic Mobility Applications (DMA) Program [3]. The DMA Program seeks to create applications that fully leverage frequently collected and rapidly disseminated multi-source data gathered from connected travelers, vehicles and infrastructure, and that increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks. The objectives of the DMA Program include:

- Create applications using frequently collected and rapidly disseminated multi-source data from connected travelers, vehicles (automobiles, transit, freight) and infrastructure;
- Develop and assess applications showing potential to improve the nature, accuracy, precision and/or speed of dynamic decision making by both system managers and system users;
- Demonstrate applications predicted to improve the capability of the transportation system to provide safe, and reliable movement of goods and people; and
- Determine required infrastructure for transformative applications implementation, along with associated costs and benefits

In 2011, the DMA Program identified seven high priority bundles of transformative mobility applications that have the potential to improve the nature, accuracy, precision and/or speed of dynamic decision making by system managers and system users (Table 1-2). As a first step, the DMA Program partnered with the research community to further develop six of these high-priority transformative concepts (i.e., EnableATIS, FRATIS, IDTO, INFLO, MMITSS, and R.E.S.C.U.M.E.), and identify corresponding data and communications needs. The seventh bundle on Next Generation ICM (Integrated Corridor Management) may be developed at a later date.

Table 1-2: List of DMA Bundles

Bundle Acronym	Objective
EnableATIS	*Enable Advanced Traveler Information System* seeks to provide a framework for multi-source, multimodal data to enable the development of new advanced traveler information applications and strategies.
FRATIS	*Freight Advanced Traveler Information System* seeks to provide freight-specific route guidance and optimizes drayage operations so that load movements are coordinated between freight facilities to reduce empty-load trips.
IDTO	*Integrated Dynamic Transit Operations* seeks to facilitate passenger connection protection, provide dynamic scheduling, dispatching, and routing of transit vehicles, and facilitate dynamic ridesharing.
INFLO	*Intelligent Network Flow Optimization* seeks to optimize network flow on freeway and arterials by informing motorists of existing and impending queues and bottlenecks; providing target speeds by location and lane; and allowing capability to form ad hoc platoons of uniform speed.
MMITSS	*Multi-Modal Intelligent Traffic Signal System* is a comprehensive traffic signal system for complex arterial networks including passenger vehicles, transit, pedestrians, freight, and emergency vehicles.
R.E.S.C.U.M.E.	*Response, Emergency Staging and Communications, Uniform Management, and Evacuation* is an advanced vehicle-to-vehicle safety messaging over DSRC to improve safety of emergency responders and travelers.
Next Gen ICM	*Next Generation Integrated Corridor Management* seeks to optimize corridor mobility through a system-wide integration of enhanced operational practices and information Services.

The DMA Program is currently sponsoring several efforts to develop a prototype and conduct a small-scale demonstration for each of the six bundles to test if the bundles can be successfully prototyped and deployed in the future. The DMA Program is also sponsoring separate, multiple efforts (one for each bundle) to conduct an independent assessment of the impacts of the prototype as well as the impacts of the bundle when deployed at various levels of potential future market acceptance in the region where a small-scale demonstration of the prototype will be conducted. The data and findings from the small-scale demonstrations and impacts assessments will help USDOT make more informed decisions regarding the technical feasibility and potential impacts of deploying the bundles more widely. Both DMA and ATDM Programs have similar overarching goals. However, each program has a unique research approach seeking to meet these goals. The DMA Program focuses on exploiting new forms of data from wirelessly connected vehicles, travelers, and the infrastructure to enable transformative mobility applications. The ATDM Program focuses its research efforts on accelerating the pace of dynamic control within transportation systems management through operational practices that incorporate predictive and active responses to changing operational conditions[1]. While on the surface, these two research agendas may seem independent, the DMA and ATDM research approaches are really two sides of the same research coin. The more active forms of control envisioned by the ATDM Program will rely on new forms of data from connected vehicles, travelers, and infrastructure to hone predictions and tailor management responses. Likewise, the transformative applications developed in the DMA Program must be incorporated within current and future dynamic system-wide management practices in order to realize their full potential.

In order to explore potential transformations in transportation systems performance, both programs require an AMS capability. AMS tools and methodologies offer a cost-effective approach to addressing complex questions on optimization of longer-range investments, shorter-term operational practices, and overall system performance. Both programs have invested significant resources in the development of advanced concepts and foundational research, but the potential impacts from deployment are uncertain and poorly quantified. Each program recognizes the need to test these concepts, applications, and operational practices as a key next step in the process of moving research from concept towards deployment. The two programs must identify the technologies, applications, and operational approaches that work cost-effectively in concert with each other in order to justify large-scale demonstrations and pilot deployments.

A capable, reliable AMS Testbed provides a valuable mechanism to address this shared need by providing a laboratory for the refinement and integration of research concepts in a virtual computer-based AMS environment prior to field deployment. An AMS Testbed as envisioned here refers to a set of computer models that can replicate the effects of public agencies and private sector in a region implementing concepts, bundles, and strategies associated with the DMA and ATDM Programs. The AMS Testbed will be implemented in a laboratory setting in that the modeling conducted will not be directly connected to the systems, algorithms, or Traffic Management Center (TMC) operators that make real-time traffic management decisions. However, it is the intent to make the AMS Testbed as closely based in reality as possible by modeling an actual metropolitan region's transportation system (e.g., road, transit, and parking networks), transportation demand (e.g., persons, vehicles, transit), and DMA and ATDM concepts, bundles, and strategies.

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[1] Operational conditions describe the frequency and intensity of specific travel conditions experienced by a traveler over the course of a year. Operational conditions are identified by a combination of specific travel and traffic demand levels and patterns (e.g., low, medium or high demand), weather (e.g., clear, rain, snow, ice, fog, poor visibility), incident (e.g., no impact, medium impact, high impact), and other planned disruptions (e.g., work zones).

A joint DMA-ATDM AMS Testbed can make significant contributions in identifying the benefits of more effective, more active systems management, resulting from integrating transformative applications enabled by new data from wirelessly connected vehicles, travelers, and infrastructure. To this end, the DMA and ATDM Programs have jointly sponsored the planning of multiple AMS Testbeds to support the two programs in evaluating and demonstrating the system-wide impacts of deploying application bundles and strategies in an AMS environment. This planning effort has resulted in a series of reports, including:

- AMS Testbed High Level Requirements for DMA and ATDM Programs (this report)
- AMS Testbed Preliminary Evaluation Plan for DMA Program [4]
- AMS Testbed Preliminary Evaluation Plan for ATDM Program [5]
- AMS Testbed Framework for DMA and ATDM Programs [6]
- AMS Testbed Initial Screening Report [7]

It is envisioned that multiple AMS Testbeds will be developed to both mitigate technical risk and enable a more rigorous evaluation of the impacts and benefits of applying DMA and ATDM approaches, given differences in regional characteristics and varying combinations of bundles and strategies. As mentioned previously, it is the intent to make these AMS Testbeds as closely based in reality as possible by modeling actual metropolitan region's transportation systems (e.g., road, transit, and parking networks), transportation demand (e.g., persons, vehicles, transit), and DMA and ATDM concepts, bundles, and strategies.

1.2 Purpose

This document presents a combined set of requirements for the AMS Testbed based on the foundational research already conducted under the ATDM Program, and the analytical needs of the DMA bundles. The purpose of this document is to provide a priority-weighted set of analytical requirements that can guide the development of an AMS Testbed framework that recognizes both technical risk and the primary evaluation needs of both programs.

1.3 Approach

One key observation is that even with combined resources between the two programs, it is not possible to solve the entire surface transportation modeling problem with a handful of near-term AMS Testbeds. A discussion of the nature of the primary hypotheses of the two programs as they pertain to AMS Testbed experimentation is provided as a prologue to the System Description in Section 2. This underlying set of hypotheses provide a foundation for the prioritization and organization of the AMS Testbed requirements developed in this task.

In order to best target ATDM and DMA program investment in AMS Testbed development, our approach to targeted requirements development includes both a requirement and an assigned priority, combining both an assessment of the technical risk in meeting the requirement, and the importance of the requirement in modeling and evaluating an ATDM strategy or a DMA bundle.

Requirements are organized in the following manner:

- Functional requirements, which will define what the AMS Testbed should do
    - Where appropriate, we identify corresponding performance requirements, defining how well the requirement should be met, and
    - Modes of operation, which will define under what conditions the requirement will be met
- Corresponding priority, which will be based on the technical risk and criticality of the requirement

2 Hypotheses and System Description

This section identifies AMS Testbed hypotheses and presents a comprehensive system description. First, we present a set of primary hypotheses for the DMA and ATDM programs that an AMS Testbed will test. Overlapping and divergent elements of these key hypotheses are explored. Next we present a system description based on the intersection of the two programs key hypotheses. The description that can be utilized to describe alternative deployed systems relevant to the overarching experimentation required in each program. We present a set of four alternative deployed systems that an AMS Testbed capability must both clearly differentiate and quantitatively evaluate. This program-independent world view forms the basis for deriving system requirements for a joint ATDM-DMA AMS Testbed. Functional requirements are introduced based on the structure of the unified system description.

2.1 Key Hypotheses

An AMS Testbed is essentially a complex experimental apparatus created to test specific research hypotheses. It is not an operational system, but must represent and evaluate alternative operational systems. The DMA and ATDM programs have differing but overlapping visions on investments in technologies and enhanced operational practices can result in more effective systems management, and a transportation system with improved mobility, safety and reduced environmental impacts.

In the ATDM program, the focus is on quantifying the value of more active and predictive systems management:

"…to conduct business in a new way, by proactively managing transportation systems and services to respond to real-time conditions while — at the same time — providing realistic choices for managing travel demand… ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Under an ATDM approach, the transportation system is continuously monitored, and through the use of available tools and assets, traffic flow is managed and traveler behavior influenced in real time to achieve operational objectives." [2]

Translating this vision to a hypothesis statement that could be tested in an AMS Testbed:

ATDM Program Hypothesis: Incorporating predictive (compared to reactive) and more active (reduced latency) dynamic transportation system management considering the full spectrum of potential traveler decision-making in response to changing operational conditions yields cost-effective gains in system efficiency and safety, and reductions in negative environmental impacts.

Such a hypothesis might be misrepresented as a truism – that in fact prediction and more active and comprehensive management must in fact be cost-effective or at least effective in yielding gains in system efficiency. However, it is not clear that all investments in improving prediction or reducing the latency of decision-making are cost-effective in all cases. More specifically, not all ATDM-related investments can be equally effective or cost-effective. Therefore, an ATDM Testbed must address both the ATDM Program hypothesis as well as its corollary ATDM Testbed hypothesis:

ATDM Testbed Hypothesis: An AMS Testbed can be developed that can accurately quantify the potential cost and benefits of system improvements incorporating predictive, active, and comprehensive responses to changing operational conditions, and effectively differentiate between more and less effective alternative system improvements within the resource and schedule constraints of the ATDM program.

Note that the differentiation among alternative approaches is not the same as designing, prototyping or perfecting methods of prediction and active management. The ATDM Testbed hypothesis is focused on the value of prediction and active management as represented in alternative systems that attempt to address the ATDM Program hypothesis, rather than representing and refining a single ATDM master prototype system.

In the DMA program, the focus is on exploiting new forms of data from wirelessly connected vehicles, travelers, and infrastructure to enable transformative mobility applications.

“The vision of the Dynamic Mobility Applications program is to expedite the development, testing, commercialization, and deployment of innovative mobility applications, fully leveraging both new technologies and federal investment to transform transportation system management, to maximize the productivity of the system and enhance the mobility of individuals within the system.” [8]

Translating this vision to a hypothesis statement that could be tested in an AMS Testbed:

DMA Program Hypothesis: Compared to legacy systems, the introduction of applications based on new forms of wirelessly-connected vehicle, infrastructure, and mobile device data yields cost-effective gains in system efficiency and safety, and reductions in negative environmental impacts.

This hypothesis is not an accepted truism within the transportation community. Enabling the capture, distribution and processing of new forms of data will certainly incur additional costs, but whether the associated benefits are actually transformative, or even cost-effective, is an open question. However, similar to the ATDM program, some applications are likely to be cost-effective or at least effective in yielding gains in system efficiency. However, it is not clear that the collective investment in enabling new forms of data capture to support some or all of the transformative applications is cost-effective in all cases. More specifically to the core of DMA program, not all DMA-related investments will be equally effective or cost-effective. Therefore, the AMS Testbed must address both the DMA Program hypothesis as well as its corollary DMA Testbed hypothesis:

DMA Testbed Hypothesis: An AMS Testbed can be developed that can accurately represent new forms of wireless data capture and defined mobility applications, quantify the potential cost and benefits associated with enabling these applications, and effectively differentiate between more and less cost-effective alternative systems incorporating differing forms of systematic data capture and the deployment of some or all mobility applications within the resource and schedule constraints of the DMA program.

The two Program and AMS Testbed hypotheses, although they focus on different aspects of a larger problem, are complementary forms of research regarding the broader surface transportation system improvement and investment planning decision. In the next section, we present a transportation system description that attempts to reflect all of the key hypotheses of the two programs.

One benefit of addressing the ATDM and DMA hypotheses jointly is to provide an analytical method of comparing alternative systems that are in fact combinations of the visions of both programs. For example, is the most cost-effective predictively-managed system more cost-effective than a reactive system with some collection of near-term mobility applications? We might also posit a less competitive research question with a complementary one: does the incorporation of some new forms of wirelessly connected vehicle and traveler data inherently enable the most cost-effective forms of predictive management? Therefore, while the two programs are asking relevant research questions in isolation of each other, a decision-maker contemplating system investments is likely more interested in identifying the most effective combination of legacy/new technology and associated predictive/active management.

Studies utilizing a joint ATDM-DMA AMS Testbed will analyze the regional mobility impacts of various combinations of DMA Applications, deployed in isolation or combination. For the ATDM Program, analyses will test various combinations of ATDM strategies based on an active management approach to demonstrate the system-wide and localized impacts and benefits of taking an ATDM approach to transportation management. Cost-effectiveness is a critical aspect to justifying demonstration and early deployment and therefore the hypotheses reflect the importance of cost-effectiveness. One part of that includes trying different sub-alternatives with improvements swapped in and out, and applications deployed in isolation and in combination. The testbed is intended to focus on the impacts or benefits of deployment, but the alternatives tested will also have an associated cost, calculated outside of the testbed.

The testbed need not seek most the complex or detailed method of emulation in every aspect of modeled system entities or user behavior. The intent of this effort is to systematically manage technical risk, and seeking ways of separating risk so that we are not completely dependent on single points of failure in any technical approach.

The testbed concept developed here is intended as an off-line test-bed, not a predictive tool to be integrated within an operational system. Therefore, the test bed is not intended to be a real-time predictor, although it is intended to emulate forms of real-time prediction. Findings from the development of one or more test beds may be useful in the design or development of improved prediction systems. However, the focus of the effort is on the projected value of a range of prediction techniques (simple, faster and less precise versus complex, slower and more precise) rather than on the development of a single highly precise prediction technique. Other concurrent FHWA research efforts are tackling the problem of developing complex and highly precise prediction methods, and findings from these efforts will be useful in correctly representing these approaches within an AMS Testbed.

Testbed development is intended to leverage open source and open data concepts where practical, to both engage potential analysts and to foster rapid adoption of analytical approaches developed in this effort. Availability of analysis plans, test bed development progress, algorithms and methodological statements, as well as input files and output data are expected to be broadly shared through the USDOT Open Source Portal (www.its-forge.net) and the USDOT Research Data Exchange (www.its-rde.net).

2.2 System Description

A system description is as an abstraction of the overall transportation system that can serve to highlight both the hypotheses posited by the two programs as well as be used as a building block to devise and document alternative system deployments evaluated within an AMS Testbed. The system description utilized in this document is shown in Figure 2-1. On the far left side of the figure, there is a column of **System Users**, who represent the travelers, drivers and workers who directly utilize the transportation system. System Users are humans, who make a range of strategic decisions regarding their travel. These decisions may be whether to travel, what mode of travel to use, when to take a trip, what route to travel on within a mode, where to park, and finally, how a collection of trips (tour) within a day will meet a variety of obligations and desired outcomes. Further there are tactical decisions that must be made, particularly as a driver, regarding how fast to travel, in what lane, and how to maneuver effectively and safely in a variety of situations. A traveler (upper left) may transition between multiple states while planning and executing travel, starting from a pre-trip state and passing through one or more combinations of pedestrian, cyclist, passenger, driver, or transit rider states prior to completing a trip. Each state will have a different set of potential decisions that collectively influence the operational status of the overall transportation system.

At the far right of the figure are the **System Managers**, who control a particular aspect of the system and are responsible for ensuring the safe and efficient operation of their element of the complete system. Note that while System Managers are humans, some aspects of system management may be automated and do not require human intervention or decision-making on a regular basis. In between the users and the managers there is a natural gap to be bridged. An isolated system user, without any technological assistance, can only perceive or understand the state of the system in their immediate locality. A system manager, without any technological assistance, has even a more limited view of system performance or the likely actions of the system users. One thought experiment we might consider is a pervasive omniscient system ideal, where all users and all managers are collectively aware of all other users' and managers' current status and anticipated future behavior. This concept represents one upper bound on the limits (and benefits) of any system to optimize joint decision making by users and managers. Reality is not ideal, however, so our system description must include delineating the underlying capabilities and limitations of both system users and system managers to make informed decisions based on the quality, latency, reliability and scope of information available to them.

