Analysis, Modeling, and Simulation (AMS) Testbed Preliminary Evaluation Plan for Active Transportation and Demand Management (ATDM) Program

www.its.dot.gov/index.htm
Final Report — November 2013
Publication Number: FHWA-JPO-13-096

Produced by Noblis, Inc.
U.S. Department of Transportation
ITS Joint Program Office
Research and Innovative Technology Administration

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-13-096	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Analysis, Modeling, and Simulation (AMS) Testbed Preliminary Evaluation Plan for Active Transportation and Demand Management (ATDM) Program	**5. Report Date** November 2013
	6. Performing Organization Code
7. Author(s) Meenakshy Vasudevan and Karl Wunderlich	**8. Performing Organization Report No.**
9. Performing Organization Name And Address Noblis, Inc., 600 Maryland Ave, SW, Suite 755, Washington, DC 20024	**10. Work Unit No. (TRAIS)**
	11. Contract or Grant No. DTFH61-11-D-00018
12. Sponsoring Agency Name and Address ITS Joint Program Office (ITS JPO), 1200 New Jersey Avenue, SE, Washington, DC 20590	**13. Type of Report and Period Covered** FINAL
	14. Sponsoring Agency Code USDOT RITA JPO

15. Supplementary Notes

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16. Abstract

Analysis Modeling and Simulation (AMS) Testbeds 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 Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (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.

The purpose of this report is to document a preliminary plan for evaluating impacts of individual ATDM strategies, and logical combinations of strategies, and identifying conflicts and synergies for maximum benefit. Elements that are covered include:

- Key research questions and hypotheses that should be tested in the AMS Testbed
- Performance measures that underpin the hypotheses
- Description of analysis scenarios
- Key technology and market penetration assumptions
- Sensitivity analyses
- Results reporting

A companion document provides a preliminary plan for DMA applications. These plans are intended to assist AMS Testbed developers in preparing an overarching evaluation methodology as well as detailed analytical plans tailored to specific sites and analytical approaches.

17. Key Words DMA, ATDM, connected vehicles, modeling, AMS, evaluation plan	**18. Distribution Statement**

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages** 30	**22. Price**

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgements

The authors wish to acknowledge several contributors to this study:

DMA-ATDM AMS Testbed Key Content Review Team: James Colyar (FHWA Operations; Noblis Task Manager), John Halkias (FHWA Operations), Kate Hartman (RITA/ITS JPO; DMA Program Manager), Joe Bared (FHWA R&D), Randy Butler (FHWA Operations), Taylor Lochrane (FHWA R&D), Robert Sheehan (RITA/ITS JPO), James Sturrock (FHWA Resource Center), Chung Tran (FHWA Resource Center), Eric Pihl (FHWA Resource Center), for their review and support.

ATDM Program: John Halkias, Wayne Berman (FHWA), James Colyar, Jim Hunt (FHWA), James Sturrock, Bob Sheehan, and Greg Jones (FHWA), for their feedback and support.

Noblis: Aaron Casey, Drennan Hicks, and Aretha Howard for formatting and 508-conversion of the report.

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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 1-1 illustrates 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	

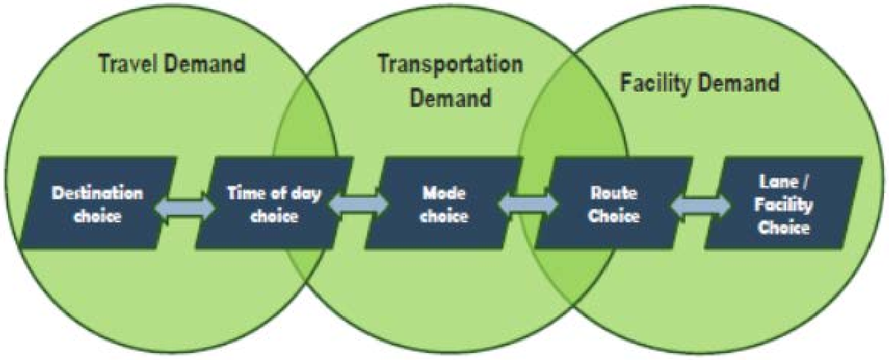

Figure 1-1: Trip Chain and Relation to Demand Activities[2]

Simultaneously, the USDOT initiated connected vehicle research to evaluate the merit of applications that leverage connected vehicles, travelers, and 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.

Bundle Acronym	Objective
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-

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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).

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.

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 [4]
- AMS Testbed Preliminary Evaluation Plan for DMA Program [5]
- AMS Testbed Preliminary Evaluation Plan for ATDM Program (this report)
- 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

The purpose of this report is to document a preliminary plan for evaluating impacts of individual ATDM strategies, and logical combinations of strategies, and identifying conflicts and synergies for maximum benefit. Elements that are covered include:

- Key research questions and hypotheses that should be tested in the AMS Testbed
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2 Key Research Questions and Hypotheses

This section identifies key research questions that the ATDM Program expects will be addressed through the AMS Testbed development and evaluation activities. A corresponding set of key hypotheses that should be tested for the ATDM Program using the AMS Testbed is presented. These research questions and hypotheses will guide the development of the rest of the components of the evaluation plan.

2.1 Key Research Questions

The ATDM Program expects the AMS Testbed effort to help address a number of key research questions, which are documented in Table 2-1.