The subtitle of the system description is "System Users, Managers, and Intermediary Technologies and Entities". Between the System Users and the System Managers in the diagram are the existing and potential technologies to bridge the gap and supply information to both Users and Managers. One way of understanding a system is to trace how messages from System Users (and their associated vehicles and devices can combined and integrated and used in conjunction with predictive tools to support decision-making by System Managers.

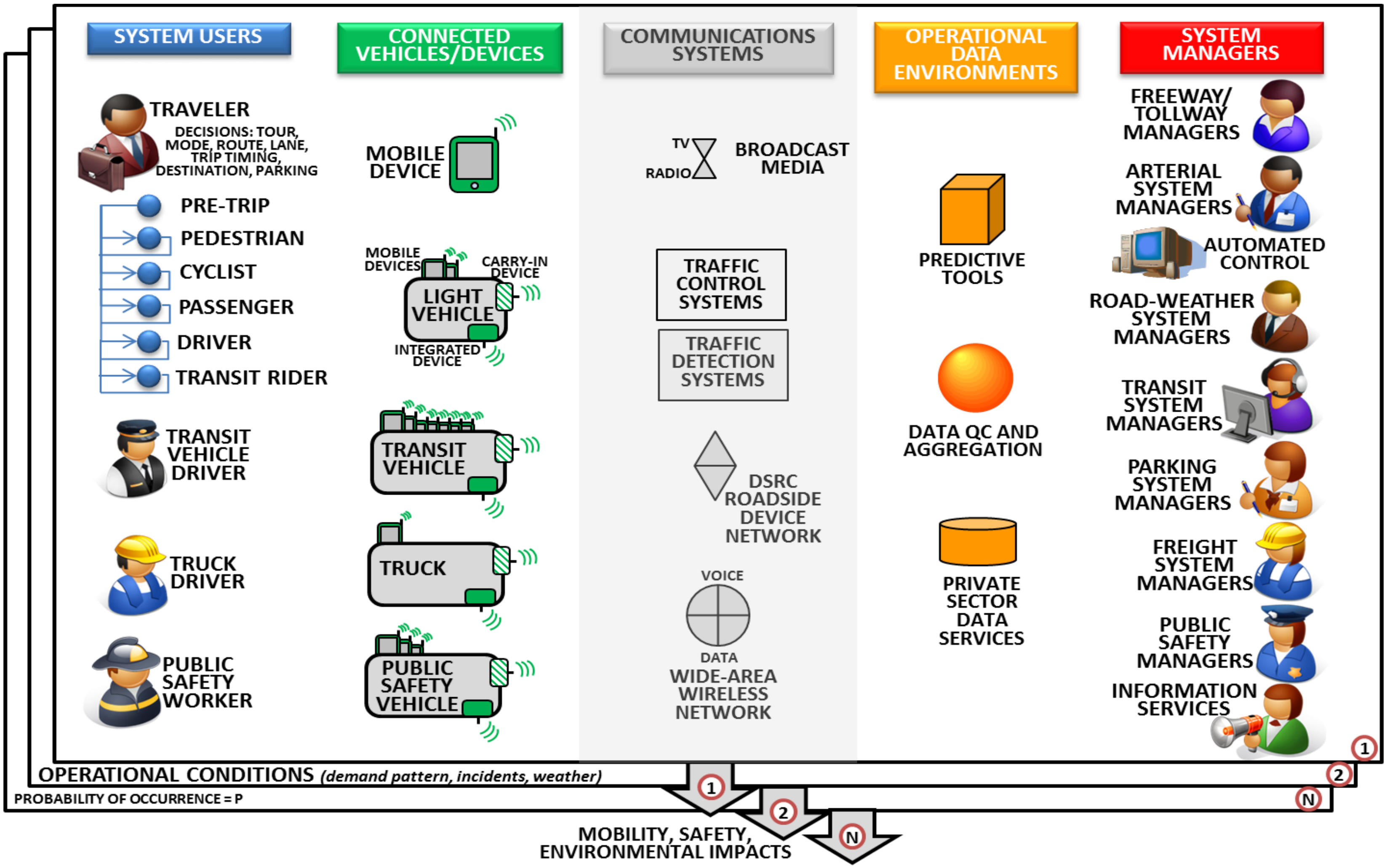

Figure 2-1:System Description: Transportation System Users, Managers, and Intermediary Entities Alternative

This left-to-right path represents the data-to-information chain for System Managers. A path extending from the right to the left can also be constructed indicating how control messages and advisory information generated by System Managers are realized in traffic control systems or other communications systems to inform System Users and influence their decisions. A right-to-left path represents the control-to-information chain for System Users.

Adjacent to the System Users on the left side of the diagram are an array of **Connected Vehicles and Devices** which are capable of sending messages through one or more communication systems over and above being passively detected by deployed traffic detection systems. These include mobile devices carried by individual system users, devices carried into and mounted within a vehicle, and devices permanently integrated into vehicles. Note that a vehicle may have multiple devices in it at any one time, including mobile devices carried by passengers or riders. Also note that the type and function of mobile or vehicle-based devices may be tailored for specific purposes, e.g., transit vehicles, trucks, and public safety vehicles.

The center column in the diagram shows the fundamental set of **Communications Systems** through which the System Users and System Managers directly or indirectly interact. One such system used by System Managers to communicate with System Users are broadcast media, delivered through television, radio, or internet. System Managers also rely on traffic detection systems that passively measure attributes of traffic flow (speed, density, throughput), and traffic control systems which signal or otherwise locally instruct drivers and other system users. Two other communications systems shown in the diagram transmit data or voice information directly from devices and vehicles equipped to interact with these networks. In the center of the diagram is a network of deployed roadside devices capable of sending or receiving messages via Dedicated Short Range Communication (DSRC). DSRC roadside technologies have been developed and tested by USDOT as a part of a broader research program but are not yet widely deployed. At the bottom of this column are wide area communications technologies that can carry either voice or data, such as the commercial cellular communications system.

Data generated either by passive detection or direct messaging can be integrated and prepared to support System Managers in the **Operational Data Environment** column. Data may be collected and assembled by private sector or public-sector entities, for example, in decision support systems supporting specific system users. In some cases private sector data services are used to supplement public sector data quality control (QC) and aggregation. Predictive tools may be employed to augment or leverage observed data to enhance the decision-making capability of one or more System Managers. Note that the function of prediction is embedded here but can reflect a full range of historical data analysis used to support decision making. Also note the notion of active management is reflected in the summative latency accumulated along the data-to-information chain (from the System User to the System Manager) plus the latency associated with the provision of adapted controls and information flowing in the control-to-information chain (from the System Manager to the System User). One critical characterization of active versus reactive system management is reflected by this total summative latency. Therefore, "active" is a relative term when comparing any two alternative systems, the one with the lower total data-to-information-to-control-to-information latency being more active than a system with a larger total latency.

The system description itself sits on a series of **Operational Conditions**, which describe different realizations of underlying variation in travel demand and transportation capacity (both recurrent and non-recurrent) resulting from multiple factors including incident patterns and variation in road/weather conditions. In our system description, we indicate that there are up to N operational conditions to be considered, each a combination of demand, incident, road/weather and other conditions. Each operational condition has a probability of occurrence. In each operational condition, we seek to characterize the mobility, safety and environmental impacts of a particular system alternative that connect the various elements of the system together in a particular way. These impacts can be quantified and monetized in a consistent and systematic way for comparison with total cost of system to determine cost-effectiveness. The ICM program has established some preliminary methods of both estimating the operational conditions space through cluster analyses, and an associated impact calculation method. [2]

The System Description presented in Figure 2- 1is not representative of any particular alternative system we might want to test and evaluate within an AMS Testbed. Instead, it shows the fundamental building blocks with which we can describe any relevant alternative system. Figures 2-2 to 2-5 present four different alternative systems that are likely of interest to the ATDM and DMA programs – alternatives that an AMS Testbed would be required to both differentiate and quantitatively evaluate.

Figure 2-2 presents **Alternative 0**, a representation of a system with, reactive management, non-integrated decision making, and no connected vehicle messaging. It is intended to serve as the “do nothing”, null, or baseline alternative for all other alternative systems. Note that this is not intended to represent every legacy system, but a specific baseline case against which other alternatives can be characterized and measured against. In this alternative, traffic detection systems are capable of discerning light and heavy vehicles. These detector data are aggregated every x minutes in independent freeway and arterial data systems where rudimentary quality control is performed. This activity consumes an additional y minutes before data are passed to freeway and arterial system managers. Making a change to control policies requires an additional z minutes to identify and implement a change in control settings. Total latency in this system is then (x+y+z) minutes, defining a baseline level of active control. Note that control decisions are made independently among all System Managers in this alternative, i.e., there is no integrated form of control across the system. For transit, freight and public safety system managers, wide-area communications is used for voice dispatch of instructions (Managers to Users) or voice status reports (Users to Managers). Information Services provide generalized system status information to Users through broadcast media such as commercial radio and TV.

This alternative, illustrated as a collection of elements from our fundamental system description, must be represented in an AMS Testbed, and its performance characterized under a suitable range of operational conditions to quantify and monetize mobility, safety and environmental impacts. Each element of the data-to-information and control-to-information chains must be represented within the analytical construct in such a way that it can be differentiated from other alternatives. Of more interest to the two program are other alternatives that reflect a fundamental change in system management brought about through the deployment of technologies and operational practices associated with the DMA and ATDM program hypotheses.

Figure 2-3 presents an alternative reflective of ATDM Program priorities: **Alternative A, More Active and Integrated System Management With Prediction**. In this case, an enhanced traffic detection system replaces the Alternative 0 unenhanced detection system. One of the attributes of the enhanced system is a capability to compile and transmit aggregated detector data twice as fast as the old unenhanced detection system (every x/2 minutes) to an integrated archive monitoring freeway, arterial and transit systems. The archive is also enhanced, not only to integrate freeway, arterial and transit data but also to perform quality control checks in half of the time similar functions are carried out in Alternative 0 (y/2 minutes).

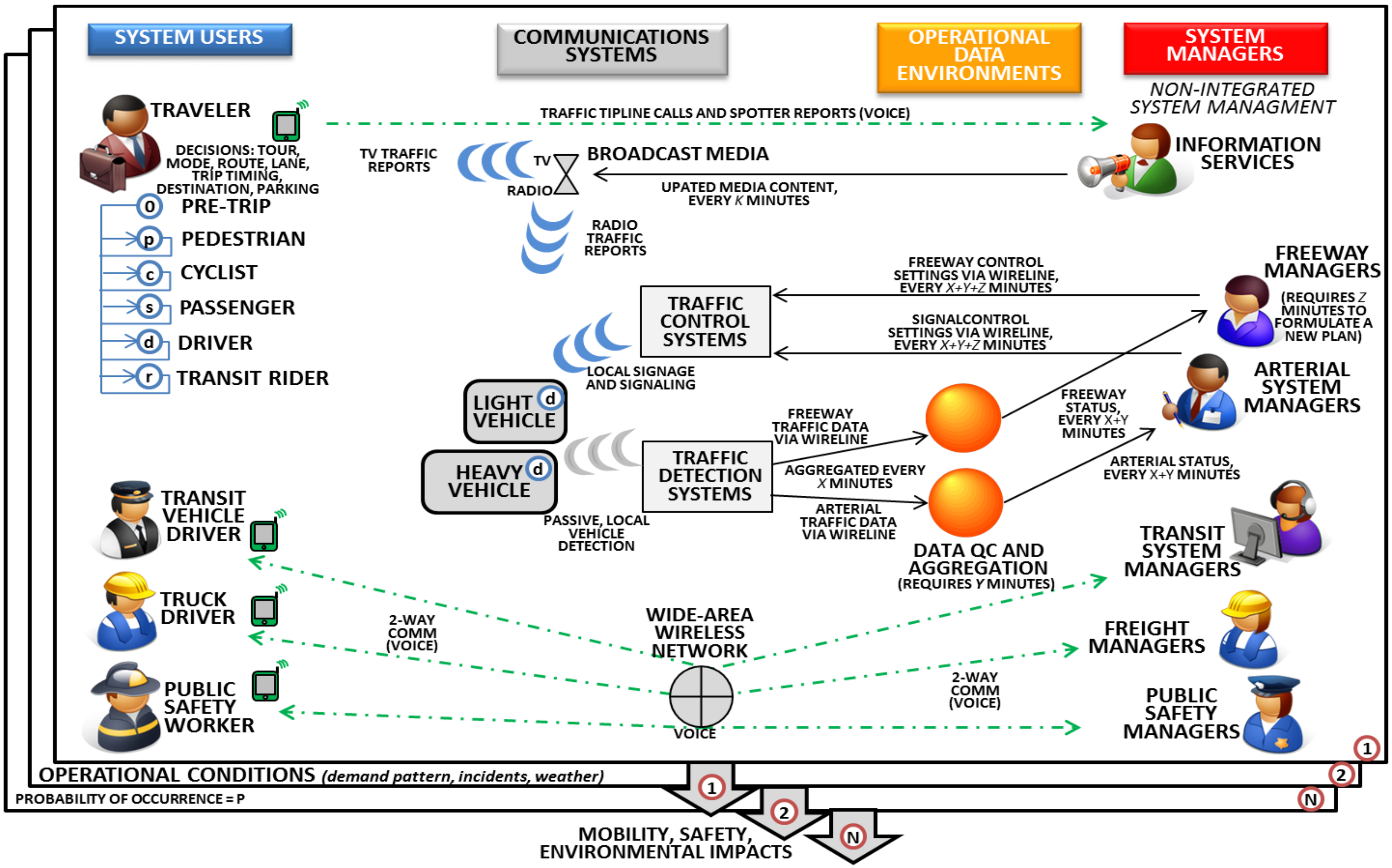

Figure 2-2:Alternative 0: Unconnected System with Non-Integrated, Reactive Management

Further, these data are prepared as inputs to a system prediction tool. The predictive tools are capable of predicting future conditions over a time horizon of *h* minutes with known accuracy, but running the tool requires an additional *p* minutes before predicted conditions are passed along to system managers.

With the support of some automated control functions, integrated control decisions can be identified and passed to traffic control systems in half of the time associated with the Alternative 0 system (within $z/2$ minutes). Total latency in this system is $p+(x/2 + y/2 + z/2)$, less than Alternative 0 when $p<(x/2 + y/2 + z/2)$. If this is the case, then Alternative A represents a more active form of system control than Alternative 0. Note that Alternative A is not the singular embodiment of the ATDM vision, only a single illustrative example that represents one particular realization of selected ATDM principles.

One side note here is that if we were to use our system description to describe an alternative central to the hypothesis of the Integrated Corridor Management (ICM) Program, we would be specifically interested in the value of integrated decision-making among Freeway Managers, Arterial system managers, and Transit System Managers, shown here with the dotted lines surrounding System Managers participating in an integrated manner.

Just as in the case of Alternative 0, the AMS Testbed must be capable of representing and differentiating Alternative A from Alternative B, characterizing performance under the same set of operational conditions to quantify and monetize mobility, safety and environmental impacts.

Figure 2-4 presents one realization of the DMA program vision, **Alternative B, Connected Vehicles with Select DMAs and Integrated Management**. In this alternative, DSRC-capable vehicles exchange frequent Basic Safety Messages (BSM) to share vehicle position and speed 10 times per second. These broadcast BSMs can also be received when connected vehicles are within range of a DSRC-capable roadside device. BSM data is passed by wireline to supplement legacy detector data and form an integrated data system that combines legacy detector data and BSM data. This integrated and quality checked-data is passed to system managers. The system managers utilize the new data to enable two particular DMAs: SPD-HARM, a speed harmonization application for freeway facilities, and I-SIG, a traffic signal control optimization application. Utilizing a new SPD-HARM optimization algorithm in the traffic management center, target speeds by lane on specific freeway segments can be calculated and provided through an existing freeway lane control system. Likewise, a vehicle queue length estimation algorithm running within the I-SIG application creates dynamically optimized signal control settings. These settings are describe automated signal phase and timing (SPaT) controls. Further, messages describing the current state of the signal control at key intersections (SPaT messages) are passed from local traffic controllers to nearby DSRC-capable devices for broadcast to nearby connected vehicles.

Like other alternatives, the AMS Testbed must at least be capable of representing and differentiating Alternative B from Alternative 0, characterizing performance under the same set of operational conditions to quantify and monetize mobility, safety and environmental impacts. Of more value, however, would be a AMS Testbed capable of differentiating and evaluating all three alternatives (0, A, and B).

Figure 2-5 presents a more robust realization of the DMA program vision, **Alternative C, BSM and BMM Synergy Enabling More DMAs**. In this extension of Alternative B, short-range BSM messages are augmented with a less frequent but more verbose Basic Mobility Message (BMM) that includes extensive vehicle status data via wide-area communications (cellular) when not in range of a DSRC-capable roadside device. Similarly, BMM-capable mobile devices provide BMM data via cellular from travelers to coordinate dynamic transit and ridesharing applications. BMM are also used to supplement freight and public safety operations.

Note that this relatively complex diagram does not include all possible DMAs, just as Figure 2-2 presents only one of 17 identified ATDM strategies. While we may be interested in assessing the nature and cost-effectiveness of these more complete alternatives, our goal in presenting these alternatives is to illustrate the key aspects of alternatives for the purpose of describing each alternative well enough to guide development of an AMS Testbed capability. What the ultimate system alternative (ATDM, DMA or some hybrid) looks like is the collective responsibility of each program, not singularly the job of the AMS Testbed developer. The AMS Testbed must focus on the representation and evaluation of alternatives, including the capability of each alternative system to adapt control settings and messaging in response to dynamic operational conditions. This includes an investigation within each alternative to understand what elements are most critical and what forms of response have the greatest positive impact. A broader set of program stakeholders are responsible for the creation of the finite and well-defined set of alternatives and their attributes to be tested within the experimental construct, but the construct itself may be useful in the refinement of each alternative.

In the next section of the document, AMS Testbed requirements are identified for the representation of system elements defined in Figure 2-1, our system description. Figures 2-2 to 2-5 reflect different realizations of alternatives that must be represented and differentiated in an AMS Testbed. Further, within each alternative, we may also be interested in swapping in and out of the analysis component elements to determine their individual contribution to an overall level of impact. In later deliverables in this AMS Testbed Planning task, we will produce evaluation plans that more explicitly deal with a proposed set of alternatives to be tested in an AMS Testbed, and the structure of an experimental design that more directly answers the specific hypotheses of the two programs.

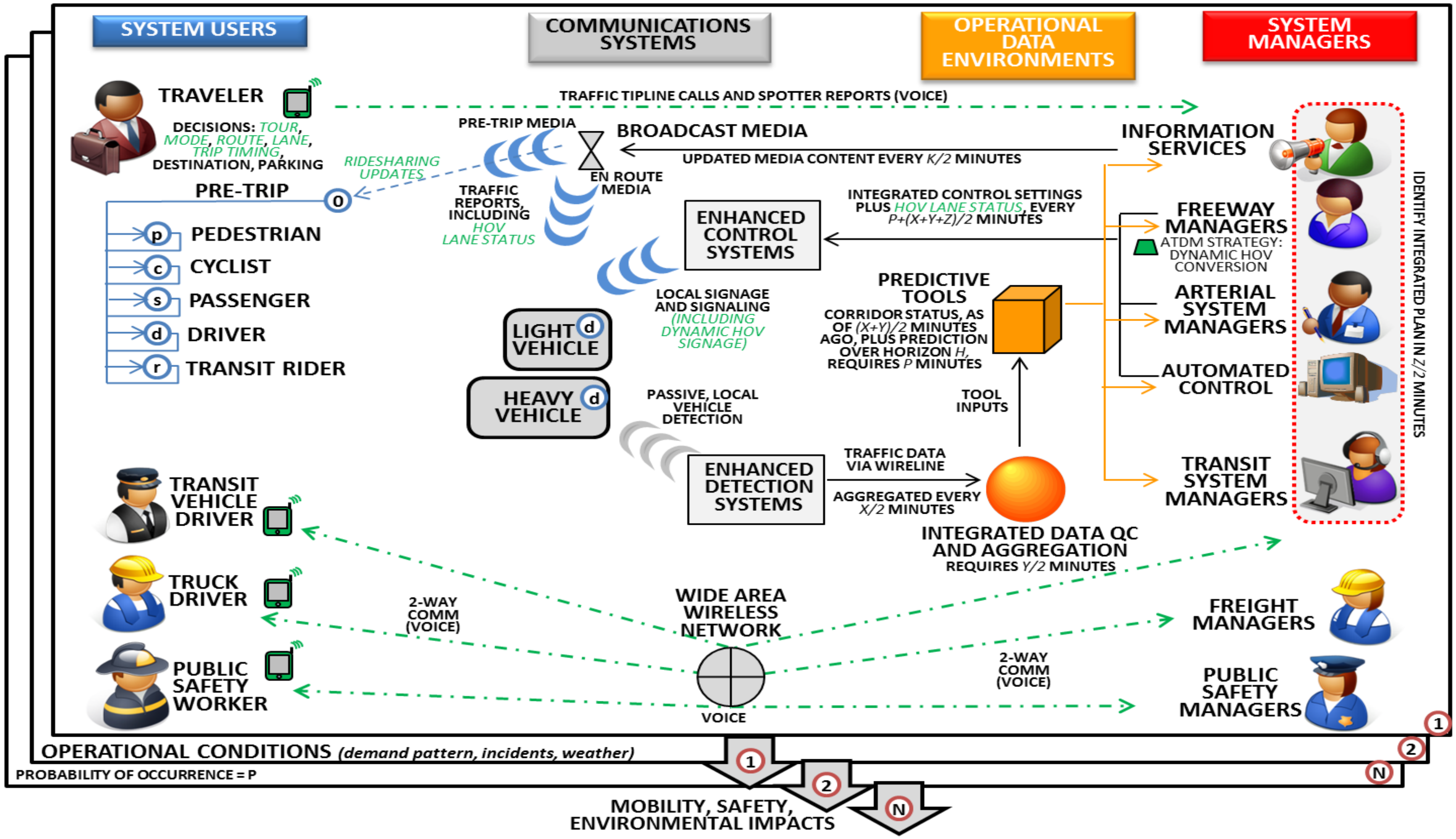

Figure 2-3: Alternative A: More Active System Management With Predictions

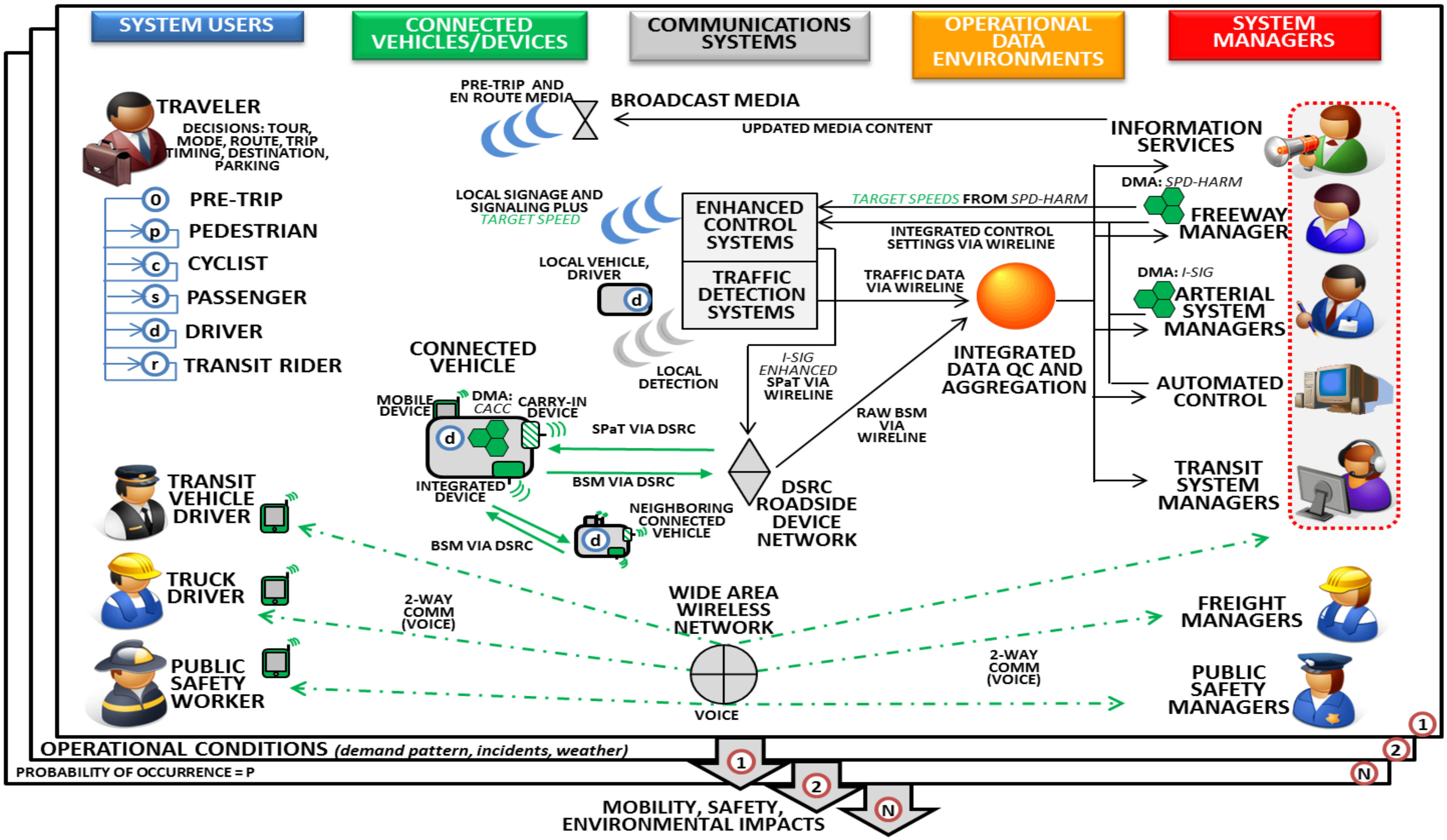

Figure 2-4: Alternative B: Connected Vehicles with Select DMAs and Integrated Management

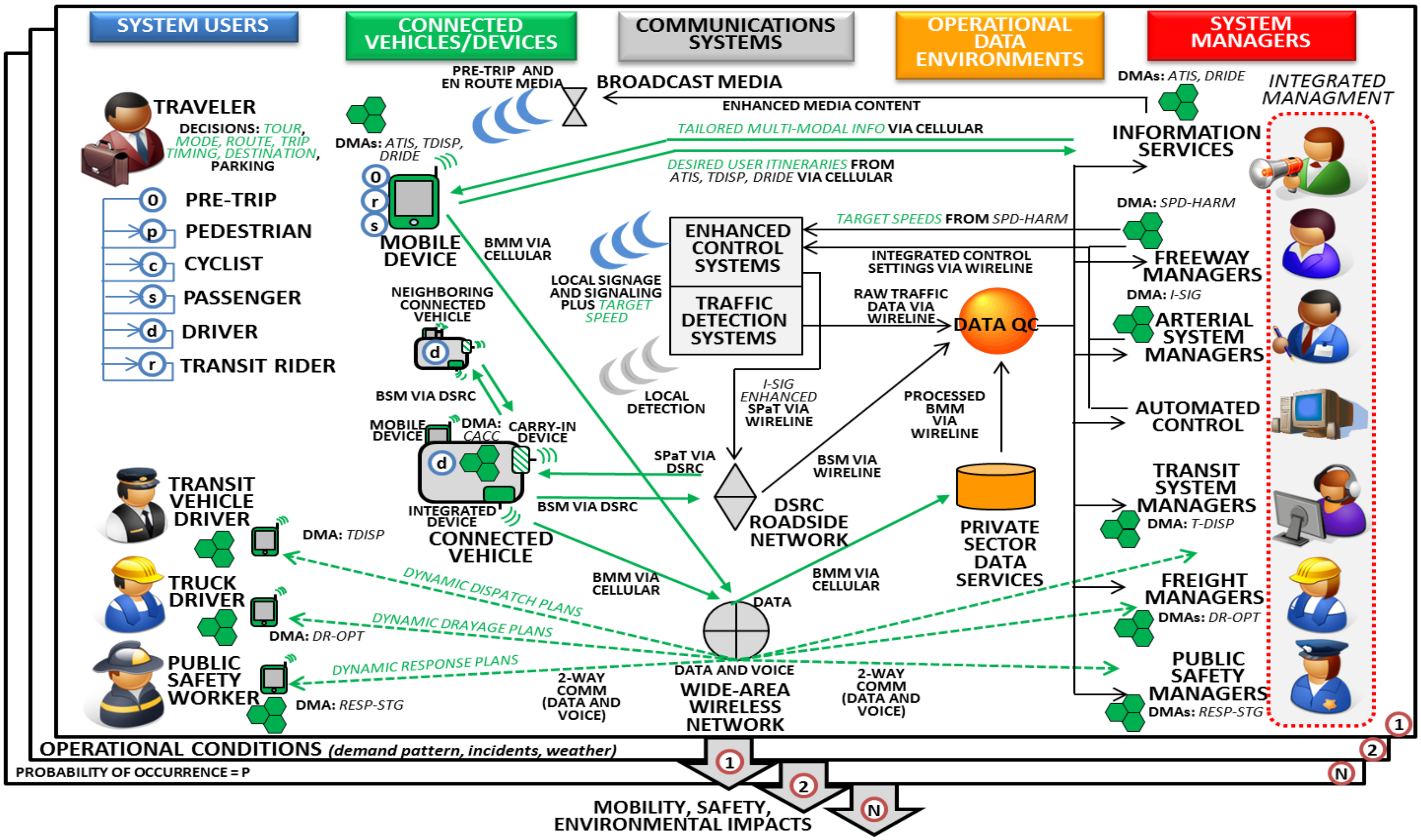

Figure 2-5: Alternative C: BSM and BMM Synergy Enabling More DMAs

3 Functional Requirements

3.1 Introduction

Requirements for representing, differentiating, and evaluating a set of alternative systems are organized by visual elements depicted within the system description diagram:

- **System Entities** (“nodes”) identified in each column of the system description diagram (System Users, Connected Vehicles/Devices, Communications Systems, Operational Data Environments, and System Managers)
- **Data and Information Flows** (“arcs”) connecting system entities, including attributes of latency, aggregation, message content, range, reliability, and accuracy (error)
- **ATDM Strategies and DMA Applications** enhancing current decision-making by System User or System Managers or enabling new forms of decision-making by Users and Managers.
- **Operational Conditions**, ambient demand, incident, and weather conditions, and
- **System Performance Measurement** (mobility, safety, environmental, cost), including the calibration of overall system dynamics.

The collection of functional requirements presented in this section represent a high-level set of capabilities required by an ATDM-DMA Testbed. However, these functional requirements are not detailed enough to allow for an analyst to directly create one or more testbeds. Each of these high-level functional requirements will have to be broken down into more detailed requirements in any follow-on testbed design and test effort.

A key term used throughout the requirements is *emulation*. Here, we use this term to imply that the AMS Testbed has the capability to represent this required element either in a disaggregate (individual) or aggregate (collective) manner. This notion extends from the emulation of human decision-making processes; the emulation of data capture, transmission and aggregation processes; and the emulation of the physical transportation system, among other considerations. We have avoided the use of the specific term *simulation* because it might be interpreted as a requirement for disaggregate treatment, and similarly avoided the broader term *model* because it might be interpreted as a requirement for aggregate treatment.

In a similar vein, we do not specify geographic requirement or time-scale requirements. These considerations will be treated as a part of an ATDM or DMA-specific analysis plan (upcoming deliverables), since depending on what alternatives must be differentiated we might consider a multi-state transportation system (to assess the impact of more active management of evacuations) or a section of a facility (to examine detailed vehicle-to-vehicle messaging enabling close platooning applications).

3.2 System User Requirements

System Users are humans, who make a range of strategic and tactical decisions regarding their travel. These decisions may be whether to travel, what mode of travel to use, when to take a trip, what route to travel on within a mode, where to park, and finally, how a collection of trips (tour) within a day will meet a variety of obligations and desired outcomes. Further there are tactical decisions that must be made, particularly as a driver, regarding how fast to travel, in what lane, and how to maneuver effectively and safely in a variety of situations. System User decision-making is subject to the nature and accuracy of available data available to them within a particular alternative. This implies that the control-to-information chain represented by System Managers communicating with System Users influences the information available to a traveler depending on the state of their trip (e.g., pre-trip or en route), the geographic location of the System User within the system, and technologies (mobile devices, or in-vehicle devices) used to process and present information supporting System User decision-making. Attributes of “nature and accuracy” pertain to the scope, precision, latency, format, context, manner, media and reliability of information users receive under each alternative system analyzed within the testbed. For example, a testbed analyst may be asked to consider the value of potential investments made to improve information provision to system users. The testbed should be capable of differentiating of system user decision making under the pre-investment “poor” information alternative and the post-investment “improved” information alternative, and report the potential safety, environmental, and mobility impacts of each alternative. Further, System Users are humans that learn over time, and exhibit different strategic and tactical behaviors associated with accumulated experience in the transportation system. Note that every decision made by system users (and system managers) are decisions made under uncertainty – there are no omniscient entities in our system description. Therefore, the challenge in modeling humans in the AMS Testbed is accurately modeling the appropriate level of uncertainty in decision-making. This uncertainty may be higher or lower, or have different dimensions based on the familiarity of the decision-maker with the transportation system and the sources of information sought or brought to the decision-maker.

A **Traveler** may transition between one or more mutually exclusive states while planning and executing travel, starting from a **Pre-Trip Traveler** state and passing through one or more combinations of **Pedestrian**, **Non-Motorized Traveler**, **Light Vehicle Passenger**, **Light Vehicle Driver,** or **Transit Rider** states prior to completing a trip. **Transit Vehicle Drivers** operate vehicles capable of transporting one or more transit riders. **Truck Drivers** are system users who operate vehicles to move goods (as opposed to travelers) through the system. **Public Safety Workers** are field personnel who act to control and manage incident and emergency conditions locally within the system. Public Safety Workers may be drivers operating public safety vehicles, passengers in public safety vehicles or pedestrians within the transportation system.

Please note that requirements associated with **Travelers** who transition from one state to another (e.g., **Light Vehicle Driver** to **Pedestrian** to **Transit Rider**) are cumulative, that is, the requirements for modeling an individual traveler includes all states experienced during a trip from origin to destination. When the term Traveler appears, these requirements pertain to all **Travelers** regardless of current state or state history. Note that requirements may differ when **Travelers** are in different states. For example, SU-4 and SU-5 are different requirements because the methods of interaction between **Drivers** and **Passengers** are different. A smartphone-based traveler information service may be safely used for **Passengers** but not **Drivers**, so modeling decision making under these conditions will differ.