Table 2-1: Key ATDM AMS Testbed Research Questions

ID	Research Question
I	**Synergies and Conflicts**
1	Are ATDM strategies more beneficial when implemented in isolation or in combination (e.g., combinations of ATM, ADM, or APM strategies)?
2	What ATDM strategy or combinations of strategies yield the most benefits for specific operational conditions?
3	What ATDM strategies or combinations of strategies conflict with each other?
II	**Prediction Accuracy**
4	Which ATDM strategy or combinations of strategies will be most benefited through increased prediction accuracy and under what operational conditions?
5	Are all forms of prediction equally valuable, i.e., what attributes of prediction quality are most critical (e.g., length of prediction horizon, prediction accuracy, prediction speed, and geographic area covered by prediction) for certain ATDM strategies?
III	**Active Management or Latency**
6	Is every investment made to enable more active control cost-effective?
7	Which ATDM strategy or combinations of strategies will be most benefited through reduced latency and under what operational conditions?
IV	**Operational Conditions, Modes, Facility Types with Most Benefit**
8	Which ATDM strategy or combinations of strategies will be most beneficial for certain modes and under what operational conditions?
9	Which ATDM strategy or combinations of strategies will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?
10	Which ATDM strategy or combinations of strategies will have the most benefits for individual facilities versus system-wide deployment versus region-wide deployment and under what operational conditions?
V	**Prediction, Latency, and Coverage Tradeoffs**

ID	Research Question
11	What is the tradeoff between improved prediction accuracy and reduced latency[2] with existing communications for maximum benefits?
12	What is the tradeoff between prediction accuracy and geographic coverage of ATDM deployment for maximum benefits?
13	What is the tradeoff between reduced latency (with existing communications) and geographic coverage for maximum benefits?
14	What will be the impact of increased prediction accuracy, more active management, and improved robust behavioral predictions on mobility, safety, and environmental benefits?
15	What is the tradeoff between coverage costs and benefits?
VI	**Connected Vehicle Technology and Prediction**
16	Are there forms of prediction that can only be effective when coupled with new forms of data, such as connected vehicle data?
VII	**Short-Term and Long-Term Behaviors**
17	Which ATDM strategy or combinations of strategies will have the most impact in influencing short-term behaviors versus long term behaviors and under what operational conditions?
18	Which ATDM strategy or combinations of strategies will yield most benefits through changes in short-term behaviors versus long-term behaviors and under what operational conditions?

2.2 Key Hypotheses

Each research question has a corresponding hypothesis that will be tested in an AMS Testbed. Table 2-2 presents the hypotheses and a mapping of each hypothesis to a research question. The table also shows the AMS Testbed technical approaches that might be suitable for testing the hypothesis.

The four AMS Testbed technical approaches that follow the AMS Testbed Framework [6] are the following:

1. **Strategic Traveler Behavior Focus**: This technical approach aims to accurately represent traveler's trip making choices prior to trip start in response to travel experiences and traffic conditions at a metropolitan regional level. Vehicle-to-vehicle or vehicle-to-pedestrian interactions are modeled in less detail in order to make the approach computationally tractable. This technical approach is mostly suited for evaluating travel demand management applications that impact pre-trip choices of travelers with respect to tour, time of departure, mode, and route, and have an immediate impact on travel demand through re-distribution or elimination of trips.
2. **Tactical Traveler Behavior Focus**: This technical approach aims to accurately represent individual vehicle and pedestrian movements and interactions between them. Strategic traveler behaviors are approximated. Given that, this approach is applicable for assessing traffic management applications that impact tactical driving behaviors and tactical movement decisions of pedestrians and bicyclists, and have significant impact on the flow of vehicles on a facility.
3. **Multi-Resolution Modeling Approach**: This technical approach aims to accurately represent traveler's trip making choices prior to trip start as well as individual vehicle and pedestrian

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[2] Latency is defined here as measure of active management. Active management will be most effective when the latency or time lag between the detection/prediction of traffic phenomena (including, queues, shockwaves, bottlenecks, incidents, breakdown conditions, etc.), and the dissemination of control or advisory information by System Managers to travelers and drivers is reduced.

movements and interactions between them. This approach is relevant for assessing applications that not only have an immediate impact on travel demand but also in managing recurring and non-recurring congestion on a facility. This approach appears to be suitable for assessing almost any application, but has the most technical risk among all technical approaches due to the need to manage online interfaces between travel demand modeling, transportation network modeling, system manager decision modeling, and communications modeling.

4. **Communications/Management Latency Focus**: This technical approach aims to accurately represent communications between vehicles, devices, and the infrastructure, as well as system managers' decision making. Thus, this approach is suited for applications that are impacted by communications bandwidth overload, dropped messages, communication latencies or system management latencies.

Table 2-2: Key ATDM AMS Testbed Hypotheses

ID	Research Question Category	Hypothesis	Research Question ID	Strategic Traveler Behavior Focus	Tactical Traveler Behavior Focus	Multi-Resolution Modeling Approach	Communications/ Management Latency Focus
1	Synergies and Conflicts	ATDM strategies that are synergistic (e.g., ADM, APM, ATM) will be more beneficial when implemented in combination than in isolation.	1	●	●	●	●
2	Synergies and Conflicts	An ATDM strategy will yield higher benefits only under certain operational conditions.	2	●	●	●	●
3	Synergies and Conflicts	Certain combinations of ATDM strategies will yield the highest benefits for specific operational conditions.	2	●	●	●	●
4	Synergies and Conflicts	Certain ATDM strategies will be in conflict with each other, resulting in no benefits or reduced benefits.	3	●	●	●	●
5	Prediction Accuracy	Improvements in prediction accuracy will yield higher benefits for certain ATDM strategies and combinations of strategies than for others.	4	⦿	●	●	●
6	Prediction Accuracy	An ATDM strategy or combinations of strategies will yield the most benefits with improvements in prediction accuracy only under certain operational conditions.	4	⦿	●	●	●
7	Prediction Accuracy	Increased prediction accuracy is more critical for certain ATDM strategies over others, with certain attributes (e.g., length of prediction horizon, prediction accuracy, prediction speed, and geographic area covered by prediction) of prediction quality being most critical.	5	⦿	●	●	●
8	Active Management or Latency	Incremental improvements in latency will result in higher benefit-cost ratio for certain ATDM strategy or combinations of strategies up to a certain latency threshold, after which benefit-cost ratio will be reduced.	6	⦿	⦿	⦿	●