Table 3-1 presents functional requirements related to System Users identified in the System Description. The columns are defined as follows:

- Column 1: Unique identifier for each requirement
- Column 2: Descriptive text for the requirement
- Column 3: Technical risk of modeling the requirement (High, Medium, Low)
- Column 4: Importance of the requirement to model a strategic application versus tactical application
- Column 5: Priority of the requirement to model a strategic application versus a tactical application
- Column 6: Traceability to ATDM Modeling needs identified in “ATDM Analysis, Modeling, and Simulation (AMS) Capabilities Assessment: Final Report (October 2012).” [9]
- Column 7: Traceability to DMA Modeling needs identified in “Dynamic Mobility Applications Analytical Needs Assessment (July 2012).” [10]
- Column 8: Traceability to ATDM Modeling requirements identified in “ATDM Analysis, Modeling, and Simulation (AMS) Analysis Plan: Final Report (October 2012).” [11]

Technical risk represents a subjective assessment of the difficulty in meeting this requirement within a near-term test bed compared to current modeling capabilities. This subjective assessment is calculated using inputs from expert stakeholder feedback (collected as a part of an expert stakeholder workshop held at the 2013 TRB Annual Meeting), members of the USDOT key content review team, and the authors of this document. While this rating by expert stakeholders was essentially unstructured, analysis of their responses can be roughly approximated with the following rubric. Those requirements rated as *High risk* often indicated, among other considerations, that primary data or proven algorithms do not exist and current simulation tools have minimal or no capability to meet this requirement. Requirements rated as *Medium risk* indicated a perception that while some data and rudimentary algorithms are available within the research community, these were generally not well integrated with current simulation tools. Requirements with *Low risk* reflect a perception that proven algorithms based on primary data collection exist and are routinely found in current modeling and simulation tools.

Importance ratings were assembled in a similar manner to technical risk assessment, and represents a subjective measure of how critical this requirement will be in differentiating among expected alternatives (such as the strawman alternatives described in the System Description section). Here, however, it was clear that there was a distinction between experts who typically conduct large-scale regional or corridor analyses and those who most typically conduct detailed tactical analyses. Therefore, to highlight these critical differences in insights, we chose to group their responses in terms of tactical and strategic application areas.

Tactical applications are applications that focus on influencing decisions and maneuvers made by system users (e.g., drivers) to pre-position or control their vehicles while en route, as well as applications that influence control/advisory decisions generated by System Managers to influence these short-term tactical behaviors/maneuvers. Examples of such applications include, Adaptive Traffic Signal Control, Adaptive Ramp Metering, Queue Warning, Dynamic Speed Limits, Cooperative Adaptive Cruise Control, etc. *Strategic applications* are applications that primarily influence long-term decisions made by travelers in response to traffic conditions and travel experiences, as well as applications that emulate control/advisory decisions made by System Managers to influence these long-term travel choices. Examples of such applications include, Traveler Information, Dynamic Pricing, Dynamic Fare Reduction. Clearly, tactical applications may have impacts on strategic decision-making and vice versa. This distinction should not be confused with long-term (habitual) behavior versus short-term behavior, which is a separate dimension for consideration in representing traveler behavior. Drivers may develop long-term tactical behaviors, e.g., proclivity for lane-changing or routinely choosing a particular lane for travel. Similarly, travelers may make short-term adjustments to strategic behaviors, such as habitual time of departure choice for a routine commute based on current weather conditions.

Priority ratings are non-subjective measures calculated combining the expert panel assessments of technical risk and importance by modeling scale (tactical and strategic). For this effort, USDOT seeks testbed development that maximizes the number of important requirements, while minimizing technical risk. Each risk is coded as follows: High =1, Medium=2, Low=3. Each importance rating is coded as: High= 3, Medium=2, Low=1. Priority rating is calculated as the average of the risk and importance coding, and rated against the following scale: High (3.0), Med-High (2.5), Medium (2.0), Low (1.5 or lower).

This table format is repeated for all requirements identified in this document.

Table 3-1: System User Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-1	The AMS Testbed shall emulate and track each **Traveler**'s time-referenced geographic location (position) as he/she plans, executes, and completes a trip within the transportation system.	Low	Medium	High	Med-High	High	M.1, E.3	C.1, D.1	E.3.x
SU-2	The AMS Testbed shall emulate and track each **Travelers'** time-referenced state and transition among various potential states (pre-trip, pedestrian, non-motorized traveler, light vehicle driver, light vehicle passenger, and transit rider) as they plan, execute, and complete trips within the transportation system.	Medium	High	Low	Med-High	Low	E.3, A.7		E.3.x
SU-3	The AMS Testbed shall emulate each **Traveler**'s time-delimited tour planning, both in the pre-trip as well as en route states, subject to the nature and accuracy of available data on travel cost (parking fee, toll, fuel consumption, transit fare), expected trip duration, trip travel time reliability, safety and environmental impact.	High	High	Low	Medium	Low	E.3, E.4, A.5, A.7	G.4	E.3.x, E.4.x

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-4	The AMS Testbed shall emulate decision making by **Pedestrians**, and **Travelers in Non-motorized Modes** of travel in the absence and presence of mobile devices, subject to the nature and accuracy of data available to support decision making.	High	Medium	Low	Low	Low	A.5, A.7		
SU-5	The AMS Testbed shall emulate decision making by **Light Vehicle Drivers** in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	High	Medium	Medium	Medium	Medium	A.5, A.7, E.4	D.3, C.3	E.4.x
SU-6	The AMS Testbed shall emulate decision making by **Light Vehicle Passengers** in the absence and presence of mobile devices subject to the nature and accuracy of data available to support decision making.	High	Medium	Low	Medium	Low	A.5, A.7	D.3, C.3	
SU-7	The AMS Testbed shall emulate decision making by **Transit Riders** in the absence and presence of mobile devices subject to the nature and accuracy of data available to support decision making.	High	Medium	Low	Medium	Low	A.5, A.7, A.8	D.3	

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-8	The AMS Testbed shall emulate tactical driving decisions made by **Light Vehicle Drivers** with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	Low	Low	High	Medium	High	A.5, E.4	D.3	E.4.x
SU-9	The AMS Testbed shall emulate and track each **Transit Driver** and associated transit vehicle's time-referenced geographic location (position) within the transportation system.	Low	High	Medium	High	Med-High	A.8	K.2	
SU-10	The AMS Testbed shall emulate tactical driving decisions made by **Transit Drivers** with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	Low	Low	High	Medium	High	A.5, E.4, A.8	D.3	E.4.x
SU-11	The AMS Testbed shall emulate fixed route/fixed schedule transit, flexible route bus, rail transit and paratransit.	High	High	Low	Medium	Low	A.8, A.7	Q.1	

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-12	The AMS Testbed shall emulate a **Transit Driver**'s adherence to dynamic transit dispatch plans (e.g., to counteract bus bunching) when received subject to the nature and accuracy of data available to support decision making.	Low	High	Low	High	Medium	A.5, E.4, A.7, A.8	D.3	E.4.x
SU-13	The AMS Testbed shall emulate decision making by **Transit Drivers** in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	Low	Medium	Medium	Med-High	Med-High	A.8, A.7, E.4	D.3	E.4.x
SU-14	The AMS Testbed shall emulate and track each **Truck Driver** and associated freight vehicle's time-referenced geographic location (position) within the transportation system.	Low	High	Medium	High	Med-High	E.4	Q.3, S.2	E.4.x
SU-15	The AMS Testbed shall emulate tactical driving decisions made by **Truck Drivers** with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	Low	Medium	High	Med-High	High	A.5, E.4	D.3, T.5, V.5	E.4.x

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-16	The AMS Testbed shall emulate a **Truck Driver**'s adherence to plans when received on dynamic routing, tours, and actions at waypoints subject to the nature and accuracy of data available to support decision making.	Low	High	Low	High	Medium	A.5, E.4	D.3, T.5, V.5	E.4.x
SU-17	The AMS Testbed shall emulate decision making by **Truck Drivers** in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	Low	Medium	Low	Med-High	Medium	A.8, A.5, E.4	D.3	E.4.x
SU-18	The AMS Testbed shall emulate and track each **Public Safety Worker** and public safety vehicle's time-referenced geographic location (position) within the transportation system, including in an active incident zone.	Low	High	Medium	High	Med-High	M.1	R.2	
SU-19	The AMS Testbed shall emulate tactical driving decisions made by **Public Safety Vehicle Drivers** with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	Low	Medium	High	Med-High	High	A.5, E.4	D.3	E.4.x

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-20	The AMS Testbed shall emulate a **Public Safety Vehicle Driver**'s adherence to plans when received on dynamic routing, and response staging subject to the nature and accuracy of data available to support decision making.	Low	High	Low	High	Medium	A.5, E.4	D.3	E.4.x
SU-21	The AMS Testbed shall emulate the time-referenced geographic location of **Public Safety Workers** acting as emergency response personnel within an active incident zone in the absence and presence of mobile devices subject to the nature and accuracy of data available to support decision making.	High	High	Medium	Medium	Low	M.1	R.2	
SU-22	The AMS Testbed shall emulate decision making by **Public Safety Vehicle Drivers** in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	Low	Medium	Low	Med-High	Medium	A.5, E.4	D.3	E.4.x
SU-23	The AMS Testbed shall emulate adherence by **Drivers** of light, transit, and freight vehicles with directions when received on presence of emergency response personnel subject to the nature and accuracy of data available to support decision making.	High	High	Low	Medium	Low	A.5, E.4	D.3	E.4.x

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SU-24	The AMS Testbed shall emulate various compliance rates of **System Users** (drivers, pedestrians, bicyclists, light vehicle passengers, transit riders, transit drivers, truck drivers, and public safety vehicle driver) when presented with advisory and regulatory information.	High	High	High	Medium	Medium	A.5, E.4	D.3	E.4.x

3.2.1 Connected Vehicles and Connected Traveler Devices Requirements

Mobile Devices include smartphones, tablets, and other hand-held devices that have their own power source and are capable of hosting one or more Applications. Mobile devices can communicate using either DSRC or cellular communications systems (or both), and are carried by a System User throughout a trip. A mobile device cannot be safely used by a driver of any vehicle during the en route portion of a trip.

Carry-In Devices are specially-designed mobile devices that can be carried into a vehicle and may be safely utilized by the driver of a vehicle while en route (e.g., aftermarket navigation systems). Carry-in devices may host one or more Applications, and may be capable of communicating using either DSRC or cellular communications systems (or both). Carry-In Devices are not intended to support System User decision making outside of a vehicle, but may be transferred between vehicles as a part of a trip or tour. These devices may or may not communicate or otherwise obtain or infer vehicle status data from a host vehicle. These devices are assumed to be powered whenever they are placed within the vehicle.

Integrated Devices are permanently located within a specific vehicle and may be safely utilized by the driver of a vehicle while en route. Integrated devices may host one or more Applications, and may be capable of communicating using either DSRC or cellular communications systems (or both). These devices can obtain or infer a specific set of vehicle status data from a host vehicle.

A **Connected Vehicle** is a vehicle equipped with one or more **Carry-In** or **Integrated Devices**. Note that a Connected Vehicle may contain Passengers utilizing Mobile Devices, however, this is not sufficient to characterize a vehicle as a Connected Vehicle. An **Unconnected Vehicle** is a vehicle which is not equipped with one or more Carry-In or Integrated Devices. An Unconnected Vehicle may carry one or more Passengers utilizing a Mobile Device.

Four specific forms of vehicles are also represented in the system. A **Transit Vehicle** is driven by a **Transit Vehicle Driver** and may carry one or more **Transit Riders**. A Transit Vehicle may be Connected or Unconnected. Note that a Transit Vehicle may contain Transit Riders utilizing Mobile Devices, however, this is not sufficient to characterize the vehicle as a Connected Transit Vehicle. Similarly a **Truck** is driven by a **Truck Driver** and may be Connected or Unconnected. A **Public Safety Vehicle** is driven by a **Public Safety Vehicle Driver** and may contain one or more **Public Safety Workers**. A Public Safety Vehicle may be Connected or Unconnected. All other vehicles are considered **Light Vehicles** driven by a **Driver** potentially carrying one or more **Passengers**. A Light Vehicle may be Connected or Unconnected.

Table 3-2 presents functional requirements related to Connected Vehicles and Connected Traveler Devices.

Table 3-2: Connected Vehicles and Connected Traveler Devices Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
CV-1	The AMS Testbed shall emulate **Mobile Devices** that are capable of transmitting messages via cellular or DSRC or both.	High	Low	High	Low	Medium		Z.2	
CV-2	The AMS Testbed shall emulate the time-referenced geographic location, operational status (ON, OFF, NOT FUNCTIONING), and power status of a **Mobile Device**, and the state of the device (in use and connected to the vehicle, not in use but within a vehicle, outside a vehicle, and in use and not connected to the vehicle.).	High	Low	High	Low	Medium		Z.2	
CV-3	The AMS Testbed shall emulate **Carry-In Devices** that are capable of transmitting messages via cellular or DSRC or both.	High	Low	High	Low	Medium		Z.2	
CV-4	The AMS Testbed shall emulate the time-referenced geographic location, and operational status (ON, OFF, NOT FUNCTIONING) of **Carry-In Devices**.	High	Low	High	Low	Medium		Z.2	
CV-5	The AMS Testbed shall emulate **Integrated Devices** that are capable of transmitting messages via cellular or DSRC or both.	High	Low	High	Low	Medium		Z.2	
CV-6	The AMS Testbed shall emulate the time-referenced geographic location, and operational status (ON, OFF, NOT FUNCTIONING) of **Integrated Devices**.	High	Low	High	Low	Medium		Z.2	

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
CV-7	The AMS Testbed shall emulate coordinated or independent transmission of messages from **Mobile Devices, Carry-in Devices and Integrated Devices** when co-located in a vehicle (light, transit, freight, public safety) via cellular or DSRC or both.	High	Low	High	Low	Medium	E.3	Z.2	
CV-8	The AMS Testbed shall emulate the reception of messages by DSRC-capable **Mobile Devices, Carry-in Devices and Integrated Devices** from other local DSRC-capable mobile, carry-in, and integrated devices.	Medium	Low	High	Medium	Med-High	E.3	Z.2	
CV-9	The AMS Testbed shall emulate the reliability of **Mobile Devices, Carry-in Devices and Integrated Devices**, specifically the reliability of a device to receive or send messages subject to local interference, device malfunction, or user error.	High	Low	High	Low	Medium		Z.2	
CV-10	The AMS Testbed shall track the time-referenced geographic- location and emulate the movement of **Connected** and **Unconnected Vehicles** within the transportation system, including time parked between trips made as a part of a multi-trip tour.	Medium	Medium	High	Low	Medium	M.1	Z.3	
CV-11	The AMS Testbed shall reflect differences in vehicle size and weight among **Light Vehicles**, **Transit Vehicles**, **Trucks** and **Public Safety Vehicles** and associated differences in vehicle performance.	Medium	Low	Medium	Low	Medium		T.6	

3.2.2 Communications Systems Requirements

Traffic Detection Systems include loop detectors, Bluetooth readers and other roadside devices that have their own power source and are capable of passively detecting and classifying attributes of vehicle or pedestrian movement within a specific range of the location of the device. The detection system includes supporting roadside/wayside communications systems that aggregate, prepare, or otherwise process local data prior to transmission to Operational Data Environments supporting System Managers.

Traffic Control Systems are signage and signaling systems such as arterial traffic signal systems, ramp metering systems, dynamic message boards, and static signage used to influence and control driver decision making in a localized area. These control systems may act in a manual or automated manner, or a pre-set or responsive manner, locally supported by dedicated local detection systems. These control settings may be directly or indirectly updated according to control decisions made by System Managers. The capability of system managers to rapidly and precisely manage control settings are inherently limited by the capability of the control systems to receive, process, and implement these changes.

Broadcast Media include pre-trip and en route forms of communication reaching system users over a wide area or geographic region, as opposed to localized forms of information provision associated with Traffic Control Systems. Examples include traffic reports delivered through commercial radio, Highway Advisory Radio (HAR) and television media as well as broadcast forms of information provided over the Internet, including color-coded congestion maps and other advisories accessed with or without utilization of a wide-area wireless network.

The **DSRC Roadside Device Network** may receive or transmit messages broadcast over the designated DSRC communications frequency (5.9 GHz). Mobile Devices and Connected Vehicles may broadcast messages via DSRC that can be received by the DSRC Roadside Network when the devices and vehicles are within communication range. The DSRC Roadside Network may receive and transmit messages from System Managers or the Traffic Control System to broadcast to devices and vehicles within range.

Wide-Area Wireless Networks include forms of wide-area communication that cover a complete geographic region, as opposed to localized forms of communications like those using the DSRC Roadside Network. Wide area messaging are not broadcast messages, but point-to-point data or voice transmissions between two entities within the system. A user utilizing a cell phone to access a 511 service to obtain a personalized traffic report is an example of utilization of a wide-area wireless voice network, as is the utilization of an application on the cell phone to obtain a data message from the 511 service provider with similar personalized content.

Table 3-3 presents functional requirements related to Communications Systems.

Table 3-3: Communications Systems Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
CS-1	The AMS Testbed shall emulate the geographic location (position), operational status (FUNCTIONING, NOT FUNCTIONING), and range of individual DSRC-capable Roadside Equipment (RSE) deployed as an element of a **DSRC Roadside Device Network**.	Medium	Low	High	Low	Med-High			
CS-2	The AMS Testbed shall emulate latency and reliability of messages passing through a **DSRC Roadside Device Network**, subject to the location and density of nearby roadside devices, relative position and capability of DSRC-capable devices (*Mobile Devices*, *Carry-In Devices*, and *Integrated Devices*) sending DSRC messages, and communications load local to individual roadside devices.	High	Low	High	Low	Medium			
CS-3	The AMS Testbed shall emulate latency and reliability of communications using a **Wide-Area Wireless Network**, subject to the location of capable devices, sources of interference, and overall communications load.	High	Low	High	Low	Medium			
CS-4	The AMS Testbed shall emulate provision of roadside/local control by **Traffic Control Systems** through dynamic message signs, lane control signs, ramp meters, and traffic signals.	Low	Low	High	Medium	High		H.3	

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
CS-5	The AMS Testbed shall emulate provision of advisory information by **Traffic Control Systems** through dynamic message signs and other forms of advisory information provision.	Low	Medium	High	Med-High	High		H.3	
CS-6	The AMS Testbed shall emulate the capability of **Traffic Control Systems** to receive, process, and implement control setting changes from *System Managers*, including the latency and reliability of response to *System Manager* direction.	High	Medium	High	Low	Medium			
CS-7	The AMS Testbed shall emulate the provision of traveler information via **Broadcast Media**, including television, radio and through the internet, including a differentiation of information delivered to *System Users* in pre-trip and en route states.	Low	High	High	High	High			
CS-8	The AMS Testbed shall emulate data capture from **Traffic Detection Systems** utilizing passive detection to estimate individual vehicle speed, location, and size or to estimate roadway segment occupancy, travel time, and aggregate vehicle flow where deployed in the transportation system, including the reliability of these sensors.	Low	High	High	High	High	M.1		
CS-9	The AMS Testbed shall emulate the accuracy, precision, latency and reliability of data aggregation and pre-processing actions within the **Traffic Detection System** prior to those data being made available to *System Managers* within an *Operational Data Environment*.	Medium	Low	Medium	Low	Medium			

3.2.3 Operational Data Environment Requirements

Operational Data Environments aggregate and enhance data passed from detection and communication systems to support System Manager decision-making. Operational Data Environments comprise a mix of data with different sources, reliability and latency. For example, a Arterial System Manager may have data on intersection turning movements collected manually once a year plus data on approach flows to the same intersections aggregated over 15 minute intervals and a smaller collection of point-to-point travel time estimates updated every 10 minutes when available from processed automated vehicle location data. An Operational Data Environment does not contain every form of data desired or useful to System Managers, and by definition is the sum of all the data available to System Managers together with all of its inherent attributes, limitations, and potential flaws.

Data QC and Aggregation, or Data Fusion, processes organize and provide quality checks to data from one or more sources to support decision making by System Managers. Note that the process of conducting this aggregation and quality check introduces some latency into the data-to-information chain, and the level of quality checking may be more or less rigorous. Finally, Data QC and Aggregation may occur independently for individual System Managers, that is, there may be stand-alone systems processing data by manager type or jurisdiction. Alternatively, integrated Data QC and Aggregation may take place wherein data from multiple sources are integrated and then utilized by multiple System Managers. Integrated Data QC and Aggregation may support independent or integrated decision-making by System Managers, but it does not itself guarantee integrated decision making. Note that within the construct of the testbed, error-free data can be emulated as well as more realistic, less accurate data. The testbed emulates data QC and Aggregation through the introduction of realistic error rates expected or measured in real control systems.

Private Sector Data Services create operational data environments from market-driven arrangements with data providers. Access to these data or services based on these data are offered to System Managers as well as other commercial clients. These services provide their own level of quality control and aggregation for their data products independent of the Data QC and Aggregation processes directly supporting System Manager decision-making.

Predictive Tools are elements of decision-support potentially embedded in an operational data environment. There are multiple forms of prediction that may be incorporated within an Operational Data Environment. When no prediction is utilized, data describing current conditions are assumed to persist indefinitely, and decision-making under such an assumption is considered *reactive*. Note that even if data are only collected once a year, if new control plans are put in place based on these data, this is still reactive management. Alternatively, current and historical data may be fused to make a prediction using statistical methods, and is described as a *historical or retrospective prediction*. Finally, a mix of current data, historical data, and complex simulation tools may be utilized to make a prediction over some time horizon, and is described *as AMS-augmented prediction*. Any combination of these predictive techniques can be employed within a decision support system that predicts the impacts of various strategy implementations, evaluates them, and recommends an optimal strategy. Note that the AMS Testbed capability as an experimental construct can be used to determine the value to overall system performance of the different forms of prediction, but is not intended to be an operational construct making real-time predictions.

Table 3-4 presents functional requirements related to Operational Data Environment.

Table 3-4: Operational Data Environment Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
OD-1	The AMS Testbed shall emulate **Data Quality Control (QC) and Aggregation** processes, including the nature and effectiveness of quality checks and aggregation of data performed for different data types.	Low	High	High	High	High	M.8, M.10, M.5		M.5.x, M.8.x
OD-2	The AMS Testbed shall emulate the processing time associated with performing **Data Quality Control and Aggregation** processes.	Low	High	High	High	High			
OD-3	The AMS Testbed shall emulate and differentiate between integrated and independent **Data Quality Control and Aggregation** processes in support of System Managers.	Medium	High	High	Med-High	Med-High			
OD-4	The AMS Testbed shall emulate the capture and aggregation of data from Connected Vehicles, Mobile Devices, and Detection Systems into **Private Sector Data Services**.	High	High	High	Medium	Medium	M.5		M.5.x
OD-5	The AMS Testbed shall account for the processing time associated with performing *Data Quality Control and Aggregation* processes within **Private Sector Data Services**.	Medium	High	High	High	High			
OD-6	The AMS Testbed shall emulate the provision of aggregated and quality controlled data products from **Private Sector Data Services** into *Data QC and Aggregation* processes supporting *System Managers*.	High	High	High	Medium	Medium			

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
OD-7	The AMS Testbed shall emulate the use of **Predictive Tools** within an Operational Data Environment, dependent on the flow of data from Data QC and Aggregation processes.	Medium	High	High	Med-High	Med-High			
OD-8	The AMS Testbed shall emulate and differentiate among alternative forms of **Predictive Tools**, including their prediction horizon, accuracy, scope and processing time.	Medium	High	Medium	Med-High	Medium			

3.2.4 System Manager Requirements

System Managers control a particular aspect of the system and are responsible for ensuring the safe and efficient operation of their element of the transportation system. Note that while System Managers are humans, some aspects of system management may be automated and do not require human intervention or decision-making on a regular basis. A System Manager, without any technological assistance, has a limited view of system performance or the actions of the System Users. System Managers are dependent on the nature, accuracy and reliability of *Operational Data Environments* created to provide insight into the state of the system and the effectiveness of potential changes to controls at their direction. Likewise, the nature of controls possible in a surface transportation system are also limited to a set of authorized alterations in traffic control systems, information provided through broadcast media, and the adjustment of policies related to the price and nature of access to elements of the transportation system. Their actions are constrained by the in the forms, scope and limitations of their control systems. Note that some elements of this control are intended to influence short-term behavior of System Users currently on the transportation system, depending on the nature of current conditions, such as the modification of target speeds on selected roadway sections. Other elements of control are intended to influence longer-term behavior of System Users, including High-Occupancy Vehicle (HOV) facility access or the cost of utilizing the facility (in the case of tolled facility).

Freeway/Tollway Managers make decisions regarding the operations of uninterrupted flow facilities, including changes to traffic control settings, the provision of information through broadcast media, and the alteration of policies related to the price and nature of access to the freeway or tolled facilities under their control.

Arterial System Managers make decisions regarding the operations of signal controlled arterial facilities, including changes to traffic signal control settings, and the selective provision of preferential timings to favor the safe and speedy movement of emergency vehicles, transit vehicles, trucks and pedestrians.

Road-Weather System Managers make decisions regarding the management of road systems under severe weather conditions, including snow removal, anticipatory treatment of road surfaces, and response to flooding and fog events.

Transit System Managers make decision regarding transit systems operations, including the creation and modification of scheduled and unscheduled transit service provision.

Parking System Managers make decisions on pricing and access to parking facilities, both on-street and off-street.

Freight System Managers make decisions regarding dray operations, fleet management, and the pricing and access to freight facilities such as port facilities.

Public Safety Managers make decision regarding the coordination and response to major incidents and other emergency situations within the transportation system. This includes the management of local incident zones, the staging of emergency response vehicles and personnel, and the closure of lanes and facilities required as a part of the incident response.

Information Service Providers are public and private sector staff who create or influence media content broadcast or directly delivered to System Users. This includes traditional broadcast media (such as television or radio), broadcast internet services (such as color-coded congestion maps), and personalized information services suggesting alternative routes, modes, or times of departure. Information provision includes descriptions of network congestion conditions, incident reports, the nature and state of management policies related to access and pricing (e.g., HOV lane access), and weather information. Information Service Providers may have independent forms of system surveillance, such as fixed wing aircraft or volunteer spotters separate from sources used by other System Managers.

Automated Control may be utilized by one or more System Managers who delegate routine decision-making and control message generation to an automated system. Automation may be used to reduce the time to make decisions, optimize control messaging, or both.

Table 3-5 presents functional requirements related to Operational Data Environment.

Table 3-5: System Manager Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SM-1	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Freeway System and Tollway Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	High	High	Med-High	Med-High			
SM-2	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Arterial System Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	Low	High	Low	Med-High			
SM-3	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Road-Weather System Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	Medium	Medium	Medium	Medium			
SM-4	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Transit System Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	High	Low	Med-High	Low			

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SM-5	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Parking System Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	High	Low	Med-High	Low			
SM-6	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Freight System Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	High	Low	Med-High	Low			
SM-7	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Public Safety Managers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	Low	High	Low	Med-High			
SM-8	The AMS Testbed shall emulate the duration and outcomes of decision-making by **Information Service Providers**, subject to the latency, accuracy, reliability and nature of Operational Data Environments available to support this decision-making.	Medium	High	Medium	Med-High	Medium			

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SM-9	The AMS Testbed shall emulate and differentiate the duration and outcomes of integrated versus independent decision-making among **System Managers**, including *Freeway and Tollway System Managers*, *Arterial System Mangers, Road-Weather System Managers, Parking System Managers, Freight System Managers, Public Safety Managers*, and *Information Service Providers*.	Medium	High	High	Med-High	Med-High			
SM-10	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Freeway System and Tollway Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence S*ystem User* decision-making.	Medium	High	High	Med-High	Med-High			
SM-11	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Arterial System Managers**, including messages passed through *Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence S*ystem User* decision-making.	Medium	Low	High	Low	Med-High			

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SM-12	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Road-Weather System Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence *System User* decision-making.	Medium	Medium	Medium	Medium	Medium			
SM-13	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Transit System Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence *System User* decision-making.	Medium	High	Low	Med-High	Low			
SM-14	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Parking System Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence *System User* decision-making.	Medium	High	Low	Med-High	Low			

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
SM-15	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Freight System Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence *System User* decision-making.	Medium	High	Low	Med-High	Low			
SM-16	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Public Safety Managers**, including messages passed through *Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks* to control or influence *System User* decision-making.	Medium	Low	High	Med-High	Low			
SM-17	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by **Information Service Providers**, including messages passed through *Broadcast Media, the DSRC Roadside Network or Wide-Area Wireless Networks* to influence *System User* decision-making.	Medium	High	Medium	Med-High	Medium			
SM-18	The AMS Testbed shall emulate the utilization of **Automated Control** by one or more *System Managers* who delegate specific forms of routine decision-making and control message generation.	Medium	Low	Low	Low	Low			

3.2.5 Data and Information Flows

Data and Information Flows are represented by directed arcs (arrows) for direct entity-to-entity communications. In the System Description figures, a series of three crescents represents broadcast information reaching many System Users . Whether direct or indirect, each flow represents a message within the system. Individual data and information flows are associated with a specific communications system (including landline systems). Each message represents a collection of data elements from one *System Entity* to one or more other *System Entities* (*System Users, Connected Vehicles/Devices, Communications Systems, Operational Data Environments, and System Managers*). Local message capture and aggregation methods are instrumental elements of message content construction, including the latency, reliability, aggregation, frequency and reliability of data elements contained in the message. Specific messages of interest to the ATDM and DMA programs are identified below:

The **Basic Safety Message (BSM)** is a local wireless broadcast message transmitted by DSRC-enabled Mobile Devices, Carry-In Devices and Integrated Devices. Any DSRC-enabled device within range of this broadcast message can receive this message. The message itself contains data about the current location of the generating device and when triggered by specific events (e.g., the activation of traction control), vehicle status data from the Connected Vehicle associated with a specific Carry-In Device or Integrated Device. The BSM is broadcast every 0.1 second and has fixed content as specified by the SAE J2735 Standard [8]. These messages will always contain Part 1 data elements and may contain Part 2 elements triggered by specific conditions (e.g., traction control status is added when traction control systems are active).

The **Basic Mobility Message (BMM)** is a point-to-point wireless data message transmitted by wireless-capable Mobile Devices, Carry-In Devices and Integrated Devices. The BMM is transmitted by either DSRC or a Wide-Area Wireless Network from BMM-capable devices to Data QC and Aggregation processes or to Private Sector Data Services. The BMM contains data regarding the current location of the generating device and where applicable, the status of the Connected Vehicle associated with specific Carry-In or Integrated Devices. The BMM is transmitted at variable rates depending on the location and status of the BMM-capable device and control messages, but no more frequently than once per second. The content of the BMM may vary but is drawn from the data elements defined within Parts I and II of the SAE J2735 Standard for the BSM.

The **Signal Phase and Timing (SPaT) Message** is a local wireless broadcast message transmitted by DSRC Roadside Devices which can be received by DSRC-capable Mobile Devices, Carry-In Devices, or Integrated Devices. The message contains data about the local signal status, is broadcast at a fixed interval and has fixed content as specified in the SAE J2735 standard.

Table 3-6 presents functional requirements related to Data and Information Flow.

Table 3-6: Data and Information Flow Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
DI-1	The AMS Testbed shall emulate the transmission and reception of **Information and Data Flows** between System Entities over a specific communications system, whether broadcast or point-to-point in nature, the interval at which the data flow occurs, and the content of the message contained in the data flow.	High	High	High	Medium	Medium	M.1, M.3		M.3.x
DI-2	The AMS Testbed shall emulate the transmission and reception of **Basic Safety Messages (BSM)** among *Connected Vehicles, Mobile Devices,* and the *DSRC Roadside Network*.	High	Medium	High	Low	Medium			
DI-3	The AMS Testbed shall emulate the transmission of **Basic Mobility Messages (BMM)** from *Connected Vehicles* and *Mobile Devices* to the *System Entity* tasked with managing BMM messaging (either a *Private Sector Data Services* or a *Data QC and Aggregation* process)	High	Medium	High	Low	Medium			
DI-4	The AMS Testbed shall emulate the transmission of **Signal, Phase and Timing (SPaT) Messages** from the *DSRC Roadside Device Network* to DSRC-capable *Connected Vehicles*.	High	Low	Medium	Low	Low	M.3		M.3.x

3.2.6 DMA Applications and ATDM Strategies

ATDM Strategies and DMA Applications enhance decision-making or enable new forms of decision-making by System Users or System Managers. These strategies and application may also provide new forms of system control for System Managers. ATDM Strategies are defined in the ATDM Concept of Operations in three categories: Active Demand Management Strategies, Active Traffic Management Strategies, and Active Parking Management Strategies. Thirty DMA s have been defined in six bundles: Freight Traveler Information Systems (FRATIS), Intelligent Dynamic Transit Operations (IDTO), Enabling Advanced Traveler Information (EnableATIS), Next Generation Integrated Corridor Management (ICM), Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E), Multi-Modal Intelligent Signal Systems (M-ISIG), and Intelligent Network Flow Optimization (INFLO). Complete Concepts of Operation and System Requirements have developed for all of the DMA bundles with the exception of EnableATIS and Next-Generation ICM. ATDM Strategies and DMA Applications have been developed separately in the two programs, and there are some overlaps and differences between the defined set of applications.

Table 3-7 presents functional requirements related to DMA applications and ATDM strategies.