9	Active Management or Latency	Reductions in latency will yield higher benefits for certain ATDM strategies and combinations of strategies than for others.	7	⦿	⦿	⦿	●
10	Active Management or Latency	An ATDM strategy or combinations of strategies will yield the most benefits with reduced latency only under certain operational conditions.	7	⦿	⦿	⦿	●
11	Operational Conditions, Modes, Facility Types with Most Benefit	Certain ATDM strategies and combinations of strategies will yield the highest benefits for specific modes and under certain operational conditions.	8	⦿	⦿	●	⦿
12	Operational Conditions, Modes, Facility Types with Most Benefit	Certain ATDM strategies and combinations of strategies will yield the highest benefits for specific facility types and under certain operational conditions.	9	⦿	●	●	●
13	Operational Conditions, Modes, Facility Types with Most Benefit	Certain synergistic ATDM strategies will yield most benefits when deployed together on individual facilities rather than as system-wide or region-wide deployments and under certain operational conditions.	10	⦿	⦿	●	⦿
14	Operational Conditions, Modes, Facility Types with Most Benefit	Certain synergistic ATDM strategies will yield most benefits when deployed together on a system rather than as facility-specific or region-wide deployments and under certain operational conditions.	10	⦿	⦿	●	⦿

15	Operational Conditions, Modes, Facility Types with Most Benefit	Certain synergistic ATDM strategies will yield most benefits when deployed together in a region rather than as facility-specific or system-wide deployments and under certain operational conditions.	10	⦿	⦿	●	⦿
16	Prediction, Latency, and Coverage Tradeoffs	Incremental improvements in prediction accuracy will result in higher benefits, when latency is fixed up to a certain threshold, after which marginal benefits will be reduced.	11	⦿	●	●	●
17	Prediction, Latency, and Coverage Tradeoffs	Incremental improvements in latency will result in higher benefits when prediction accuracy is fixed up to a certain threshold, after which marginal benefits will be reduced.	11	⦿	⦿	⦿	●
18	Prediction, Latency, and Coverage Tradeoffs	Maximum system benefit will be obtained at an intermediate point balancing prediction accuracy and latency.	11	⦿	⦿	⦿	●
19	Prediction, Latency, and Coverage Tradeoffs	Incremental improvements in prediction accuracy will result in higher benefits when geographic coverage is fixed up to a certain threshold, after which marginal benefits will be reduced.	12	⦿	●	●	●
20	Prediction, Latency, and Coverage Tradeoffs	Incremental increase in geographic coverage will result in higher benefits when prediction accuracy is fixed up to a certain threshold, after which marginal benefits will be reduced.	12	●	⦿	●	⦿
21	Prediction, Latency, and Coverage Tradeoffs	Maximum system benefit will be obtained at an intermediate point balancing prediction accuracy and geographic coverage.	12	⦿	⦿	⦿	⦿

22	Prediction, Latency, and Coverage Tradeoffs	Incremental improvements in latency will result in higher benefits when geographic coverage is fixed up to a certain threshold, after which marginal benefits will be reduced.	13	⦿	⦿	⦿	●
23	Prediction, Latency, and Coverage Tradeoffs	Incremental increase in geographic coverage will result in higher benefits when latency is fixed up to a certain threshold, after which marginal benefits will be reduced.	13	●	⦿	●	⦿
24	Prediction, Latency, and Coverage Tradeoffs	Maximum system benefit will be obtained at an intermediate point balancing latency and geographic coverage.	13	⦿	⦿	⦿	⦿
25	Prediction, Latency, and Coverage Tradeoffs	Increases in prediction accuracy, more active management, and improvements in robust behavioral predictions will result in significant mobility, safety, and environmental benefits.	14	⦿	⦿	⦿	⦿
26	Prediction, Latency, and Coverage Tradeoffs	ATDM strategies will reduce the impact of congestion by delaying its onset, and reducing its duration and geographic extent. ATDM strategies will impact all three characteristics of congestion (onset, duration, and extent) but different strategies will impact specific congestion characteristics differently. Traveler and system mobility measures will vary inversely with respect to congestion characteristics, but not uniformly by characteristic.	14	⦿	⦿	●	⦿
27	Prediction, Latency, and Coverage Tradeoffs	Incremental increase in geographic coverage will result in higher benefit-cost ratio up to a certain coverage cost threshold, after which benefit-cost ratio will be reduced.	15	●	⦿	●	⦿

28	Connected Vehicle Technology and Prediction	Prediction will be most effective only when coupled with connected vehicle data capture and communications technologies that can systematically capture motion and state of mobile entities, and enable active exchange of data between vehicles, travelers, roadside infrastructure, and system operators.	16	⦿	⦿	⦿	●
29	Short-Term and Long-Term Behaviors	Certain ATDM strategies and combinations of strategies will influence short-term behaviors more than long-term behaviors under certain operational conditions, while others will influence long-term behaviors more than short-term behaviors under certain operational conditions.	17	⦿	⦿	●	⦿
30	Short-Term and Long-Term Behaviors	Certain ATDM strategies and combinations of strategies will have the most impact through changes in short-term behaviors under certain operational conditions, while others will have the most impact through changes in long-term behaviors under certain operational conditions.	18	⦿	⦿	●	⦿

● - Applicable ⦿ - Partially applicable ○ - Not applicable

3 Key Performance Measures

This section identifies key performance measures that are common to all ATDM strategies. Performance measures have been identified as part of the ATDM Concept of Operations development effort [2]. The strategy-specific performance measures reveal the primary impacts of the strategy. In addition, it is essential to define system-level measures that are strategy independent. Defining such measures provides a level playing field when examining what combinations of strategies are most effective in concert with one another to improve overall system performance.