Table 3-7: DMA Application and ATDM Strategy Requirements

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-1	The AMS Testbed shall emulate **Dynamic Shoulder Lanes**.	*Dynamic Shoulder Lanes*	Low	Medium	High	Med-High	High	E.4		E.4.x
AP-2	The AMS Testbed shall emulate driver behaviors in **Dynamic Shoulder Lanes** that are distinct from behaviors on regular lanes.	*Dynamic Shoulder Lanes*	High	Low	High	Low	Medium	A.5		
AP-3	The AMS Testbed shall emulate restriction of access to **Dynamic Shoulder Lanes** by vehicle type (e.g., transit) and vehicle occupancy (e.g., HOV 2+, HOV 3+).	*Dynamic Shoulder Lanes*	Low	Medium	High	Med-High	High	E.4		E.4.x
AP-4	The AMS Testbed shall emulate **Dynamic Lane Use Control**, including shoulder lanes.	*Dynamic Lane Use Control, Dynamic Shoulder Lane Use*	High	Medium	High	Low	Medium	E.4		E.4.x
AP-5	The AMS Testbed shall emulate **Dynamic HOV/Managed Lanes**.	*Dynamic HOV/Managed Lanes*	Low	High	Medium	High	Med-High	E.4		E.4.x

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-6	The AMS Testbed shall emulate detection of position, start time, duration, and length of queues on freeways and arterials in support of a **Queue Warning** DMA or **Queue Warning** strategy supporting *System Manager* decision-making.	Queue Warning (**Q-WARN**), *Queue Warning*	Low	Medium	High	Med-High	High	E.4	H.1-H.4	E.4.x
AP-7	The AMS Testbed shall emulate altered driving behavior in response to **Queue Warning** messages generated by the Q-WARN DMA and delivered to *Carry In* or *Integrated Devices* within *Connected Vehicles* or through local signage within the Traffic Control System.	**Q-WARN**, *Queue Warning*	High	Medium	High	Low	Medium	A.5, E.4	H.5	E.4.x
AP-8	The AMS Testbed shall emulate the estimation of dynamic target speed recommendations by roadway section and lane made by the **SPD-HARM** application or the **Dynamic Speed Limits** strategy deployed in support of *System Managers*.	Dynamic speed harmonization (**SPD-HARM**), *Dynamic Speed Limits*	Low	Low	High	Medium	High	E.4	I.1-I.4	E.4.x

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-9	The AMS Testbed shall emulate transmission of **SPD-HARM** enhanced target speed recommendations via message signs; or directly to *Carry-In* or *Integrated Devices* running the SPD-HARM application within a *Connected Vehicle*.	**SPD-HARM**, *Dynamic Speed Limits*	Medium	Low	High	Low	Med-High	E.4	I.4	E.4.x
AP-10	The AMS Testbed shall emulate driver decision-making in response to target speed recommendations made by the **SPD-HARM** application running on a *Carry-In* or *Integrated Device* within a *Connected Vehicle*.	**SPD-HARM**, *Dynamic Speed Limits*	High	Low	High	Low	Medium	A.5, E.4	I.5, Y.7	
AP-11	The AMS Testbed shall emulate altered driving behavior in response to combined queue warning and target speed recommendations made by a combined **Q-WARN/SPD-HARM** application.	**Q-WARN, SPD-HARM**, *Queue Warning, Dynamic Speed Limits*	High	Medium	High	Low	Medium		H.5,I.5	E.4.x

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-12	The AMS Testbed shall emulate the creation, movement, and dispersion of a platoon of *Connected Vehicles* utilizing **Coordinated Adaptive Cruise Control** (CACC) application, traveling at the same speed and maintaining the same gap with their respective leaders in the platoon.	Coordinated Adaptive Cruise Control (**CACC**)	High	Low	High	Low	Medium	E.4, E.5	J.1-J.5	E.4.x, E.5.x
AP-13	The AMS Testbed shall emulate the identification and implementation of altered signal control settings enhanced by the **M-ISIG** DMA bundle or the ATDM **Adaptive Traffic Signal Control and Adaptive Ramp Metering** strategies.	Multi-Modal Intelligent Signal Systems (**M-ISIG**), *Adaptive Traffic Signal Control, Adaptive Ramp Metering*	Low	Low	High	Medium	High	E.4, E.5	O.1-O.5, P.1-P.5, R.1-R.4, S.1-S.4, T.1-T.6	E.4.x, E.5.x

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-14	The AMS Testbed shall emulate the identification and implementation of signal control settings optimized to allow for the rapid and safe movement of Public Safety Vehicles (**PREEMPT**), Trucks (**FSP**), Transit Vehicles (**TSP**), and Pedestrians (**PED-SIG**).	**PREEMPT, FSP, TSP, PED-SIG,** *Transit Signal Priority*	Low	Low	High	Medium	High	E.4, E.5	P.1-P.5, R.1-R.4, S.1-S.4	E.4.x, E.5.x
AP-15	The AMS Testbed shall emulate the dynamic creation of high-occupancy vehicles through the **DRIDE** application running on Mobile Devices or through other **Dynamic Ridesharing** services supporting informal ridesharing.	**DRIDE**, *Dynamic Ridesharing*	Medium	High	Low	Med-High	Low	A.8, E.3	N.1-N.5	E.3.x
AP-16	The AMS Testbed shall emulate multi-modal forms of traveler information services that include cost, reliability and parking delivered pre-trip through Broadcast Media or pre-trip and en route through Mobile Devices, Carry-In Devices, and Integrated Devices.	**EnableATIS**, *Predictive Traveler Information, Dynamic Routing*	Medium	High	Medium	Med-High	Medium	E.4, E.5	C.1-C.7, D.1-D.5, F.1 – F.5, G.1 – G.6, H.1-H.5	E.4.x, E.5.x

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-17	The AMS Testbed shall emulate **Active Parking Management Strategies** employed to support decision-making by *Parking System Managers*, including Dynamic Wayfinding, Dynamic Overflow Transit Parking, Dynamic Parking Reservation, and Dynamic Priced Parking	*Active Parking Management Strategies*	High	High	Low	Medium	Low	E.3	G.1-G.6	E.3.x
AP-18	The AMS Testbed shall emulate **Dynamic HOV Lane Conversion**, including dynamic alterations to access policy (e.g., HOV-2 to HOV-3) and price.	*Dynamic HOV Conversion*	Low	High	Medium	High	Med-High	E.4		
AP-19	The AMS Testbed shall emulate **Intelligent Dynamic Transit Operations (IDTO)**, including transit connection protection and dynamic dispatch.	**T-DISP, TCONNECT**, *Dynamic Transit Capacity Assignment, On-Demand Transit, Transfer Connection Protection*	Low	High	Low	High	Medium	A.8	K.1 – K.4, L.1 – L.3, N.1-N.5	

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-20	The AMS Testbed shall emulate **Incident Management** practices, including the management of local incident zones, the staging of emergency response vehicles and personnel, and the closure of lanes and facilities required as a part of the incident response.	**R.E.S.C.U.M.E**	High	Medium	High	Low	Medium		X.1-X.6, Y.1-Y.7	
AP-21	The AMS Testbed shall emulate **Dynamic Pricing and Dynamic Fare Reduction** strategies, including dynamic changes to roadway tolls or transit fares.	*Dynamic Pricing, Dynamic Fare Reduction*	Medium	High	Low	Med-High	Low	A.8		
AP-22	The AMS Testbed shall emulate the concurrent deployment of two or more DMAs or ATDM strategies, including synergies or conflicts arising from this interaction.	**Next Gen ICM**	Medium	Medium	Medium	Medium	Medium	E.1, E.2		
AP-23	The AMS Testbed shall emulate **Dynamic Junction Control**	*Dynamic Junction Control*	High	Low	High	Low	Medium			
AP-24	The AMS Testbed shall emulate **Dynamic Merge Control**	*Dynamic Merge Control*	High	Low	High	Low	Medium			

ID	Requirement	DMA Application / *ATDM Strategy*	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
AP-25	The AMS Testbed shall emulate **Dynamic Lane Reversal or Contraflow lanes**, including dynamically adjusting the lane directionality in response to real-time traffic conditions.	*Dynamic Lane Reversal*	High	High	Medium	Medium	Low			
AP-26	The AMS Testbed shall emulate freight operations, including drayage optimization and freight traveler information	*FRATIS*	Low	High	Low	High	Medium		T.1-T.6, U.1-U2	

3.2.7 Operational Condition and System Performance Measurement

Operational Conditions describe different realizations of natural variation in travel demand and incident patters, and variation in weather conditions. In our system description, we indicate that there are up to *N* operational conditions to be considered, each a combination of demand, incident, weather and other conditions. Each operational condition has a probability of occurrence.

System Performance Measures characterize the mobility, safety and environmental impacts of a particular system alternative that connect the various elements of the system together in a particular way. These impacts can be quantified and monetized in a consistent and systematic way for comparison with total cost of system to determine cost-effectiveness, and must be assessed over the full range of identified operational conditions.

Table 3-8 presents functional requirements related to Operational Condition and System Performance.

Table 3-8: Operational Condition and System Performance Requirements

ID	Requirement	Technical Risk (High, Medium, Low)	Strategic Importance (High, Medium, Low)	Tactical Importance (High, Medium, Low)	Strategic Priority (High, Medium, Low)	Tactical Priority (High, Medium, Low)	ATDM Model Needs Traceability	DMA Model Needs Traceability	ATDM Model Req. Needs Traceability
OC-1	The AMS Testbed shall emulate a range of **Operational Conditions**, including variations in travel demand, weather, and incident patterns.	Low	High	High	High	High	E.1, E.2		
OC-2	The AMS Testbed shall be capable of calculating, storing, and reporting a consistent set of **Performance Measures** describing mobility, safety and environmental impacts, over all Operational Conditions and subject to multiple alternative systems linking System Users and System Managers.	Medium	High	High	Med-High	Med-High	M.4		M.4.x
OC-3	The AMS Testbed shall be capable of being calibrated and validated using relevant **Performance Measures** against real-world conditions, both in terms of the representation of Operational Conditions and Alternative Systems, where such data are available from actual surface transportation systems.	Medium	High	High	Med-High	Med-High	E.1, E.2		

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12. Society of Automotive Engineers (SAE) standard J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary, November 2009.

APPENDIX A. ATDM Strategies' Modeling Needs

Table A-1: Requirements Traceability Matrix for ATDM Strategies' Modeling Needs [9]

ID	ATDM Modeling Need	AMS Testbed Requirement ID
M.1	Collect and process real-time data from a variety of sources	SU-1, SU-18, SU-21, CV-10, CS-8, OD-1
M.2	Collect and process historical data from a variety of sources	
M.3	Access transportation network (highway and transit) data from a variety of sources	
M.4	Generate the desired performance metrics to monitor the system	
M.5	Integrate data collected from difference sources.	OD-4
M.6	Visualization capabilities must support analysis.	
M.7	Understand demand patterns.	
M.8	Validate the data before analysis.	OD-10
M.9	The process must support the required analysis scale, both temporal and spatial.	
M.10	Auto-correct or self-validate based on the latest data.	OD-10
A.1	Use both real-time and historical data to assess and predict future performance	
A.2	Continuously predict system performance in real time in a moving window	
A.3	Predict performance measures that align with agencies' goals and objectives	
A.4	Consider possible demand and supply changes in the forecast period and their net impact on system performance.	
A.5	Explicitly capture human factors and their impact on network demand and supply.	SU-3, SU-4, SU-5, SU-6, SU-7, SU-8, SU-10, SU-12, SU-15, SU-16, SU-17, SU-19, SU-20, SU-22, SU-23, SU-24, AP-2, AP-7, AP-10
A.6	Capture uncertainties in demand and supply.	
A.7	Support multimodal analysis capability.	SU-2, SU-3, SU-4, SU-5, SU-6, SU-7, SU-11, SU-12, SU-13
A.8	Explicitly model transit impacts on system demand and operations.	SU-7, SU-9, SU-10, SU-11, SU-12, SU-13, SU-17
A.9	Include visualization capabilities to display forecasted network conditions.	

ID	ATDM Modeling Need	AMS Testbed Requirement ID
E.1	Assess whether the ATDM strategy should be implemented to achieve agency goals and objectives.	
E.2	Identify the best strategy or group of strategies to implement by evaluating multiple scenarios in parallel.	
E.3	Model the impact of ATDM strategy on different elements of the trip chain.	SU-2, SU-3, CV-7, CV-8
E.4	Model microscopic driver behavior changes resulting from dynamic actions, as applicable (e.g., for variable speed limit).	SU-3, SU-8, SU-10, SU-12, SU-13, SU-14, SU-15, SU-16, SU-19, SU-23, SU-24, AP-7, AP-10
E.5	Model the demand-supply interactions resulting from implementation of ATDM strategies.	
E.6	Consider anticipated behavior changes to predict future performance.	
E.7	Support multiple spatial and temporal extents of analysis (e.g., region, corridor, peak period, peak hour).	

APPENDIX B. DMA BUNDLES' Modeling Needs

Table B-1: Requirements Traceability Matrix for DMA Bundles' Modeling Needs [10]

ID	Modeling Function for EnableATIS Bundle: ATIS	AMS Testbed Requirement ID
C.1	Detect real-time traffic information	SU-1, AP-16
C.2	Develops minimum time path for travelers based on dynamic assignment (single mode and multi modes)	AP-16
C.3	Accommodates route diversion, speed changes and modal shift to travel condition information.	SU-5, SU-6, AP-16
C.4	Implements dynamic route assignment and route shifts for each mode.	AP-16
C.5	Provides for off-line demand adjustment by mode choice	AP-16
C.6	Provides static assignment of route and mode for macroscopic and sketch planning tools	AP-16
C.7	Develops estimate of travel time under various traffic condition scenarios	AP-16
ID	**Modeling Function for EnableATIS Bundle: WX-INFO**	**AMS Testbed Requirement ID**
D.1	Detect real-time traffic information	SU-1, AP-16
D.2	Develop dynamic minimum time path for travelers based on off-line weather condition(capacity and speed change)	AP-16
D.3	Control Traveler behaviors (compliance rate, route diversion, speed changes and modal shift) based on travel condition information and weather condition	SU-5, SU-6, SU-7, SU-8, SU-10, SU-12, SU-13, SU-15, SU-16, SU-17, SU-19, SU-20, SU-22, SU-23, SU-24, AP-16
D.4	Multiple traveler compositions reflecting service market penetration rate and vehicle type	AP-16
D.5	Off-line demand adjustment by weather condition	AP-16

ID	Modeling Function for EnableATIS Bundle: T-MAP	AMS Testbed Requirement ID
F.1	Implement dynamic transit assignment by transit schedule	AP-16
F.2	Develop minimum time path for travelers (Route Guidance) with adjusted demand by off-line T-MAP utilization ratios	AP-16
F.3	Control Traveler behaviors (route diversion and mode shift) based on T-MAP information	AP-16
F.4	Multi traveler compositions including T-MAP-enabled traveler group	AP-16
F.5	Sketch level travel time estimation under two different map availability scenarios	AP-16
ID	**Modeling Function for EnableATIS Bundle: S-PARK**	**AMS Testbed Requirement ID**
G.1	Model parking facility (e.g., location, available spaces)	AP-16, AP-17
G.2	Calculate minimum time paths (Route Guidance) considering multi modes based on real-time parking information, transit schedule, and highway congestion.	AP-16, AP-17
G.3	Dynamically track available parking spaces and predicts availability on vehicle's expected arrival time at parking facility.	AP-16, AP-17
G.4	Control Traveler behaviors (i.e., route diversion, destination change, and modal shift) based on parking lot information	SU-3, AP-16, AP-17
G.5	Multi traveler compositions including S-PARK users	AP-16, AP-17
G.6	Sketch level travel time estimation under two different park and ride scenarios given proper database	AP-16, AP-17
ID	**Modeling Function for INFLO Bundle: Q-WARN**	**AMS Testbed Requirement ID**
H.1	Model non-recurrent congestion (e.g., incident, work zone).	AP-6
H.2	Detect existing queues in real-time	AP-6
H.3	Generate warning messages for upstream vehicles.	CS-4, CS-5, AP-6
H.4	Provide upstream vehicles with Queue warning messages	AP-6
H.5	Control Traveler behaviors (driver compliance, route diversion, speed change) in response to queue warning information	AP-7, AP-11

ID	Modeling Function for INFLO Bundle: SPD-HARM	AMS Testbed Requirement ID
I.1	Model non-recurrent congestion (e.g., incident, work zone).	AP-8
I.2	Detect traffic congestion conditions	AP-8
I.3	Determine target speed based on detected recurrent and non-recurrent traffic conditions	AP-8
I.4	Provide target speed information to drivers.	AP-9, AP-8
I.5	Control Traveler behaviors (e.g., driver compliance, speed change) in response to target speed information	AP-10, AP-8
ID	**Modeling Function for INFLO Bundle: CACC**	**AMS Testbed Requirement ID**
J.1	Model non-recurrent congestion (e.g., incident, work zone).	AP-12
J.2	Detect existing traffic congestion conditions in real-time	AP-12
J.3	Calculate target speed and gap guidance for CACC-enabled vehicles based on traffic and incident conditions.	AP-12
J.4	Provides target speed and gap guidance to CACC drivers	AP-12
J.5	Control Traveler behaviors (e.g., driver compliance, speed change) in response to target speed information	AP-12
ID	**Modeling Function for IDTO Bundle: T-CONNECT**	**AMS Testbed Requirement ID**
K.1	Model a hold request from a pedestrian.	AP-19
K.2	Model transit vehicles (e.g., positions of transit vehicles and their schedules and passenger loads).	SU-9, AP-19
K.3	Determine feasibility of holding based on minimizing the total passenger delay (with proper logic and constraints).	AP-19
K.4	Manipulate dynamic transit operation based on pedestrian hold requests based on proper logic to determine its feasibility; Grants, if feasible the hold so that a passengers can make the connection; If not feasible, an alternative transit itinerary will be provided)	AP-19