All analytical experimentation conducted in support of ATDM objectives should at a minimum examine the following key system-level, application-independent mobility [8], safety, and environmental performance measures:

- **Travel Time Reliability**: Travel time reliability is a measure of the consistency or dependability in travel times experienced by a traveler making the same trip over many days and operational conditions. The FHWA Office of Operations has recommended four measures to characterize travel time reliability (i) 90th or 95th percentile travel time, (ii) buffer index, (iii) planning time index, and (iv) frequency that congestion exceeds some expected threshold [9].
- **Delay:** Delay is defined as the travel time in excess of some subjective minimum travel time threshold [10]. Typically, discussions of delay focus solely on roadway-only travel and delays are estimated with respect to travel times at posted speeds or 85th percentile speeds. Delays should be computed across all modes and by both vehicles and persons.
- **Reliable Throughput:** Reliable throughput is defined as traveler trips or traveler miles delivered reliably by the system [8]. Typically, throughput is defined as a point measure. Traveler trips and miles traveled (without considering reliability) are often ineffective measures when differentiating a well-managed system and a poorly managed system . For example, a twenty-mile trip completed in 25 minutes counts equally with the same twenty-mile trip completed in one hour. Reliable traveler trips should be computed as the total number of trips with travel times less than or equal to the 95th percentile travel time for that trip. Reliable traveler miles delivered should be computed as the total miles traveled on the reliable trips.
- **Fuel Consumption:** Fuel consumption is defined as the amount of fuel consumed in a given distance (e.g., gallons per 100 miles) [11]. Fuel consumption is the inverse of fuel economy, which is defined as the average number of miles traveled per gallon of fuel consumed [11].
- **Emissions:** Emissions is defined as the exhaust gas or flue gas emitted as a result of the combustion of fuels such as natural gas, gasoline/petroleum, diesel fuel, fuel oil, or other fuel types. Emissions that are principal pollutants of concern include: Hydrocarbons (HC), Carbon monoxide (CO), Carbon dioxide (CO2), Nitrogen oxides (NOx), Particulate matter (PM), Sulfur oxide (SOx), and Volatile organic compounds (VOCS).
- **Crashes:** Crashes are defined as unintended collisions between two or more vehicles [12]. Conflict is an observable situation in which two or more road users approach each

other in time and space to such an extent that there is risk of collision if their movements remain unchanged.

In 2010, the DMA Program sponsored the development of an open source performance measurement application, (the DMA Performance Measurement Application, DMA-PMA) that estimates the above mode-independent performance measures [13]. The application was developed by making use of trip-based system performance measure algorithms developed as part of the USDOT's Integrated Corridor Management (ICM) Program and adapting them for use with observed data to measure impact in mobility and productivity. The algorithms developed under ICM, estimate key measures of corridor performance (delay, travel time reliability, and throughput) from time-variant traffic simulation outputs. The software code for the performance measurement application will be released through the DMA Program's Open Source Application Development Portal [14], and is available for use and or modification by analysts and developers.

Performance measures in addition to those mentioned in the ATDM Concept of Operations and the aforementioned strategy-independent system-level measures may be identified when AMS Testbed development activities are conducted.

4 Analysis Scenarios

This section discusses analysis scenarios. Each analysis scenario is a combination of a specific operational condition and an alternative being examined.

4.1 Operational Conditions

It is essential to identify under what travel or operational conditions a strategy might be most beneficial to facilitate a System Manager's decision-making process as to what strategy or collection of strategies to deploy. As hypothesized earlier in Section 2, an ATDM strategy may not yield similar benefits under all operational conditions. Certain ATDM strategies may be more valuable than others depending on the operational condition. For example, for an incident scenario predictive traveler information and queue warning may be more valuable than the other strategies in improving travel time reliability and reducing delays. Secondly, operational conditions do not have the same probability of occurrence. Some may occur more frequently than others, and these may vary by testbed location. Knowledge of operational conditions that will occur most frequently will be helpful to the System Manager in deciding to what strategy or collection of strategies to focus on.

Appendix A presents two data-driven approaches suggested for grouping the days based on similar travel or operational conditions - one that makes use of a pre-determined bins (Option 1: Pre-Determined Binning) and another that makes use of cluster analysis to identify the bins or clusters (Option 2: Cluster Analysis). The preferred option is Option 2, which uses cluster analysis.

4.2 Baseline/Do-Nothing Alternative

The baseline or the Do-Nothing alternative describes the current state of the testbed location being modeled. The baseline should be modeled to reveal potential improvements that can be realized by deploying the ATDM strategy or collections of strategies at the testbed location. The delta from the baseline helps identify the most effective strategies for the location, and provides quantitative and or qualitative evidence of the value of investing in ATDM strategies to decision-makers and stakeholders that have a vested interest in the testbed location.

Modeling the baseline also helps other areas and agencies recognize the range of benefits that is possible through ATDM for possible future implementation in their areas. If the AMS Testbed is calibrated to an area that is either a progressive site and a front-runner among its peers or lagging behind its peers in ITS deployments, then it might become necessary to model a second Baseline or Do-State-of-the-Practice Alternative that describes a national state of the practice to capture the full extent of benefits that can be achieved. If resources and schedule permit, it is advisable to model a baseline for each operational condition that is observed at the testbed location.

4.3 Alternatives

Alternatives should be defined based on the research questions being addressed at the testbed location, and the operational conditions identified for the location. The parameters that should be examined include predictive capability, active management, and strategies. The parameters and the corresponding ranges should be tailored for each testbed location and type of modeling approach used, and testbed location-specific alternatives should be developed.

4.3.1 Predictive Capability

The AMS Testbed should be capable of modeling and examining the effectiveness of ATDM strategies for various types of prediction capabilities, including the time horizon over which prediction is performed, the speed and accuracy of prediction, and capability to predict System User behaviors. Depending on the type of modeling approach used for the System Manager Simulator [6], capability to predict System Managers' behaviors may also need to be modeled and varied.

Prediction Time Horizon

Time horizon may be varied as follows:

- Short-term (10 min)
- Mid-term (10-30 min)
- Long-term (>30 min)

Prediction Speed

Prediction speed may be varied as follows:

- Short lead time (< 5 min)
- Medium lead time (5 – 20 min)
- Long lead time (> 20 min)

Prediction Accuracy

Prediction accuracy may be varied as follows:

- Low (>50% error)
- Medium (10-50% error)
- High (<10% error)

System Users' Behavioral Prediction

Behavioral prediction capability may be varied as follows:

- None modeled
- Randomly assigned
- Behavioral models

4.3.2 Active Management Capability

The AMS Testbed should be capable of modeling and examining the effectiveness of ATDM strategies with increased active management. Active management capability is a measure of latency between detection/prediction of traffic phenomena (including bottlenecks, queues, shockwaves, incidents, etc.) and dissemination of control or advisory information by System Managers to System Users (travelers and drivers), and the level of automation used by System Managers for system management decisions.

Control latency may be varied as follows:

- Low (< 5 min)
- Medium (5-30 min)
- High (> 30 min)

System management automation may be varied as follows:

- Use of Decision Support Systems (DSS) without human intervention
- Human decision-making, represented by discrete choice models, in the absence of DSS
- Use of Decision Support Systems (DSS) with human intervention represented by discrete choice models

4.3.3 ATDM Strategies

The AMS Testbed should be capable of modeling individual ATDM strategies and logical combinations of strategies. Logical combinations may be identified as strategies with common objectives. Identifying synergies between strategies helps to not only assess the added benefit of combining strategies but also prevents overestimating or underestimating benefits and costs, which is a common problem when examining strategies only in isolation. For example, if a queue warning strategy is found to increase throughput by 20% and dynamic speed limits is also found to increase throughput by 20%, an agency cannot expect a 40% increase in throughput by implementing both queue warning and dynamic speed limits. A joint deployment of the two strategies might for example yield only a 30% increase in throughput due to both strategies being deployed on nearby facilities rather than on the same facility or a 50% increase due to simultaneous smoothing of traffic while enabling re-routing and lane re-positioning.

5 Assumptions, Sensitivity Analyses, and Reporting

This section discusses assumptions, sensitivity analyses, and results reporting. From a portfolio of (expected) multiple analytical test beds and multiple experiments within each test bed, the ATDM analyst must construct a defensible collective argument either supporting or rejecting the overarching ATDM hypotheses. This will not be straightforward nor trivial. However, a systematic method must be developed that integrates results at differing scales from a variety of analytical tools to provide nuanced responses to the key ATDM research questions.

Detailed micro-simulation tools may be required to identify primary impacts of strategies influencing tactical driving behaviors. Different disaggregate tools may be required to capture the impact of strategies influencing strategic traveler decision-making. The overarching evaluation methodology must address both the statistical significance comparing the same tool in multiple runs and operational conditions for two alternatives, as well as a logical approach for integrating results from different locations and tools to address key ATDM hypotheses.

More detailed analysis plans leveraging the tools and data associated with the analytical effort must be prepared for each tool and testbed location in the overall plan. This section provides some guidance on the preparation of both the overarching evaluation method as well as the detailed testbed location-specific analysis plans.

5.1 Key Assumptions

It is critical to develop valid and realistic assumptions, as the analyses may result in benefits that are unachievable or unrealistic in the field.

Assumptions need to be developed for:

- **Market adoption of technologies and strategies**, including number of parking lots that sign up to serve as overflow parking facilities, etc.
- **Vehicle/Traveler detection**, including type, number, and location of loop detectors, license plate readers, Bluetooth sniffers, video cameras, etc.
- **Mobile devices**, including number of devices, communication technology, type of data, status, power, etc. The number of devices may be assumed to be higher for urban areas (close to 50%) than for non-urban areas.
- **Infrastructure footprint**, including number and location of sign gantries, number and location of signal controllers with adaptive signal control or transit signal priority capabilities, etc. For example, sign gantries may be assumed to be deployed every half mile along freeway corridors in urban areas and every mile in non-urban areas.
- **Driver/Traveler/System Manager behavioral responses**, including compliance rate of drivers (light, freight, and transit), etc. For example, a motorist may not comply with

dynamic speed limits or HOV/managed lane restrictions. These may be assumed to vary randomly by time of day, by congestion level, and or by driver aggressiveness.

- **Policy**, including assumptions for each strategy. For example, how often will pricing be changed? How are integrated control decisions made? Will speed limits be advisory or enforced?

5.1.1 Sensitivity Analyses

Sensitivity analyses helps to measure the impact of uncertainty in assumptions since these will affect the benefits/costs analyses, and ultimately the decisions made. In more detailed, testbed location-specific analysis plans to be developed, this section should identify the parameters corresponding to assumptions that will be varied.