ID	Modeling Function for IDTO Bundle: T-DISP	AMS Testbed Requirement ID
L.1	Provide travelers with dynamic transit route using fixed route and flexible route service based on real-time requests.	AP-19
L.2	Determine the best route based on traffic conditions as well as the transit pick-up and drop-off requests.	AP-19
L.3	Control Traveler behaviors (driver compliance and route diversion) based on T-DISP information	AP-19
ID	**Modeling Function for IDTO Bundle: D-RIDE**	**AMS Testbed Requirement ID**
N.1	Multiple vehicle compositions including ridesharing-enabled vehicle types.	AP-15, AP-19
N.2	Model ride sharing requests on short notice (locations, request frequency and time)	AP-15, AP-19
N.3	Search for ridesharing vehicles to serve the requests	AP-15, AP-19
N.4	Develop the best ridesharing option incorporating the information of transit schedule, availability, and location and real-time traffic condition.	AP-15, AP-19
N.5	Control Traveler behaviors (ridesharing driver's compliance and route diversion)	AP-15, AP-19
ID	**Modeling Function for M-ISIG Bundle: ISIG**	**AMS Testbed Requirement ID**
O.1	Detect real-time traffic congestions	AP-13
O.2	Model traffic compositions to consider various modes (auto, transit, pedestrian, freight)	AP-13
O.3	Determine optimal traffic signal timing by incorporating proper optimization algorithms that consider all traveler modes (vehicle, transit, pedestrian, freight)	AP-13
O.4	Provides optimal signal timing control to travelers in real-time	AP-13
O.5	Control Traveler behaviors (driver compliance, route diversion, speed change) in response to optimal traffic signal controls	AP-13

ID	Modeling Function for M-ISIG Bundle: TSP	AMS Testbed Requirement ID
P.1	Dynamic transit simulation based on transit schedule	AP-13, AP-14
P.2	Detect real-time traffic congestions	AP-13, AP-14
P.3	Detect real-time transit vehicle information (e.g., position, speed, passenger load)	AP-13, AP-14
P.4	Determine optimal transit priority strategy by incorporating proper algorithms that consider auto, transit, and pedestrian modes	AP-13, AP-14
P.5	Real-time intersection traffic signal control based on the optimal TSP strategy	AP-13, AP-14
ID	**Modeling Function for M-ISIG Bundle: PREEMPT**	**AMS Testbed Requirement ID**
R.1	Model emergency vehicles (e.g., departure time, desired speed, origin-destination)	AP-13, AP-14
R.2	Detect real-time emergency vehicle information (e.g., position, speed, passenger load)	SU-18, SU-21, AP-13, AP-14
R.3	Generate preemption calls	AP-13, AP-14
R.4	Real-time intersection traffic signal control based on the preemption calls	AP-13, AP-14

ID	**Modeling Function for M-ISIG Bundle: FSP**	**AMS Testbed Requirement ID**
S.1	Model freight modes (e.g., type, departure time, desired speed, origin-destination)	AP-13
S.2	Detect real-time freight vehicle or train information (e.g., position, speed, passenger load)	SU-14, AP-13
S.3	Generate preemption calls	AP-13
S.4	Real-time intersection traffic signal control based on the preemption calls	AP-13
ID	**Modeling Function for FRATIS Bundle: F-ATIS**	**AMS Testbed Requirement ID**
T.1	Model freight vehicles (e.g., truck or train and departure time, desired speed, origin-destination)	AP-26
T.2	Model non-recurrent congestion (e.g., incident, work zone, weather condition).	AP-26
T.3	Detect real-time traffic information	AP-26
T.4	Provide freight operators with traffic information	AP-26
T.5	Model freight operator behaviors (compliance, route diversion, and speed changes) based on traffic Information.	SU-15, SU-16, AP-26
T.6	Multiple vehicle compositions (auto, transit, and freight)	CV-11, AP-26
ID	**Modeling Function for FRATIS Bundle: DR-OPT**	**AMS Testbed Requirement ID**
U.1	Model drayage vehicles (e.g., freight arrival time, loading/unloading time)	AP-26
U.2	Determine optimal drayage vehicle operation by incorporating proper optimization algorithms	AP-26

ID	Modeling Function for FRATIS Bundle: F-DRG	AMS Testbed Requirement ID
V.1	Model freight vehicles (e.g., truck or train and departure time, desired speed, origin-destination)	AP-26
V.2	Model non-recurrent congestion (e.g., incident, work zone, weather condition).	AP-26
V.3	Detect real-time traffic information and create route-guidance by using a proper algorithm that considers the real-time traffic condition, restricted roadways, special weather issues, itinerary constraints	AP-26
V.4	Provide freight operators with the route guidance information	AP-26
V.5	Model freight operator behaviors (compliance, route diversion, and speed changes) based on traffic Information.	SU-15, SU-16, AP-26
V.6	Multiple vehicle compositions (auto, transit, and freight)	AP-26
ID	**Modeling Function for R.E.S.C.U.M.E. Bundle: EVAC**	**AMS Testbed Requirement ID**
W.1	Model passive evacuees who are not able to evacuate by their own by using proper database	
W.2	Model special vehicles for passive evacuees (e.g., route, schedule)	
W.3	Develop optimal path information for evacuees based on shelter location, grocery location, lodge information, ATM location	
W.4	Provide active evacuees with the optimal path information	
W.5	Provide passive evacuees with proper evacuation modes	
W.6	Control evacuee behaviors (e.g., compliance, route diversion) based on the path information	
W.7	Multiple traveler compositions reflecting active and passive evacuees	

ID	Modeling Function for R.E.S.C.U.M.E. Bundle: RESP-STG	AMS Testbed Requirement ID
X.1	Model emergency responder vehicles (e.g., route, departure time)	AP-20
X.2	Model Incidents (e.g., location, occurrence time, duration, severity)	AP-20
X.3	Detect real-time traffic congestions	AP-20
X.3	Detect incidents in real-time	AP-20
X.5	Develop optimal route guidance for emergency responders such that responders, travelers, and crash victim are safe while less disruptive to traffic.	AP-20
X.6	Provide route guidance with emergency responders	AP-20
ID	**Modeling Function for R.E.S.C.U.M.E. Bundle: INC-ZONE**	**AMS Testbed Requirement ID**
Y.1	Model incident scene (occurrence time, location, work zone size, severity)	AP-20
Y.2	Detect real-time traffic congestions	AP-20
Y.3	Detect incidents in real-time	AP-20
Y.4	Detect vehicles near the incident scene and identify dangerous vehicles	AP-20
Y.5	Determine safe speed for the vehicles near the incident scene	AP-20
Y.6	Provide the vehicles near the incident scene work zone with safe speed advisory	AP-20
Y.7	Control Traveler behaviors (e.g., compliance, speed change) in response to the speed advisory information	AP-10, AP-20
ID	**Modeling Function for R.E.S.C.U.M.E. Bundle: MAYDAY**	**AMS Testbed Requirement ID**
Z.1	Model run-off crash situation (e.g., location, occurrence time, mayday dissemination)	
Z.2	Model wireless communications (e.g., coverage)	CV-1, CV-2, CV-3, CV-4, CV-5, CV-6, CV-7, CV-8, CV-9
Z.3	Multiple vehicle types (normal vehicles vs. communication device-equipped vehicles, market penetration rates)	CV-10

APPENDIX C. ATDM Modeling Requirements

Table C-1: ATDM Modeling Requirements for The Monitoring System [11]

ID	AMS Needs	ATDM AMS Component	Modeling Requirement
M.1.1	M.1	Data Generator	The AMS framework shall include geospatial and temporal aggregation procedures, and a standardized data schema for the integrated multi-modal database.
M.2.1	M.2	Data Generator	The AMS framework shall include the historical data in disaggregate and geospatially/temporally aggregated form, and in the standardized data schema.
M.3.1	M.3	Data Generator	The AMS framework shall maintain an updated account of all the supply elements in the transportation network; both roadways and transit.
M.4.1	M.4	Network Simulator	The AMS framework shall generate simulated traffic flows. The results from the simulation runs shall be used to calculate various performance measures including: traveler throughput in terms of the number of trips completed during the simulation run, mobility delays, travel time reliability in terms of the variation of actual travel time observed during the simulation run from the desired travel time, safety measured as the number of vehicle-to-vehicle conflicts, and quantity of emissions.
M.5.1	M.5	Data Generator	The AMS framework shall integrate data from various sources into the standardized schema of the integrated multi-modal database.
M.7.1	M.7	Network Simulator	The AMS framework shall include advanced travel demand models, such as activity-based models to capture travel demand patterns across the region.
M.8.1	M.8	Data Generator	The AMS framework shall validate the data processed by data errors detection and auto-correction algorithms before analysis.
M.9.1	M.9	Network Simulator	The AMS framework shall include a multi-resolution integrated simulation framework to support different analysis scales.
M.9.1	M.9	Network Simulator	The AMS framework shall include a multi-resolution simulation framework which can analyze ATDM strategies with respect to ATDM goals.
M10.1	M10	Data Generator	The AMS framework shall include data errors detection algorithms, auto-correction for erroneous values, imputation techniques for missing data, geospatial and temporal aggregation methods, and a standardized data schema for the integrated multi-modal database.

Table C-2: ATDM Modeling Requirements for Assessing The System Performance [11]

ID	AMS Needs	ATDM AMS Component	Modeling Requirement
A.1.1	A.1	Network Simulator	The AMS framework shall include advanced travel demand models, such as activity-based models, to predict travel demand in the next 30 minute future window based on historical and real-time data. It shall also include a log of possible/scheduled supply changes in that time window.
A.2.1	A.2	Network Simulator	The AMS framework shall include advanced travel demand models, such as activity-based models, to predict travel demand in the next 30 minute future window based on historical and real-time data. It shall also include a log of possible/scheduled supply changes in that time window.
A.2.2	A.2	Network Simulator	The AMS framework shall include mesoscopic DTA simulation models which can predict future network conditions in a moving time window.
A.3.1	A.3	Network Simulator	The AMS framework shall use the travel demand for the forecast period to run simulation analysis. The results from these simulation runs shall be translated to performance measures by a performance interpreter component.
A.4.1	A.4	Network Simulator	The AMS framework shall keep a track of possible or scheduled changes in demand or supply of the transportation system.
A.5.1	A.5	Network Simulator	The AMS framework shall include models capturing the human factors such as user trust, adaptability, compliance, acceptance of the technology, etc.
A.6.1	A.6	Network Simulator	The AMS framework shall capture the inherent uncertainties in data collection, limited knowledge about user preferences, future conditions, etc. in terms of error terms.
A.7.1	A.7	Network Simulator	The models in the AMS framework shall be integrated across different modes of transportation. The interlinking between these models is especially important at transit access locations, as the accessibility of transit mode from roadways is an important driving factor in transit use.
A.8.1	A.8	Network Simulator	The models in the AMS framework shall incorporate the impact of transit schedule, operations, and fare pricing structure on the traveler behavior.

Table C-3: ATDM Modeling Requirements for Evaluating Impact Strategies [11]

ID	AMS Needs	ATDM AMS Component	Modeling Requirement	Strategy
A.5.2	A.5	Network Simulator	The AMS framework shall be able to model the perceived suitability of the shoulder lanes for travel during severe weather conditions	Dynamic Shoulder Lanes
A.5.3	A.5	Network Simulator	The AMS framework shall be able to model the user trust in the advisories issued by the TMC	Enhanced Transit Information and Trip Planning Systems
E.1.1	E.1	Network Simulator	The models in the AMS framework shall include a multi-resolution simulation framework which can analyze ATDM strategies with respect to ATDM goals.	All
E.2.1	E.2	Data Generator and Network Simulator	The simulation framework in the Network Simulator component and the database structure in the Data Generator component shall support parallel computing of four strategies at once. The performance measures generated from these simulation runs shall be tangible, tractable, and un-ambiguous.	All
E.3.1	E.3	Network Simulator	The route choice models for motorists shall include the parking space availability as one of the key driving factors towards the end of the trip.	Dynamic Parking Information
E.3.2	E.3	Network Simulator	The models in the AMS framework shall capture the impact of dynamic pricing in mode-choice, time-of-day choice, and lane/facility choice. The models shall make use of the demographics data to determine the price sensitivity of the population.	Dynamic Pricing
E.3.3	E.3	Network Simulator	The mode choice models in the AMS framework shall model dynamic ridesharing as a carpool mode option. The utility of this mode option shall be linked with the availability of the ride.	Dynamic Ridesharing
E.3.4	E.3	Network Simulator	The algorithms for matching the ride-request demand to the ride-offering supply within the geographically and temporally practical context shall be used in the mode choice model to generate the mode splits of traveler population.	Dynamic Ridesharing
E.3.5	E.3	Network Simulator	The models in the traveler behavior models especially the route choice and lane choice models shall capture the impact of dynamic speed limits.	Dynamic Speed Limits
E.3.6	E.3	Network Simulator	The availability of the transit service (as a function of the dynamic scheduling and dynamic routing) shall be linked to the utility of the dynamic transit service mode option in the mode choice model.	Dynamic Transit Service

ID	AMS Needs	ATDM AMS Component	Modeling Requirement	Strategy
E.3.7	E.3	Network Simulator	The time-of-day choice, mode choice and route choice models shall be linked to the dynamic price structure of the parking facilities to capture the changes in traveler behavior.	Dynamically Priced Parking
E.3.8	E.3	Network Simulator	The dynamic pricing algorithm shall be sensitive to the performance measures.	Dynamically Priced Parking
E.3.9	E.3	Network Simulator	The models in the AMS framework shall include utility-based discrete choice models to capture destination choice, mode choice, time-of-day choice, and route choice affected by the traveler information. While the destinations choice, mode choice and time-of-day choice can be captured in mesoscopic DTA models, modeling route choice shall be done on a microscopic simulation platform.	Enhanced Transit Information and Trip Planning Systems
E.3.10	E.3	Network Simulator	The models in the AMS framework shall capture the impact of the information conveyed to travelers on the travel demand.	Enhanced Transit Information and Trip Planning Systems
E.4.1	E.4	Network Simulator	The driving behavior models in the AMS framework shall be responsive to the ATSC implementation.	Adaptive Traffic Signal Control
E.4.2	E.4	Network Simulator	The AMS framework shall be able to modify the ATSC algorithms to account for significantly different traffic conditions, such as lower average speeds, slower turning maneuvers, longer queues, etc.	Adaptive Traffic Signal Control
E.4.3	E.4	Network Simulator	The Network Simulator component of the AMS framework shall have a distinct microscopic simulation component with advanced driving behavior models.	All
E.4.4	E.4	Network Simulator	The models in the AMS framework shall capture the impact of dynamic pricing in mode-choice, time-of-day choice, and lane/facility choice. The models shall make use of the demographics data to determine the price sensitivity of the population.	Dynamic lane/ facility pricing
E.4.5	E.4	Network Simulator	The lane/facility choice models in the AMS framework shall capture the impact of added lane capacity on lane/facility choice. The mode choice and route choice models may also capture the impact of dynamic shoulder lanes. The modeler shall especially consider the safety concerns of the shoulder lane use while modeling the driving behavior.	Dynamic Shoulder Lanes

ID	AMS Needs	ATDM AMS Component	Modeling Requirement	Strategy
E.4.6	E.4	Network Simulator	The utility-based discrete choice models in the traveler behavior models especially the route choice and lane choice models shall capture the impact of dynamic speed limits.	Dynamic Speed Limits
E.4.7	E.4	Network Simulator	The AMS framework shall be able to determine safe driving speeds under the severe weather conditions	Dynamic Speed Limits
E.4.8	E.4	Network Simulator	The AMS framework shall be able to model the driving behavior under reduced visibility of DMS	Dynamic Speed Limits
E.4.9	E.4	Network Simulator	The AMS framework shall be able to capture the risk-avert driving behavior in the car-following and lane changing models	Dynamic Speed Limits
E.4.10	E.4	Network Simulator	The models in the AMS framework shall include utility-based discrete choice models to capture the mode choice, time-of-day choice, and route choice affected by the traveler information. While the mode choice and time-of-day choice can be captured in mesoscopic DTA models, modeling route choice shall be done on a microscopic simulation platform.	Enhanced Transit Information and Trip Planning Systems
E.4.11	E.4	Network Simulator	The route choice and lane choice model shall be able to capture the "urgency" of the traveler to make a decision on the route choice and the lane choice as a response to the queue warning. These models shall consider every individual traveler's driving behavior characteristics such as aggressiveness, compliance to advisories, etc.	Queue Warning
E.4.12	E.4	Network Simulator	The models shall use queue warning information in conjunction with the dynamic speed limits in terms of "interaction terms" to capture the compound effect of these strategies on travelers.	Queue Warning
E.4.13	E.4	Network Simulator	The models shall capture the on and off-ramp driving behavior of the travelers in terms of maneuvers such as merging: courtesy, normal or forced, etc.	Queue Warning
E.5.1	E.5	Data Generator and Network Simulator	The AMS framework shall maintain an updated inventory of available parking spaces.	Dynamic Parking Information
E.5.2	E.5	Network Simulator	The driving behavior models in the AMS framework shall be responsive to the ATSC implementation.	Adaptive Traffic Signal Control
E.5.3	E.5	Network Simulator	The supply component of the AMS framework shall incorporate the ATSC algorithms to be implemented in the analysis.	Adaptive Traffic Signal Control