5.1.2 Results Reporting

In more detailed, testbed location-specific analysis plans to be developed, this section should document the benefits/costs analyses of ATDM strategies. Benefit/cost ratio is useful in comparing the relative value of the strategies.

Estimate Monetized Benefits

Benefits should be monetized for calculating the benefits/costs ratio. Monetization may be done using the federal government's standard guidance on monetizing benefits. Net Present Value (NPV) may be determined by applying discount rates as suggested in the Office of Management and Budget (OMB) Circular A-94.

Estimate Costs

Cost for each strategy should include, capital costs, operations and maintenance (O&M) costs, and replacement costs. The one-time capital cost for each strategy should include development, testing, and integration costs. Capital costs and O&M costs may be further disaggregated to include incremental costs. O&M costs should include items such as staffing, in addition to hardware and software costs. Appropriate service costs associated with use of commercial services, such as cellular, should also be included. Costs should not only be calculated for individual strategies, but also for interdependent strategies with common objectives, and interdependent strategies with common technology needs.

Reporting

Parametric analysis, sensitivity analyses and probability models can play a key role to show tradeoffs between various types and levels of prediction, active management, and coverage, and benefits/costs from specific ATDM strategies. Results should be documented in table format as well as in graphical charts. There should be a clear link between the reporting and hypotheses that are tested. Given below are some illustrative charts that show the results while providing a visual confirmation of the hypotheses. Figure 5-1**.** shows the expected impact of prediction error and latency in system control on system delay, while providing a visual proof for hypotheses 7, 8, and 9. Figure 5-2 shows the expected impact of prediction error and latency in system control on system delay for various alternatives, while validating hypotheses 7, 8, 9, 18, and 20. Figure 5-3 shows the operational conditions under which a full ATDM alternative has the most impact, providing visual proof for hypotheses 4 and 5. Similar charts should be developed, and existing ones presented below should be modified with actual results.

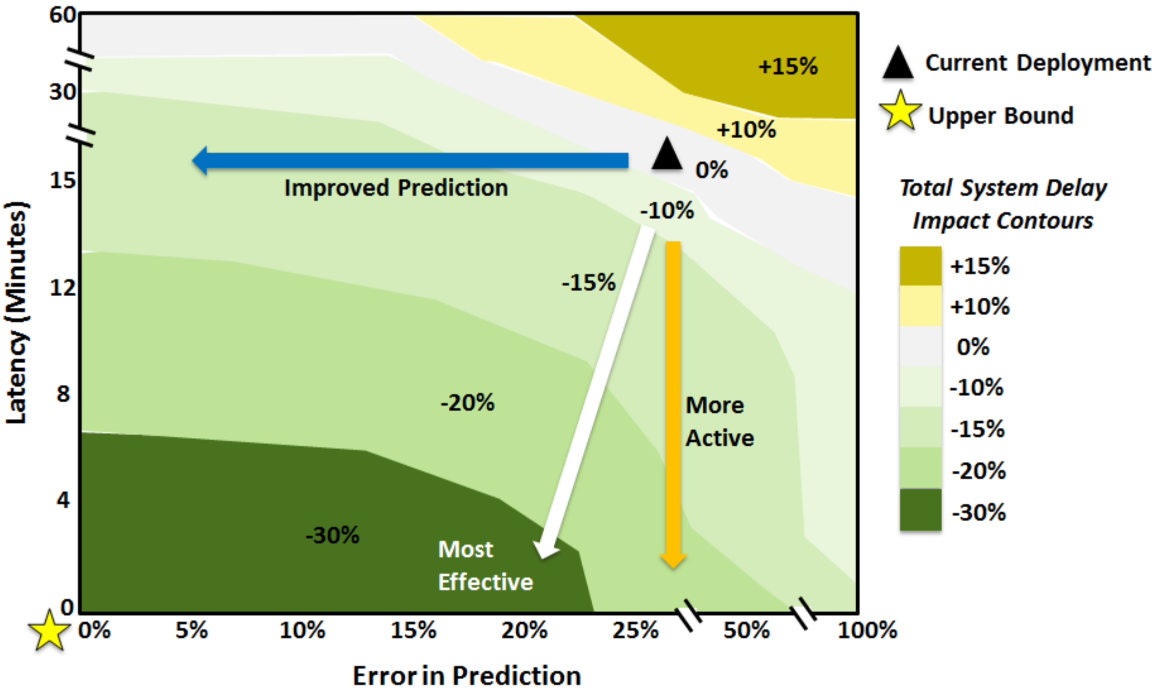

Figure 5-1: What the AMS Testbed Can Reveal: Effect of Prediction Error and Latency in System Control on System Delay