ID	AMS Needs	ATDM AMS Component	Modeling Requirement	Strategy
E.5.4	E.5	Network Simulator	The AMS framework shall be able to account for limited data availability from the roadway sensors which affects the input data for the ATSC algorithms	Adaptive Traffic Signal Control
E.5.5	E.5	Network Simulator	The information channel to disseminate dynamic parking information to travelers using mobile devices or DMS shall be modeled by the AMS framework along with the dynamics of these dissemination methods.	Dynamic Parking Information
E.5.6	E.5	Network Simulator	The models in the AMS framework shall use the price sensitivity of the traveler population to determine the demand elasticity, and subsequent impact of pricing on the travel demand.	Dynamic pricing
E.5.7	E.5	Network Simulator	The AMS framework shall capture the impact of added capacity of shoulder lane use in attracting more demand.	Dynamic Shoulder Lanes
E.5.8	E.5	Network Simulator	The AMS framework shall be able to model the appropriate safe speed limits to travel in the shoulder lanes	Dynamic Shoulder Lanes
E.5.9	E.5	Network Simulator	The dynamic scheduling algorithms for the regional transit operations shall be incorporated in the supply control component of the simulator framework.	Dynamic Transit Service
E.5.10	E.5	Network Simulator	The simulation framework shall have a feedback loop to the dynamic scheduling and dynamic routing algorithms of transit operations to fine-tune them based on recent transit demand.	Dynamic Transit Service
E.5.11	E.5	Network Simulator	The dynamic parking pricing scheme shall be based on levels of congestion or other factors which are derived from the outputs of the travel demand model.	Dynamically Priced Parking
E.5.12	E.5	Network Simulator	The models in the AMS framework shall capture the impact of the information conveyed to travelers on the travel demand.	Enhanced Transit Information and Trip Planning Systems
E.5.13	E.5	Network Simulator	The AMS framework shall be able to model travelers' propensity to cancel the trip or switch modes to transit under severe weather conditions should be explicitly modeled in the activity based models.	Enhanced Transit Information and Trip Planning Systems
E.6.1	E.6	Network Simulator	The ATSC algorithms in the AMS framework shall include the anticipated traveler response to changes in signal timings, in designing the traffic signal cycles.	Adaptive Traffic Signal Control

ID	AMS Needs	ATDM AMS Component	Modeling Requirement	Strategy
E.6.2	E.6	Network Simulator	The models in the AMS framework shall use the price sensitivity of the traveler population to determine the demand elasticity, and the subsequent impact of pricing on the travel demand.	Dynamic pricing
E.6.3	E.6	Network Simulator	The mode-choice and route-choice models in the AMS framework shall include the anticipated traveler response to the pricing strategy.	Dynamic pricing
E.6.4	E.6	Network Simulator	The traveler behavior models in the AMS framework shall use the anticipated traveler behavior in the analysis of the effectiveness of the strategy.	Dynamic Shoulder Lanes
E.6.5	E.6	Network Simulator	The design of dynamic speed limits shall consider the anticipated user response to the advisories based on traveler behavior factors such as user acceptance and user reliability in travel advisories.	Dynamic Speed Limits
E.6.6	E.6	Network Simulator	The models in the AMS framework shall anticipate user reactions to the information conveyed to the traveler, in the analysis done for determining the traveler information to be disseminated.	Enhanced Transit Information and Trip Planning Systems
E.6.7	E.6	Network Simulator	The models in the AMS framework shall anticipate user reactions to the information conveyed to the traveler using DMS etc..	Enhanced Transit Information and Trip Planning Systems
E.7.1	E.7	Network Simulator	The algorithms for matching the ride-request demand to the ride-offering supply within the geographically and temporally practical context shall be used in the mode choice model to generate the mode splits of traveler population.	Dynamic Ridesharing

APPENDIX D. List of Acronyms

Acronym	Name
ATDM	Active Transportation and Demand Management
ATIS	Advanced Traveler Information Systems
ATM	Advanced Traffic Management
ATSC	Adaptive Traffic Signal Control
BMM	Basic Mobility Message
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CONOPS	Concept of Operations
CS	Communications Systems
CV	Connected Vehicle
DI	Data and Information
DMA	Dynamic Mobility Applications
DMS	Dynamic Message Signs
DOT	Department of Transportation
DRG	Dynamic Routing of Vehicles
D-RIDE	Dynamic Ridesharing
DR-OPT	Drayage Optimization
DSRC	Dedicated Short Range Communications
DTA	Dynamic Traffic Assignment
ECO	Connected Eco Driving
EFP	Multimodal Integrated Payment System
EnableATIS	Enable Advanced Traveler Information System
ETC	Electronic Toll Collection System
EVAC	Emergency Communications and Evacuation
F-ATIS	Freight Real-time Traveler Information with Performance Monitoring
F-DRG	Freight Dynamic Route Guidance
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRATIS	Freight Advanced Traveler Information System
FSP	Freight Signal Priority
FTA	Federal Transit Administration
HAR	Highway Advisory Radio
HOV	High-Occupancy Vehicle
HSR	Hard Shoulder Running
ICM	NxGen Integrated Corridor Management
IDTO	Integrated Dynamic Transit Operations
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
INFLO	Intelligent Network Flow Optimization
I-SIG	Intelligent Traffic Signal System
ITS	Intelligent Transportation Systems

Acronym	Name
JPO	Joint Program Office
MAYDAY	Mayday Relay
MDSS	Maintenance Decision Support System
M-ISIG	Multi-Modal Intelligent Traffic Signal System
MMITSS	Multimodal Intelligent Traffic Signal System
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OC	Operational Condition
OD	Operational Data
PED-SIG	Mobile Accessible Pedestrian Signal System
PREEMPT	Emergency Vehicle Preemption
Q-WARN	Queue Warning
R.E.S.C.U.M.E	Response, Emergency Staging and Communications, Uniform Management, and Evacuation
RAMP	NxGen Ramp Metering System
RESP-STG	Incident Scene Pre-Arrival Staging
RITA	Research and Innovative Technology Administration
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SM	System Manager
S-PARK	Smart Park and Ride
SPaT	Signal Phasing and Timing
SPD-HARM	Dynamic Speed Harmonization
SU	System User
T-CONNECT	Connection Protection
T-DISP	Dynamic Transit Operations
T-MAP	Universal Map Application
TMC	Transportation Management Center
TRB	Transportation Research Board
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
WX-INFO	Real-Time Route Specific Weather
WX-MDSS	Enhanced MDSS Communications

APPENDIX E. Dynamic Mobility Applications and ATDM Strategies

Table E-1: Dynamic Mobility Applications Sorted by Application Bundle

Enable ATIS: Enable Advanced Traveler Information Systems • ATIS: Multi-Modal Real-Time Traveler Information • S-PARK: Smart Park and **Ride** • T-MAP: Universal Map Application • WX-INFO: Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles	**MMITSS**: Multimodal Intelligent Traffic Signal System • FSP: Freight Signal Priority • I-SIG: Intelligent Traffic Signal System • PED-SIG: Mobile Accessible Pedestrian Signal System • PREEMPT: Emergency Vehicle Preemption with Proximity Warning • TSP: Transit Signal Priority
FRATIS: Freight Advanced Traveler Information Systems • DR-OPT: Drayage Optimization • F-ATIS: Freight Real-Time Traveler Information with Performance Monitoring • F-DRG: Freight Dynamic Route Guidance	**R.E.S.C.U.M.E.:** Response, Emergency Staging and Communications, Uniform Management, and Evacuation • EVAC: Emergency Communications and Evacuation • INC-ZONE: Incident Scene Work Zone Alerts for Drivers and Workers • AACN-RELAY: Advanced Automatic Crash Notification System • RESP-STG: Incident Scene Pre-Arrival Staging and Guidance for Emergency Responders
IDTO: Integrated Dynamic Transit Operations • D-RIDE: Dynamic Ridesharing • T-CONNECT: Connection Protection • T-DISP: Dynamic Transit Operations	**INFLO**: Intelligent Network Flow Optimization • CACC: Cooperative Adaptive Cruise Control • Q-WARN: Queue Warning • SPD-HARM: Dynamic Speed Harmonization

ATDM Strategies

Active Traffic Management Strategies

- **Dynamic Shoulder Lanes:** This strategy enables the use of the shoulder as a travel lane(s), known as Hard Shoulder Running (HSR) or temporary shoulder use, based on congestion levels during peak periods and in response to incidents or other conditions as warranted during non-peak periods. In contrast to a static time-of-day schedule for using a shoulder lane, an ATDM approach continuously monitors conditions and uses real-time and anticipated congestion levels to determine the need for using a shoulder lane as a regular or special purpose travel lane (e.g., transit only).
- **Dynamic Lane Use Control:** This strategy involves dynamically closing or opening of individual traffic lanes as warranted and providing advance warning of the closure(s) (typically through dynamic lane control signs), in order to safely merge traffic into adjoining lanes. In an ATDM approach, as the network is continuously monitored, real-time incident and congestion data is used to control the lane use ahead of the lane closure(s) and dynamically manage the location to reduce rear-end and other secondary crashes.
- **Dynamic Speed Limits:** This strategy adjusts speed limits based on real-time traffic, roadway, and/or weather conditions. Dynamic speed limits can either be enforceable (regulatory) speed limits or recommended speed advisories, and they can be applied to an entire roadway segment or individual lanes. In an ATDM approach, real-time and anticipated traffic conditions are used to adjust the speed limits dynamically to meet an agency's goals/objectives for safety, mobility, or environmental impacts.
- **Queue Warning:** This strategy involves real-time displays of warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists that queues or significant slowdowns are ahead, thus reducing rear-end crashes and improving. In an ATDM approach, as the traffic conditions are monitored continuously, the warning messages are dynamic based on the location and severity of the queues and slowdowns.
- **Adaptive Ramp Metering:** This strategy consists of deploying traffic signal(s) on ramps to dynamically control the rate vehicles enter a freeway facility. This in essence smoothes the flow of traffic onto the mainline, allowing efficient use of existing freeway capacity. Adaptive ramp metering utilizes traffic responsive or adaptive algorithms (as opposed to pre-timed or fixed time rates) that can optimize either local or system-wide conditions. Adaptive ramp metering can also utilize advanced metering technologies such as dynamic bottleneck identification, automated incident detection, and integration with adjacent arterial traffic signal operations. In an ATDM approach, real-time and anticipated traffic volumes on the freeway facility will be used to control the rate of vehicles entering the freeway facility. Based on the conditions, the ramp meter rates will be adjusted dynamically.
- **Dynamic Junction Control:** This strategy consists of dynamically allocating lane access on mainline and ramp lanes in interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day. For off-ramp locations, this may consist of assigning lanes dynamically either for through movements, shared through-exit movements, or exit-only. For on-ramp locations, this may involve a dynamic lane reduction on the mainline upstream of a high volume entrance ramp, or might involve extended use of a shoulder lane as an acceleration lane for a two-lane entrance ramp which culminates in a lane drop. In an ATDM approach, the volumes on the mainline lanes and ramps are continuously monitored and lane access will be dynamically changed based on the real-time and anticipated conditions.
- **Dynamic Merge Control:** This strategy (also known as dynamic late merge or dynamic early merge) consists of dynamically managing the entry of vehicles into merge areas with a series

of advisory messages (e.g., displayed on a DMS or lane control sign) approaching the merge point that prepare motorists for an upcoming merge and encouraging or directing a consistent merging behavior. Applied conditionally during congested (or near congested) conditions, dynamic merge control can help create or maintain safe merging gaps and reduce shockwaves upstream of merge points. In an ATDM approach, conditions on the mainline lanes and ramps approaching merge areas are continuously monitored and the dynamic merge system will be activated dynamically based on real-time and anticipated congestion conditions.

- **Adaptive Traffic Signal Control:** This strategy continuously monitors arterial traffic conditions and the queuing at intersections and dynamically adjusts the signal timing to optimize one or more operational objectives (such as minimize overall delays). Adaptive Traffic Signal Control approaches typically monitor traffic flows upstream of signalized locations or segments with traffic signals, anticipating volumes and flow rates in advance of reaching the first signal, then continuously adjusting timing parameters (e.g., phase length, offset, cycle length) during each cycle to optimize operational objectives.
- **Transit Signal Priority:** This strategy manages traffic signals by using sensors or probe vehicle technology to detect when a bus nears a signal controlled intersection, turning the traffic signals to green sooner or extending the green phase, thereby allowing the bus to pass through more quickly. In an ATDM approach, current and predicted traffic congestion, multi-agency bus schedule adherence information, and number of passengers affected, may all be considered to determine conditionally if, where, and when transit signal priority may be applied.
- **Dynamic Lane Reversal Or Contraflow Lane Reversal:** This strategy consists of the reversal of lanes in order to dynamically allocate the capacity of congested roads, thereby allowing capacity to better match traffic demand throughout the day. In an ATDM approach, based on the real-time traffic conditions, the lane directionality is updated quickly and automatically in response to or in advance of anticipated traffic conditions.

Active Demand Management Strategies

- **Dynamic Ridesharing:** This strategy involves travelers using advanced technologies, such as smart phones and social networks, to arrange a short-notice, one-time, shared ride. This facilitates real-time and dynamic carpooling to reduce the number of auto trips/vehicles trying to use already congested roadways.
- **Dynamic Transit Capacity Assignment:** This strategy involves re-organizing schedules and adjusting assignments of assets (e.g., buses) based on real-time demand and patterns, to cover the most overcrowded sections of network. In an ATDM approach, real-time and predicted travel conditions can be used to determine the changes needed to the planned transit operations, thereby potentially reducing traffic demand and subsequent delays on roadway facilities.
- **On-demand Transit:** This strategy involves travelers making real-time trip requests for services with flexible routes and schedules. This allows users to request a specific transit trip based on their individual trip origin/destination and desired departure or arrival time.
- **Predictive Traveler Information:** This strategy involves using a combination of real-time and historical transportation data to predict upcoming travel conditions and convey that information to travelers pre-trip and en-route (such as in advance of strategic route choice locations) in an effort to influence travel behavior. In an ATDM approach, predictive traveler information is incorporated into a variety of traveler information mechanisms (e.g., multi-modal trip planning systems, 511 systems, dynamic message signs) to allow travelers to make better informed choices.

- **Dynamic Pricing:** This strategy utilizes tolls that dynamically change in response to changing congestion levels, as opposed to variable pricing that follows a fixed schedule. In an ATDM approach, real-time and anticipated traffic conditions can be used to adjust the toll rates to achieve agency goals and objectives.
- **Dynamic Fare Reduction:** This strategy involves reducing the fare for use of the transit system in a particular corridor as congestion or delay on that corridor increases. This encourages selection of transit mode to reduce traffic volumes entering the corridor. Fare changes are communicated in real-time to the traveling public, through general dissemination channels such as the transit website, as well as personalized messages to subscribers. In an ATDM approach, real-time and predicted highway congestion levels and/or the utilization levels of the transit system can be used to adjust transit fare in real-time to encourage mode shift necessary to meet agencies goals and objectives.
- **Transfer Connection Protection:** This strategy involves improving the reliability of transfers from a high frequency transit service (e.g., a train) to a low frequency transit service (e.g., a bus). For example, the train is running late, so the bus is held back so train passengers can make their connection with the bus; or providing additional bus services at a later time to match the late arrival time of the train. This ensures that the connections are not missed.
- **Dynamic HOV / Managed Lanes :** This strategy involves dynamically changing the qualifications for driving in a high-occupancy vehicle (HOV) lane(s). HOV lanes (also known as carpool lanes or diamond lanes) are restricted traffic lanes reserved at peak travel times or longer for exclusive use of vehicles with a driver and one or more passengers, including carpools, vanpools and transit buses. The normal minimum occupancy level is 2 or 3 occupants. Many agencies exempt other vehicles, including motorcycles, charter buses, emergency and law enforcement vehicles, low emission vehicles, and/or single-occupancy vehicles paying a toll. In an ATDM approach, the HOV lane qualifications are dynamically changed based on real-time or anticipated conditions on both the HOV and general purpose lanes. Qualifications that can potentially be dynamically adjusted include the number of occupants (e.g., from 2 to 3 occupants), the hours of operation, and the exemptions (e.g., change from typical HOV operation to buses only). Alternatively, the HOV restrictions could be dynamically removed allowing general use of the previously managed lane.
- **Dynamic Routing:** This strategy uses variable destination messaging to disseminate information to make better use of roadway capacity by directing motorists to less congested facilities. These messages could be posted on dynamic message signs in advance of major routing decisions. In an ATDM approach, real-time and anticipated conditions can be used to provide route guidance and distribute the traffic spatially to improve overall system performance.

Active Parking Management Strategies

- **Dynamically Priced Parking.** This strategy involves parking fees that are dynamically varied based on demand and availability to influence trip timing choice and parking facility or location choice in an effort to more efficiently balance parking supply and demand, reduce the negative impacts of travelers searching for parking, or to reduce traffic impacts associated with peak period trip making. In an ATDM approach, the parking availability is continuously monitored and parking pricing is used as a means to influence travel and parking choices and dynamically manage the traffic demand.
- **Dynamic Parking Reservation:** This strategy provides travelers the ability to utilize technology to reserve a parking space at a destination facility on demand to ensure availability. In an ATDM approach, the parking availability is continuously monitored and system users can reserve the parking space ahead of arriving at the parking location.

- **Dynamic Wayfinding:** This is the practice of providing real-time parking-related information to travelers associated with space availability and location so as to optimize the use of parking facilities and minimize the time spent searching for available parking. In an ATDM approach, the parking availability is continuously monitored and routing information to the parking space is provided to the user.
- **Dynamic Overflow Transit Parking:** This strategy dynamically utilizes overflow parking facilities in the vicinity of transit stations and/or park-and-ride facilities when the existing parking facilities are at or near capacity. The overflow parking are typically underutilized, such as large retail parking lots, and transit agencies could have agreements with these entities for occasional use of pre-designated, underutilized areas of the parking lots. In an ATDM approach, the parking demand and availability is continuously monitored and real-time determinations are made if overflow parking is needed, and accompanying dynamic routing information would be provided to travelers.

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