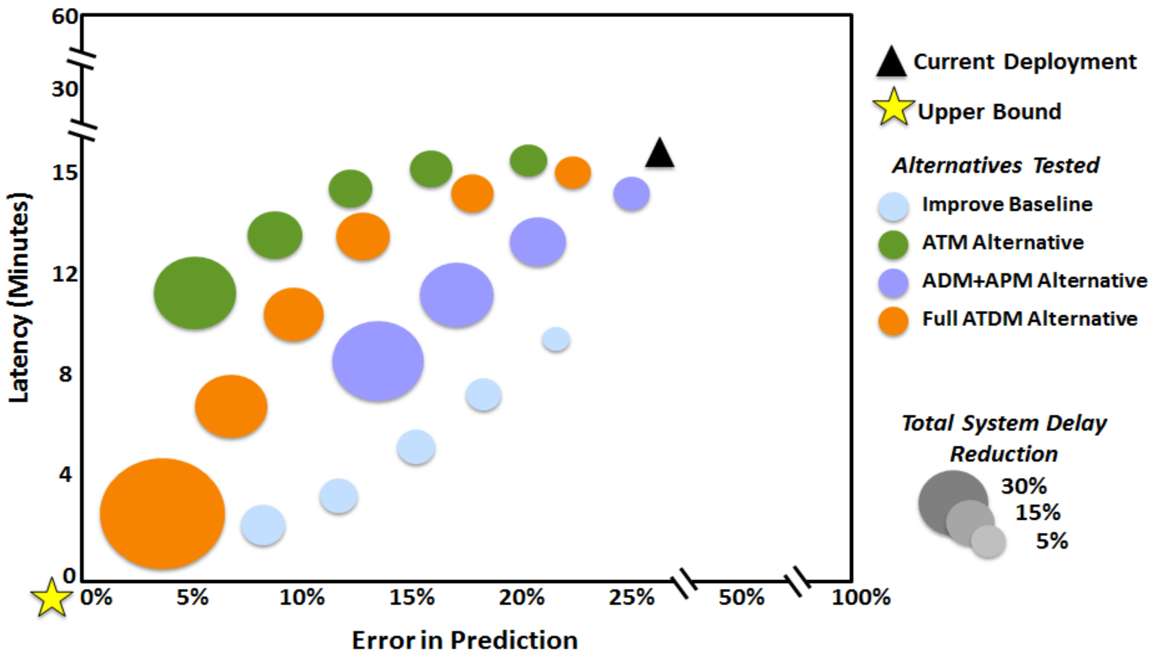

Figure 5-2: What the AMS Testbed Can Reveal: Effect of Prediction Error and Latency in System Control on System Delay for Alternative Strategies

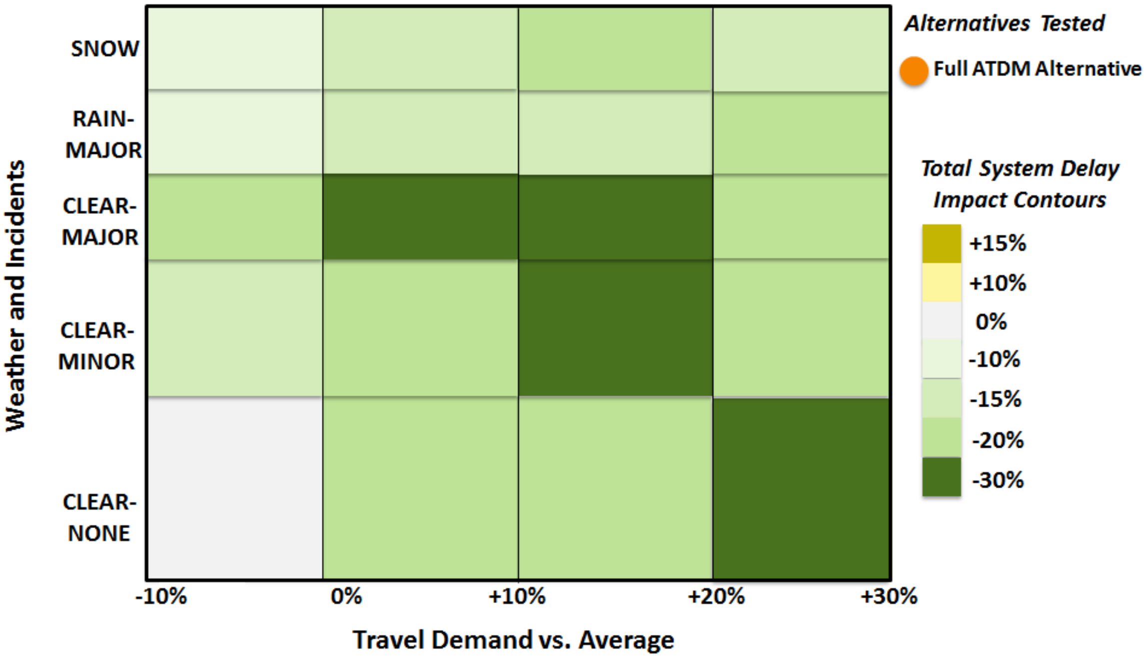

Figure 5-3: What the AMS Testbed Can Reveal: Under What Operational Conditions is Alternative Most Effective

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APPENDIX A. Technical Approaches to Identifying Operational Conditions

This section presents two data-driven approaches are suggested for grouping the days based on similar travel or operational conditions - one that makes use of a pre-determined bins (Option 1: Pre-Determined Binning) and another that makes use of cluster analysis to identify the bins or clusters (Option 2: Cluster Analysis). The preferred option is Option 2, which uses cluster analysis.

Option 1: Pre-Determined Binning Approach

This approach makes use of pre-determined groups based on operational conditions identified by the analyst in the data. In this approach the analyst identifies factors, which are revealed by the data, that influence the operational or travel conditions at the site; defines bins or groups of operational conditions; and assigns days into different bins or groups. An **example approach** for grouping days into pre-determined bins is given below

Step 1: Data Assembly and Influencing Factors Identification

The goal of this step is to assemble and analyze data to determine the factors that will influence operational conditions for the site. The example below assumes the presence of inclement weather and incidents in the data.

Demand: Screenline counts or volumes may be used. These measures may be calculated for the entire network or the principal corridors. Averages should be calculated for each day; these may be averages for the entire day, or just the peak periods, depending on the goals of the analysis. If the analysis includes an assessment of a transit-specific strategy, then in addition to calculating the traffic demand for each day, it might also be necessary to calculate the transit ridership for each day.

Weather: Contextual weather data, including precipitation, rain, wind, etc., may be obtained from: http://www.weather.gov. Average or maximum (worst case) precipitation levels and wind speed should be calculated for the entire network or region as a whole for each day. These may be averages or the maximum for the entire day, or just the peak periods, depending on the goals of the analysis.

Incident: Incident reports should be available from each site's state department of transportation. Incidents may be classified in the incident databases by day, location, time (notification, arrival, and clearance), type (e.g., debris, non-injury collision, injury collision, disabled), and impacted lanes (e.g., single lane, multiple Lanes, shoulder, HOV, total closure).

Step 2: Bin Definition

The goal of this step is to define bins. In our example, each bin is defined as a combination of a specific congestion index (measure of level of demand), weather index (measure of level of disruption due to weather), and incident index (measure of level of disruption due to incident). Hence, the total number of bins is the product of the number of congestion indices, number of weather indices, and number of incident indices. Although examples are provided on how indices might be chosen, the number and definitions of indices should be identified based on the data. It is critical to not choose too many indices to avoid the problem of several nearly empty bins. Having a limited number of days in a bin will not produce statistically significant results. If there are too many indices, an option is to develop a composite index that combines disruption due to weather and incident (supply disruption index).

Congestion Index: Example congestion indices for each day could be as follows:

1. Low demand
2. Medium demand
3. High demand

Weather Index: Analyze data to identify the types and severity of adverse weather that are experienced by the site. Example weather indices could be as follows:

1. Clear, sunny day
2. Low impact due to weather (e.g., precipitation of < 0.25” or fog)
3. Medium impact due to weather (e.g., precipitation of >= 0.25” and < 0.5”)
4. High impact due to weather (e.g., blowing snow, precipitation of >= 0.5”)

NOTE: The text in parenthesis are examples. The definitions should be based on the observed data. For example, if the region experiences very little rain and no snow, then two indices may be sufficient (0 and 1).

Incident Index: Analyze data to identify the types and severity of incidents experienced by the site. Example incident indices could be as follows:

1. No incidents
2. Low impact (e.g., non-blocking incidents, vehicle on shoulder)
3. Medium impact (e.g., single blocked lanes, police activity for non-blocking incident)
4. High impact (e.g., all or multiple blocked lanes, single blocked lane with police activity)

NOTE: The text in parenthesis are examples. The definitions should be based on the observed data. If the site has only 2 types of incidents, the indices would be 0, 1, and 2.

In the example above, we defined 3 congestion indices, 4 weather indices, and 4 incident indices, resulting in a total of 48 bins (3 x 4 x 4).

Step 3: Grouping Days

The goal of this step is to group days into bins defined in Step 2. In the example, we have defined 48 bins. If the analyst discovers that some of the bins have limited number of days, then the bins should be re-defined so that the number of values that an index can assume is reduced or the number of indices are reduced by defining composite indices as mentioned previously.

Option 2: Cluster Analysis Approach

In this option, an external template of bins is not imposed on the data; rather cluster analysis is used to identify the number and composition of clusters that minimize variation within each cluster (i.e., between component days in a cluster) and maximize variation between clusters.

As a first step, the analyst should assemble the data using the process described in Step 1 under Option 1. Once the data are assembled, cluster analysis may be performed over all days using cluster analysis algorithms or a statistical package that offers cluster analysis. Examples of statistical and data mining tools that offer cluster analysis are the commercial tool, MATLAB [15], or the open source data mining software, WEKA (Waikato Environment for Knowledge Analysis) [16].

The ICM Program [17] and the SHRP 2 L08 effort [18] have developed approaches for identifying operational conditions and their associated probabilities of occurrence. Similar approaches may also be used when developing the AMS Testbed.

APPENDIX B. List of Acronyms

Table B-1: List of Acronyms

Acronym	Name
ADM	Active Demand Management
AMS	Analysis, Modeling, and Simulation
APM	Active Parking Management
ATDM	Active Transportation and Demand Management
ATIS	Multi-Modal Real-Time Traveler Information
ATM	Advanced Traffic Management
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CO2	Carbon Dioxide
CONOPS	Concept of Operations
DMA	Dynamic Mobility Applications
DMA-PMA	DMA Performance Measurement Application
DOT	Department of Transportation
DRG	Dynamic Routing of Vehicles
D-RIDE	Dynamic Ridesharing
DR-OPT	Drayage Optimization
DSRC	Dedicated Short Range Communications
DSS	Decision Support Systems
ECO	Connected Eco Driving
EFP	Multimodal Integrated Payment System
EnableATIS	Enable Advanced Traveler Information 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
GPS	Global Positioning System
HOV	High-Occupancy Vehicle
ICM	Next Generation 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
JPO	Joint Program Office
MAYDAY	Mayday Relay
MDSS	Maintenance Decision Support System
MMITSS	Multi-Modal Intelligent Traffic Signal System
NHTSA	National Highway Traffic Safety Administration
NPV	Net Present Value
OMB	Office of Management and Budget
OSADP	Open Source Application Development Portal
PED-SIG	Mobile Accessible Pedestrian Signal
PREEMPT	Emergency Vehicle Priority
Q-WARN	Queue Warning
RESP-STG	Incident Scene Pre-Arrival Staging

RITA	Research and Innovative Technology Administration
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SHRP2	Strategic Highway Research Program
SPaT	Signal Phasing and Timing
SPD-HARM	Dynamic Speed Harmonization
T-CONNECT	Connection Protection
T-DISP	Dynamic Transit Operations
T-MAP	Universal Map Application
TMC	Transportation Management Center
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
VMT	Mileage Based User Fees
VOCS	Volatile Organic Compounds
WEKA	Waikato Environment for Knowledge Analysis
WX-INFO	Real-Time Route Specific Weather
WX-MDSS	Enhanced MDSS Communications

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